Title: New Applications for Supergraphs

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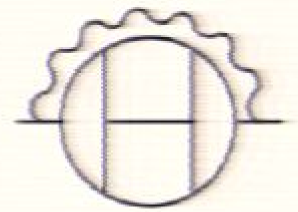
Abstract:

New Applications for Supergraphs



Joseph Minahan

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C. Sieg, JM *in progress*

15 August 2011
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Introduction

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  - BES solution Beisert, Eden, Staudacher (2006)
- How do these structures show up in field theory calculations?
  - In components, it seems to rely on miraculous cancellations.
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Introduction

- $SU(2|2) \ltimes SU(2|2)$ superalgebra tells us a lot about $\mathcal{N} = 4$ SYM
  - Dispersion relation Beisert (2005)
  - S-matrix (up to the dressing phase) Staudacher (2004), BS(2005), *op. cit.*
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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)

Introduction

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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)
- While the structures are important for $\mathcal{N} = 4$ SYM, is $\mathcal{N} = 4$ SYM important for these structures?
  - Can they be applied to other SCFTs?

Introduction

- $SU(2|2) \ltimes SU(2|2)$ superalgebra tells us a lot about $\mathcal{N} = 4$ SYM
  - Dispersion relation Beisert (2005)
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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)
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  - S-matrix (up to the dressing phase) Staudacher (2004), BS(2005), *op. cit.*
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  - A possible all-loop relation for classes of supergraphs based on a 3-loop calculation of the dilatation operator Sieg (2010)
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Outline

- Some relevant facts about superspace
- Relating the dispersion relation to classes of superspace graphs
- Applying superspace calculations to the "Cubic" Leigh-Strassler model
  - Planar protected states
  - One-pair and multi-pair states and their anomalous dimensions
  - Tuning the coupling
  - Hagedorn transition?
- Concluding remarks

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- Relating the dispersion relation to classes of superspace graphs
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  - Planar protected states
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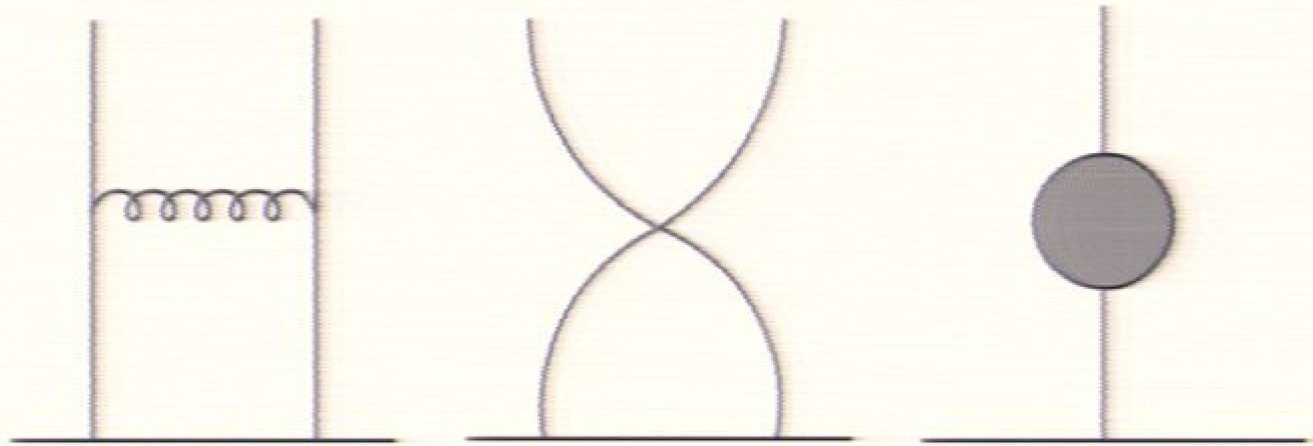

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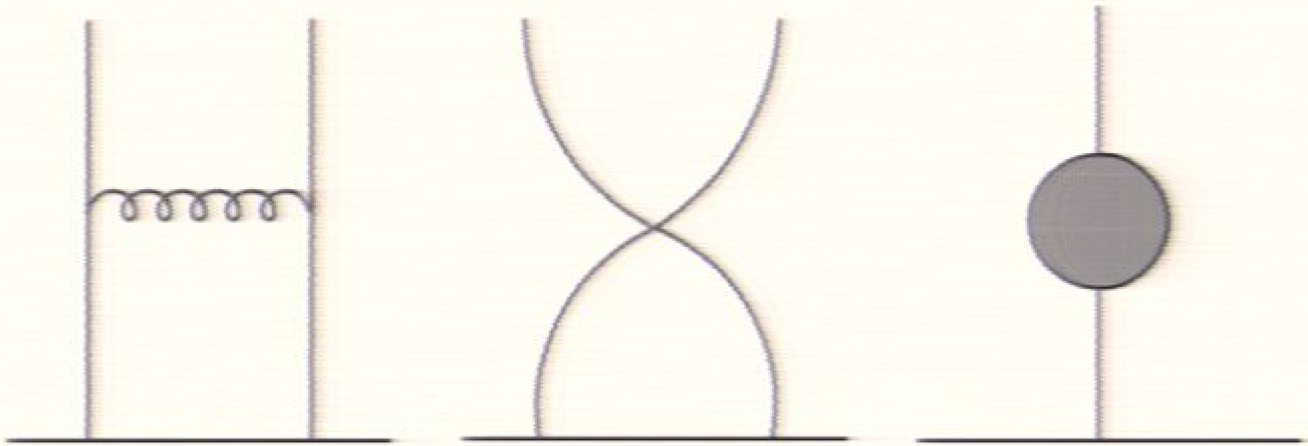

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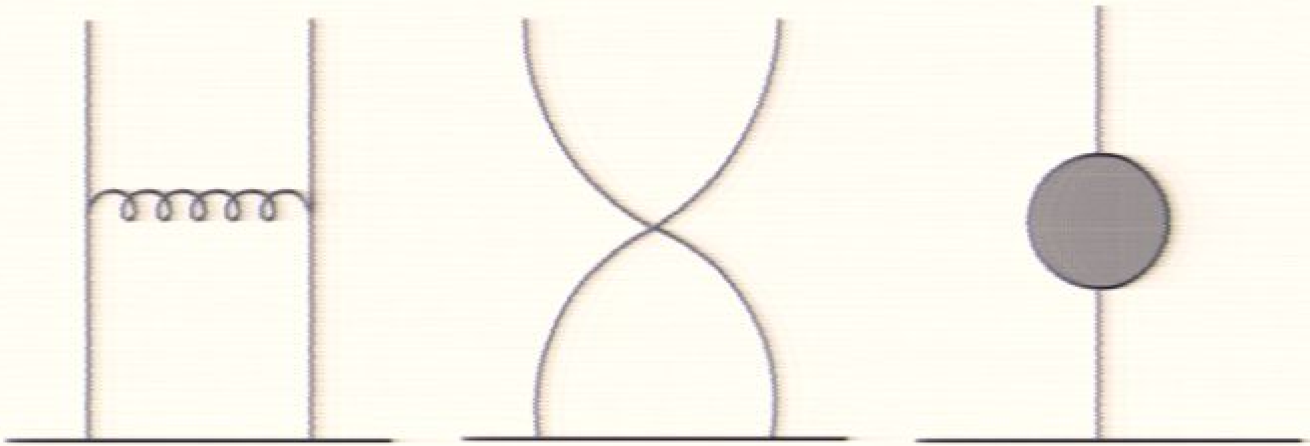

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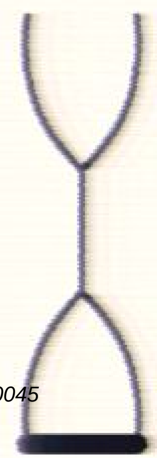

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Naturally comes with a "chiral function"

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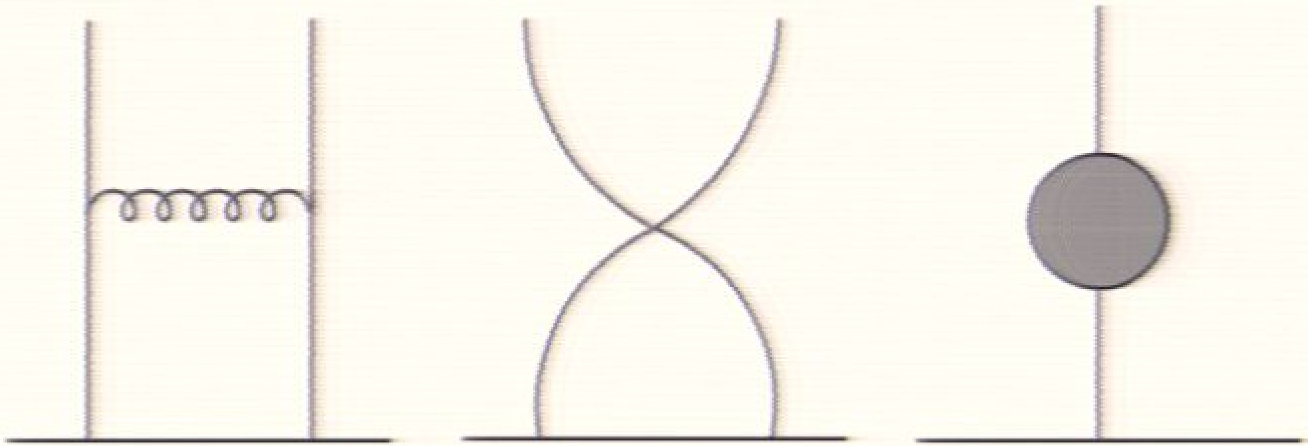

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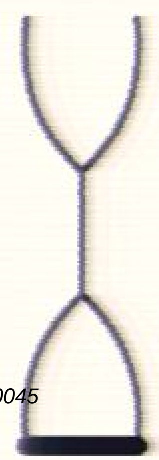

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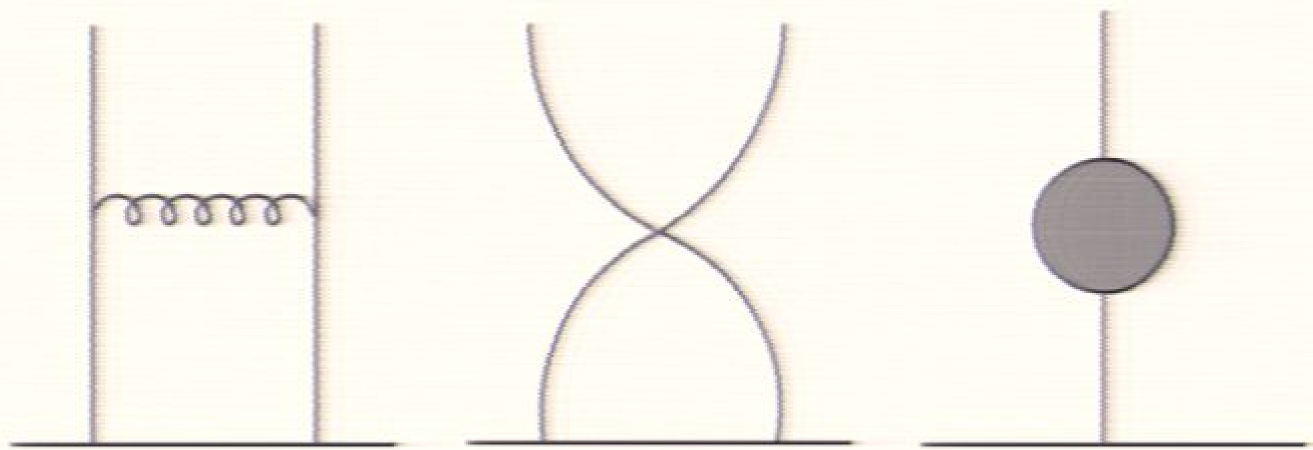

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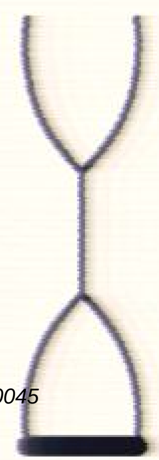

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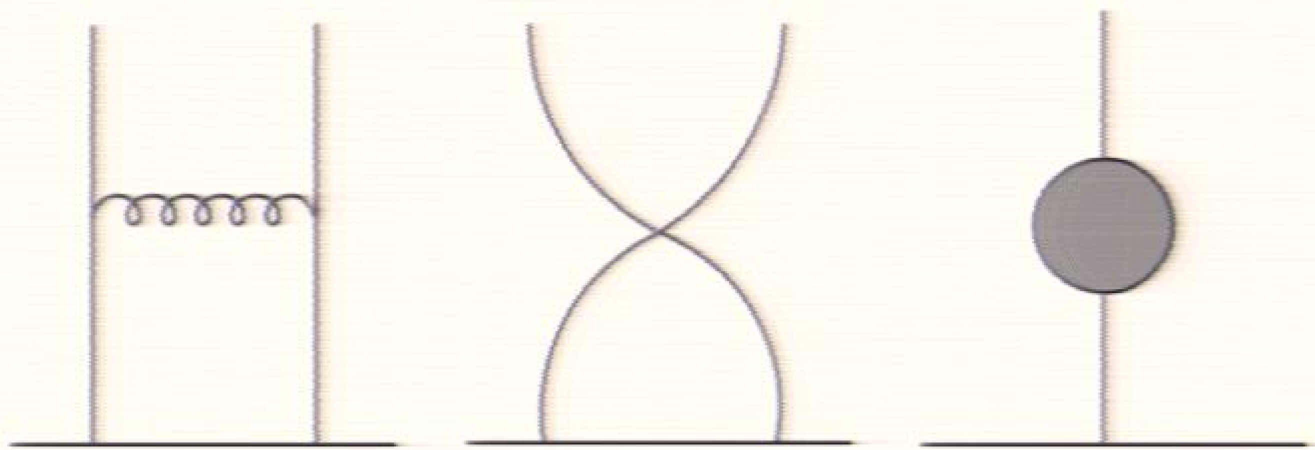

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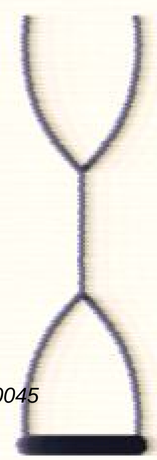

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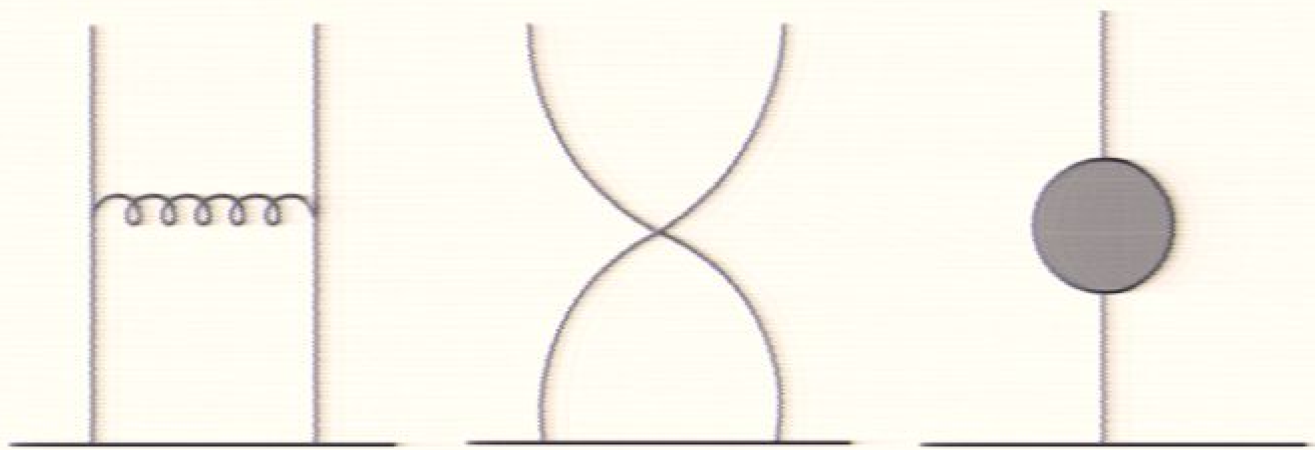

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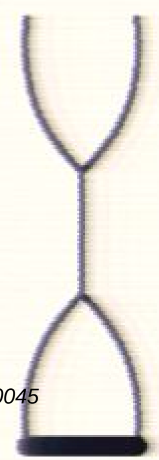

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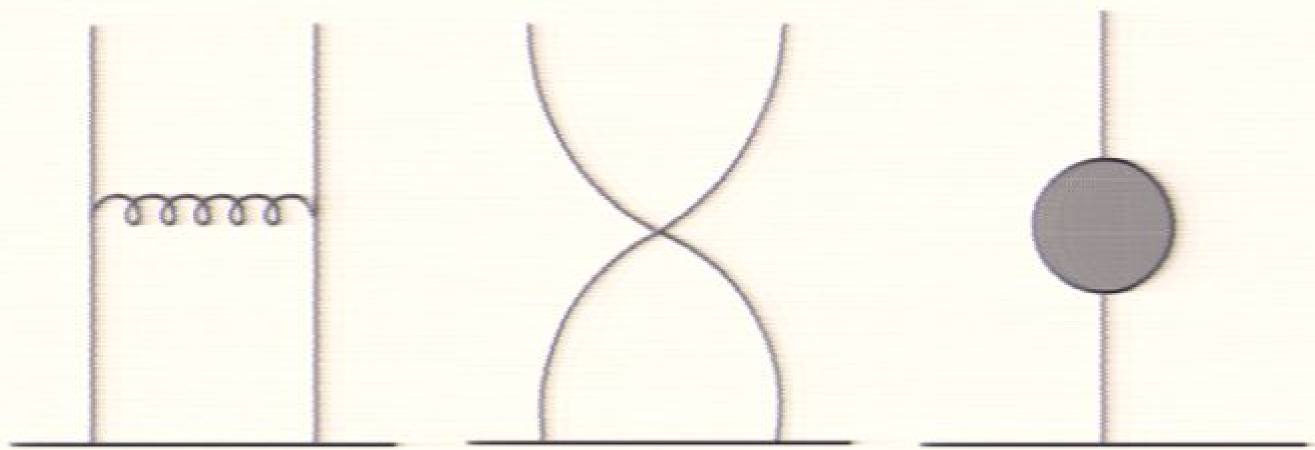

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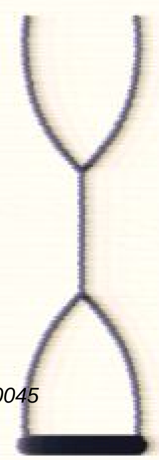

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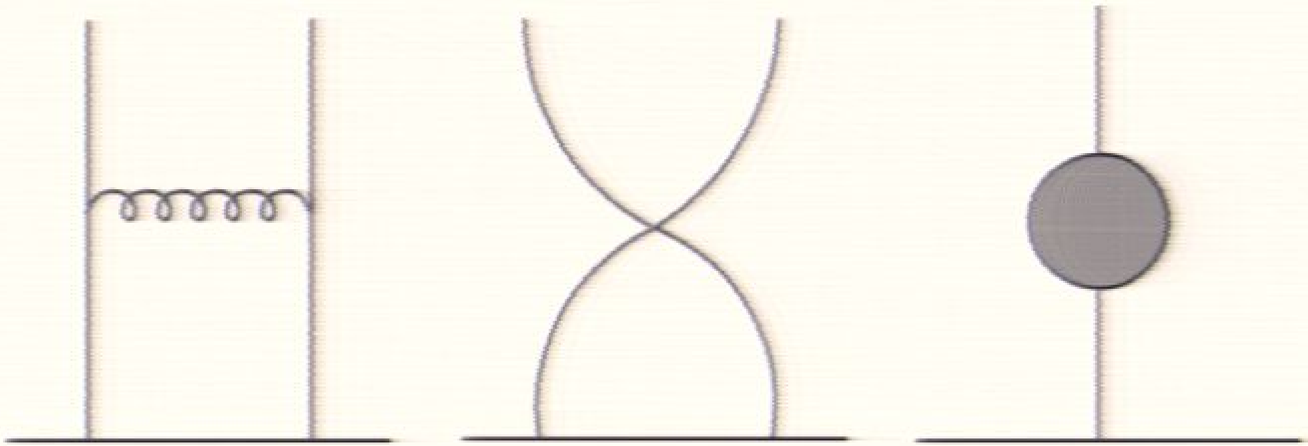

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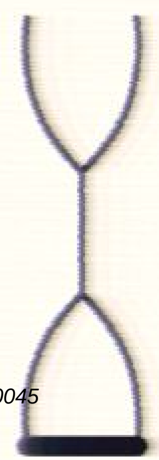

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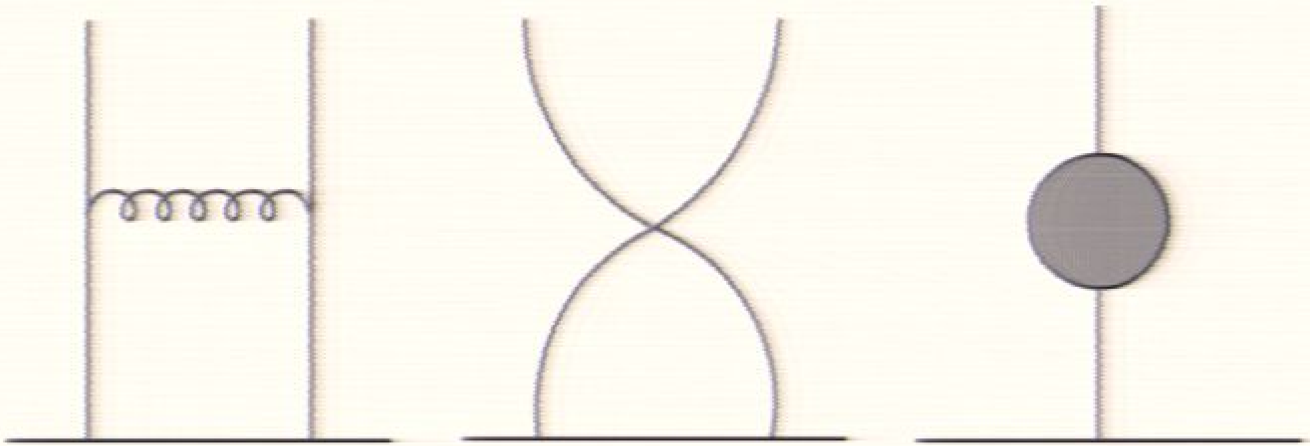

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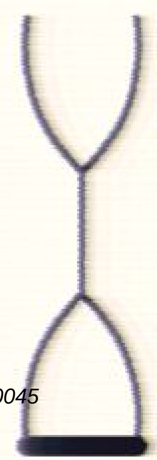

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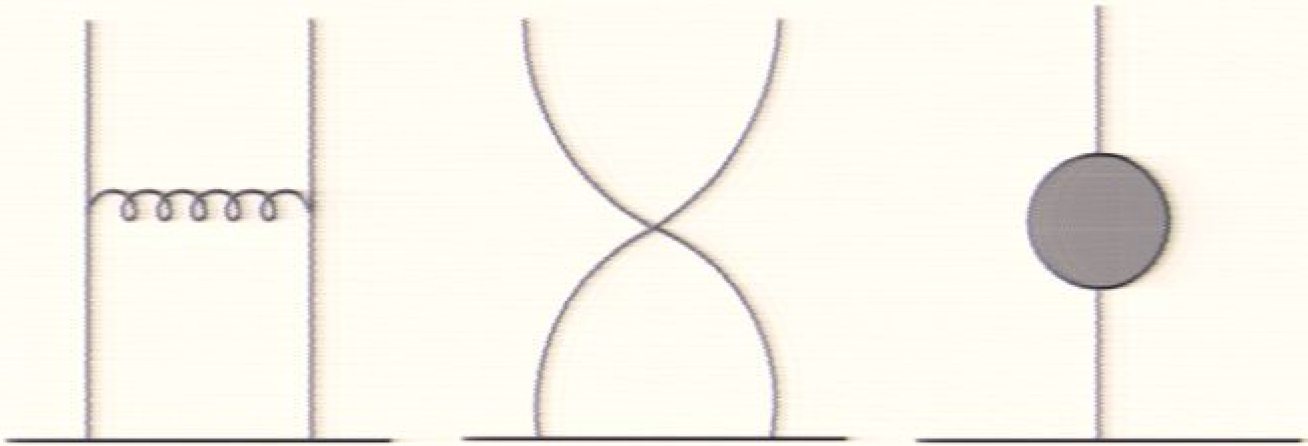

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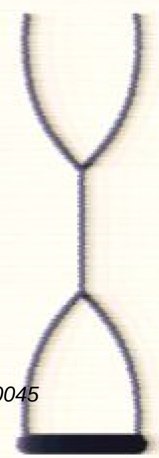

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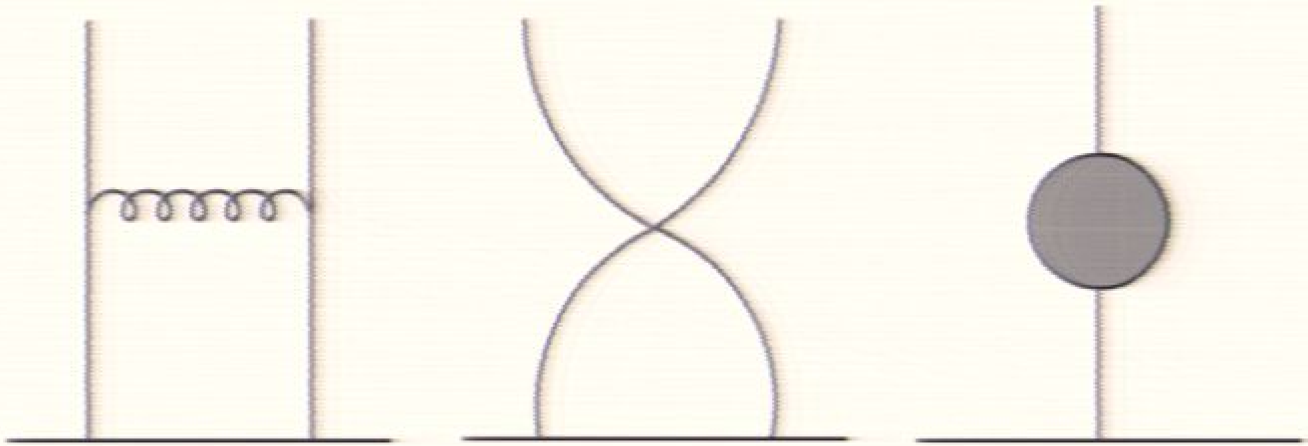

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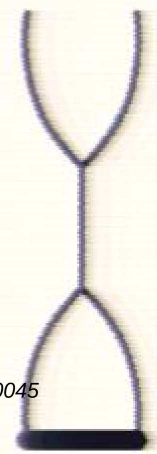

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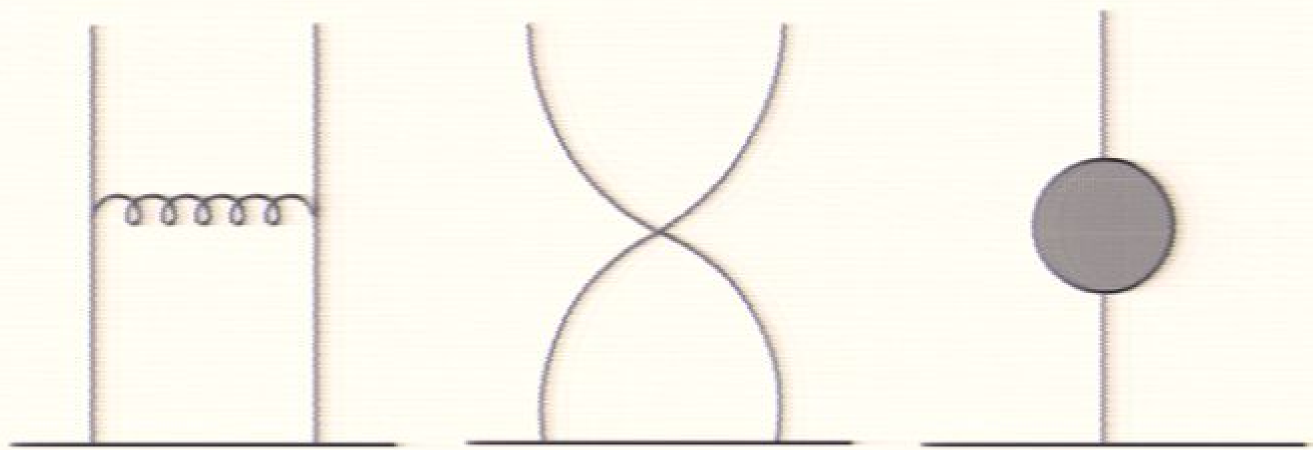

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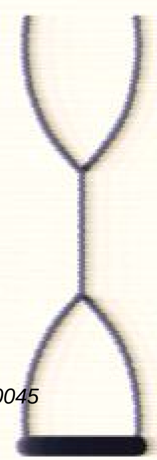

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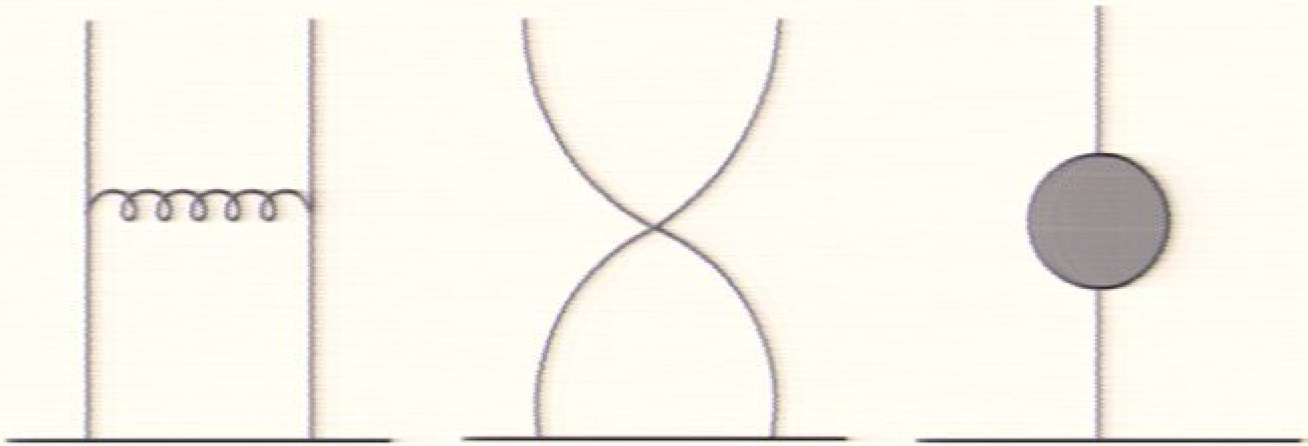

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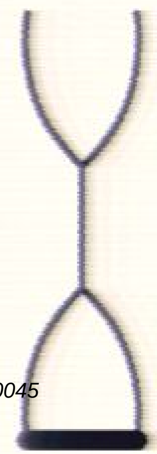

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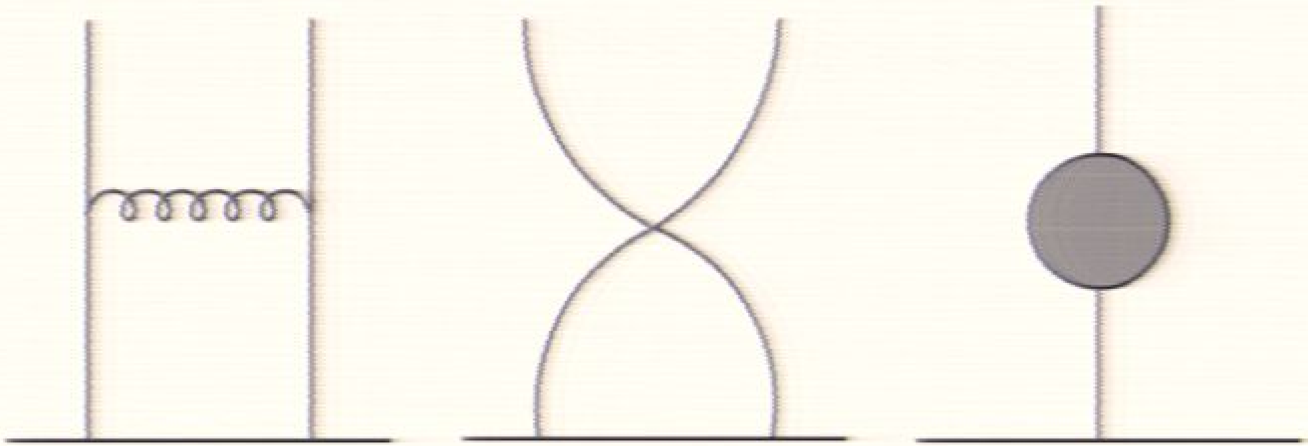

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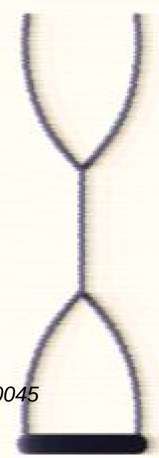

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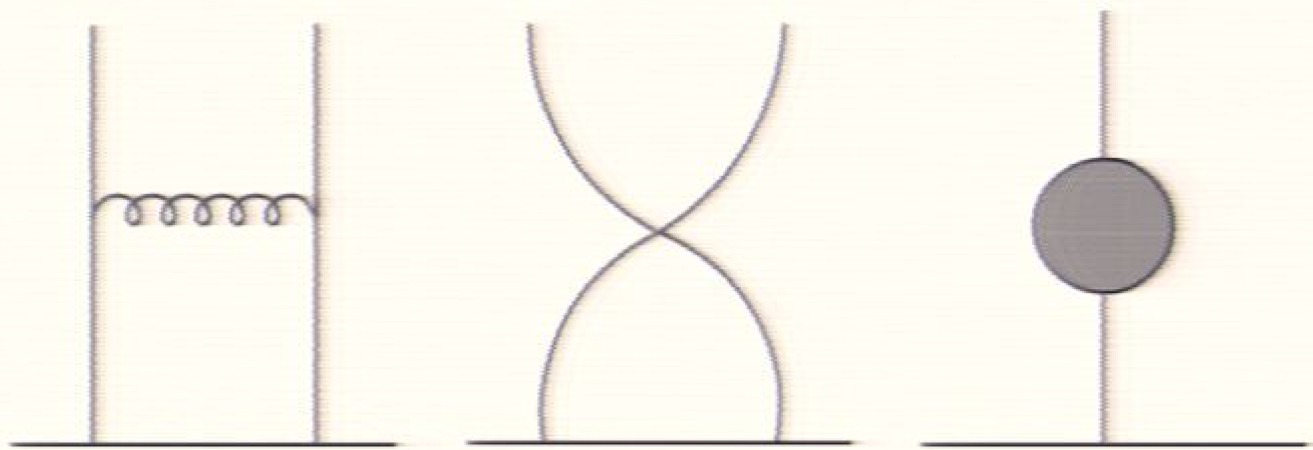

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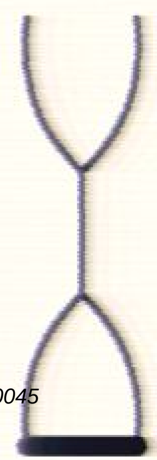

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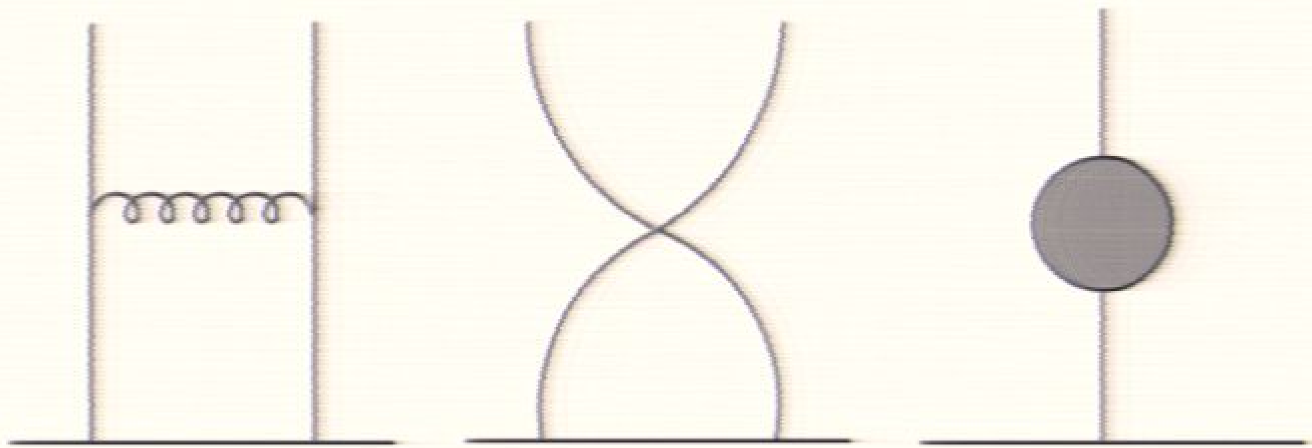
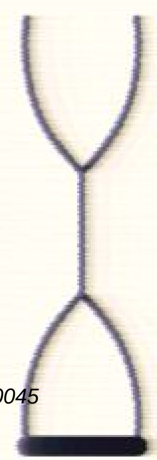


Superspace ($SU(2)$ sector)

$$g^2 \equiv \frac{g_{YM}^2 N}{16\pi^2}$$



$$= 2g^2\chi(1)$$

Naturally comes with a "chiral function"

$$\chi(1) = \sum_{j=1}^{L} (1 - P_{j,j+1})$$

Why use superspace?: One-loop in $\mathcal{N} = 4$ SYM

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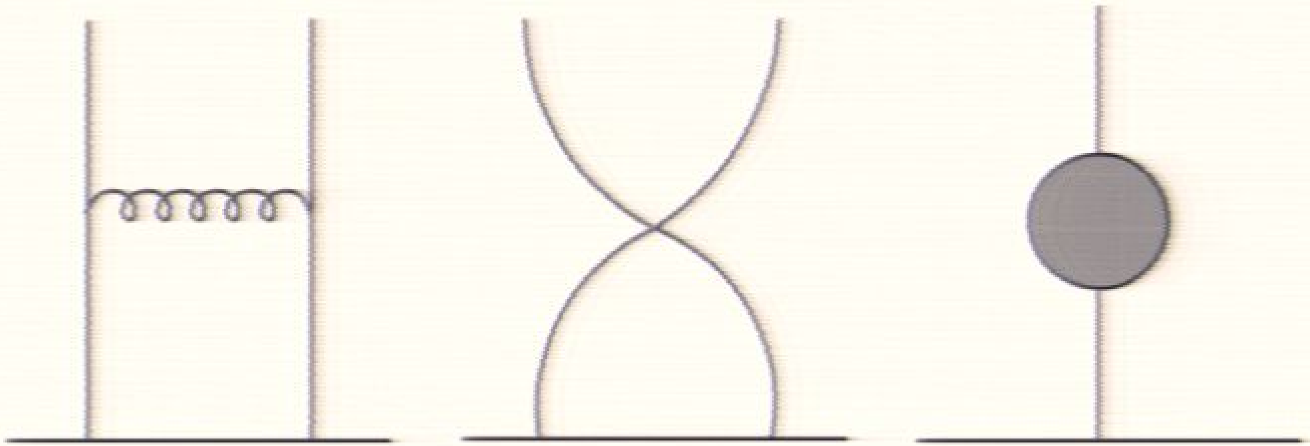

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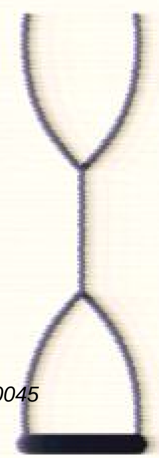

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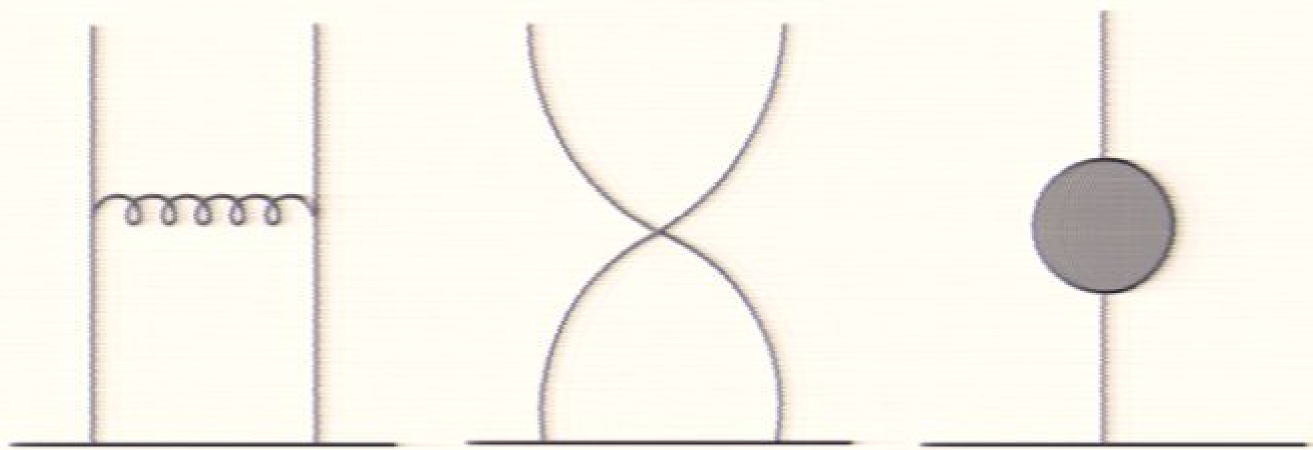

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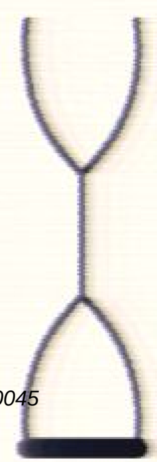

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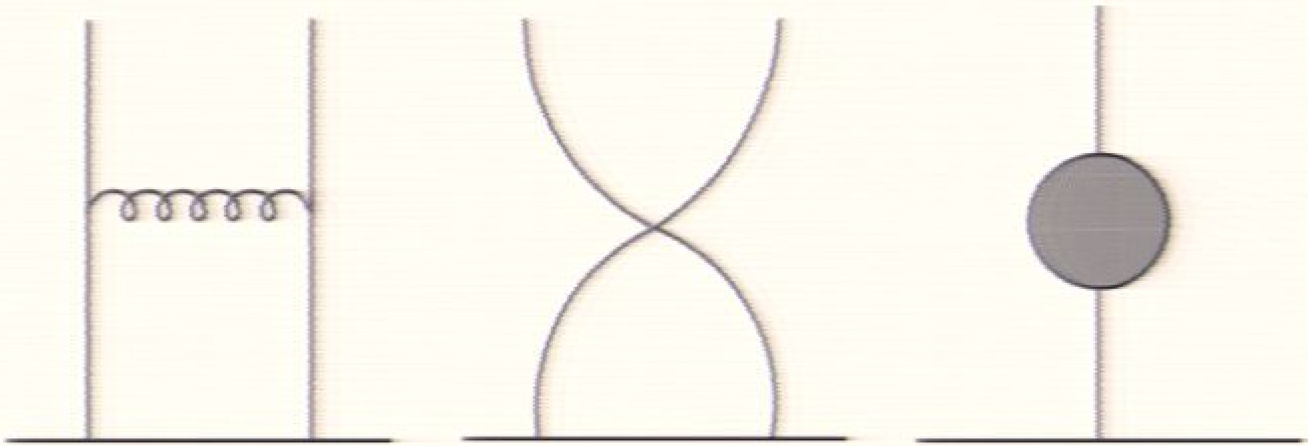

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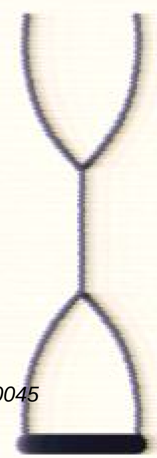

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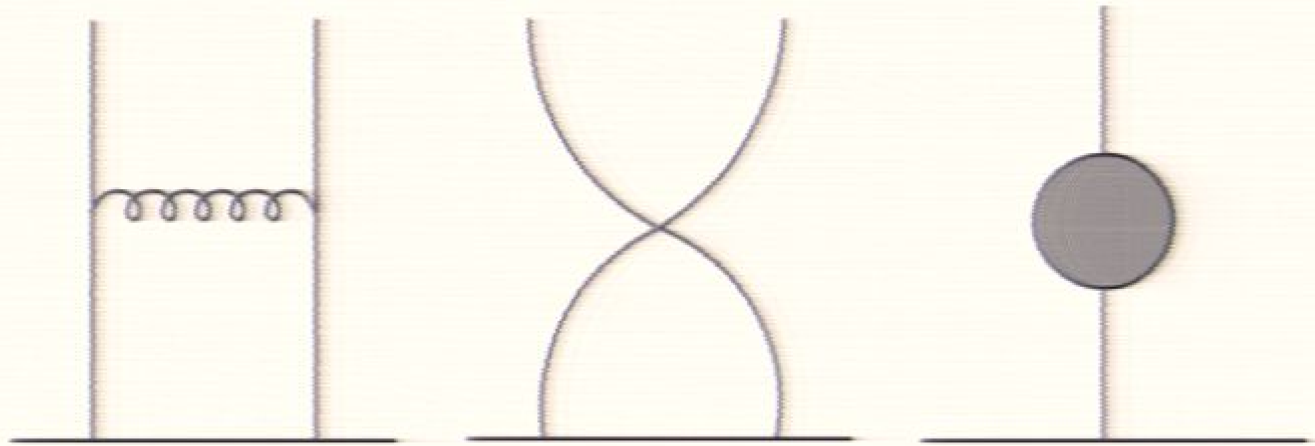

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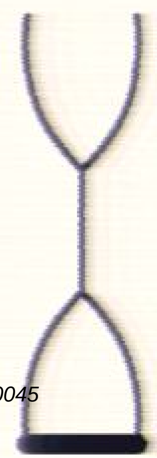

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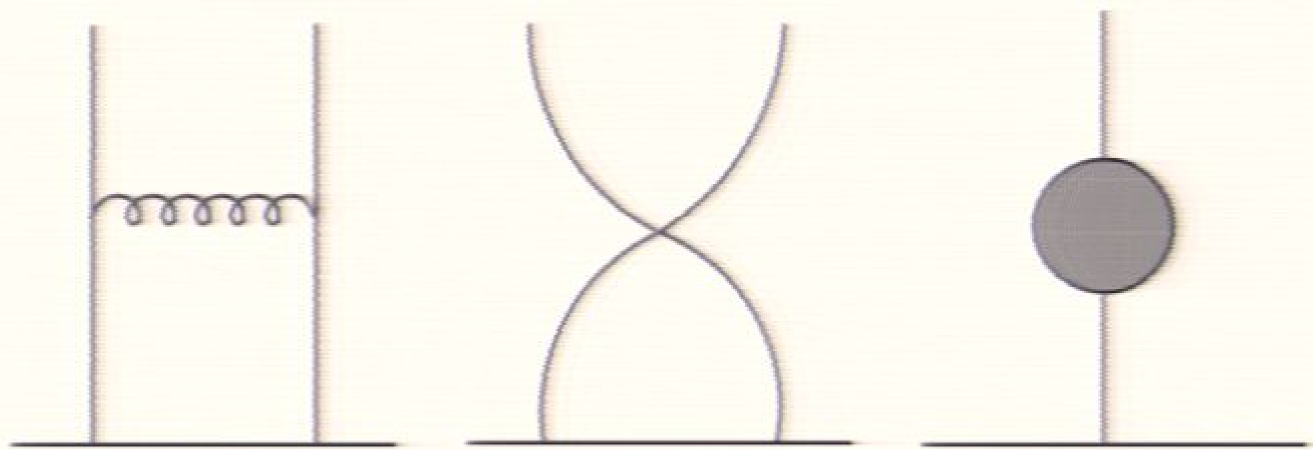

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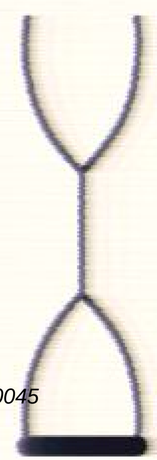

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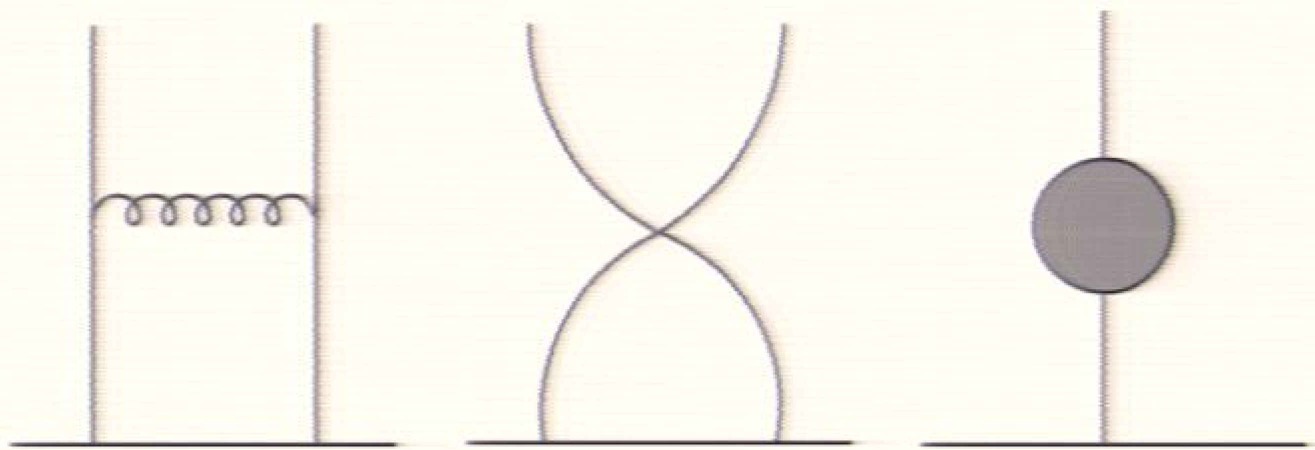

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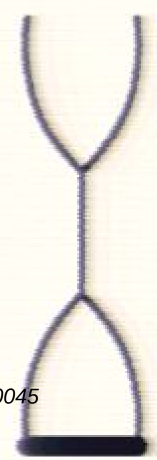

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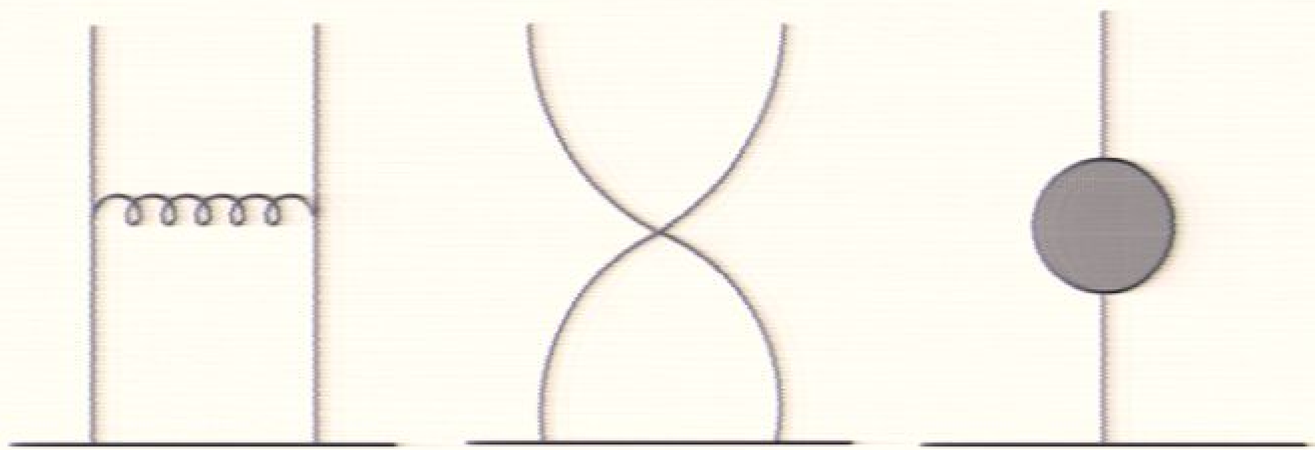

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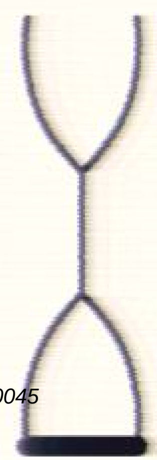

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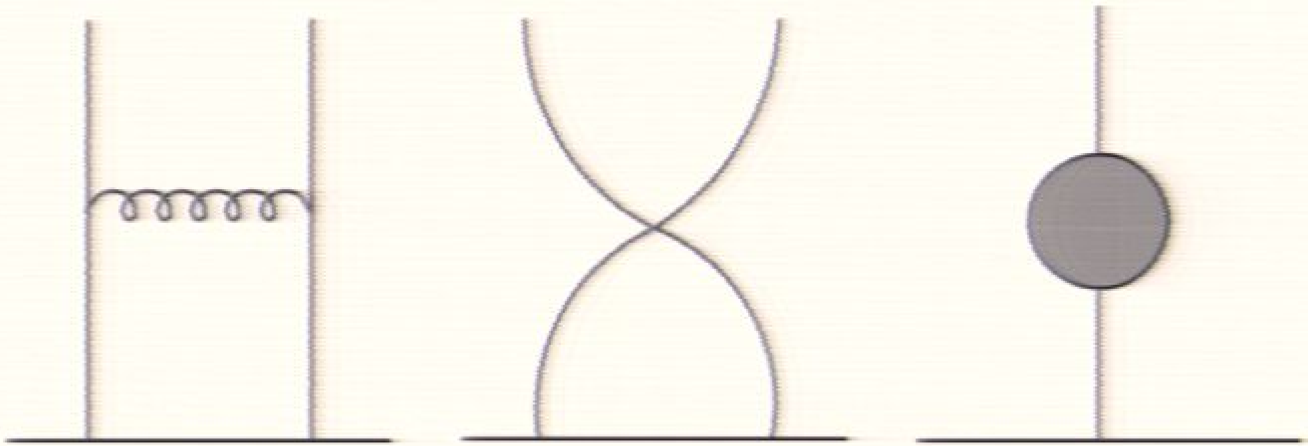

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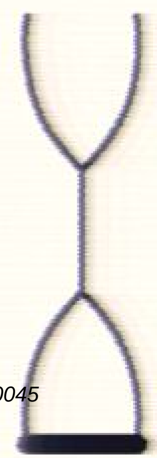

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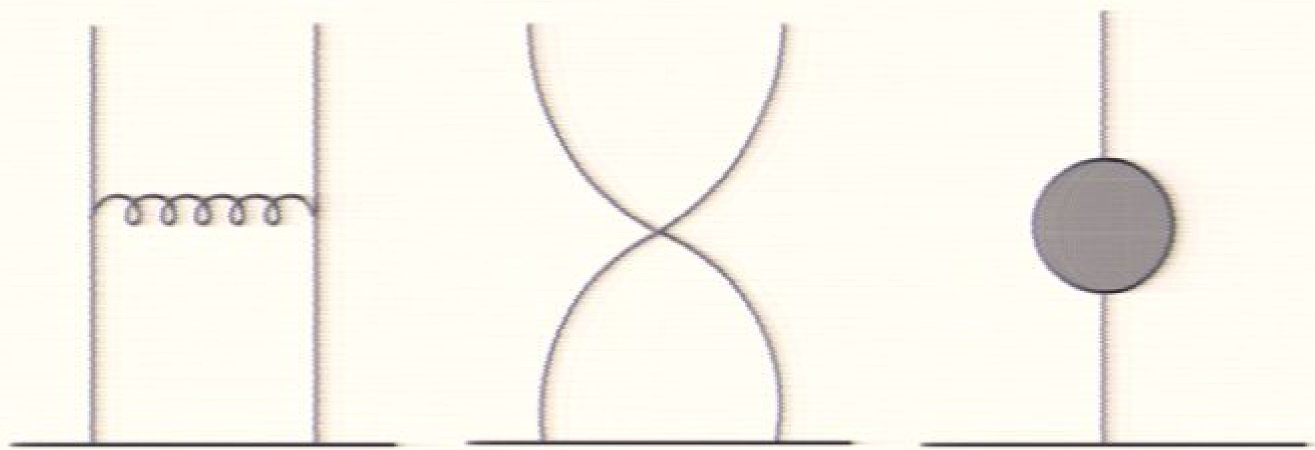

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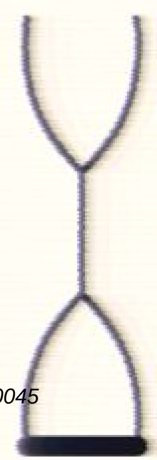

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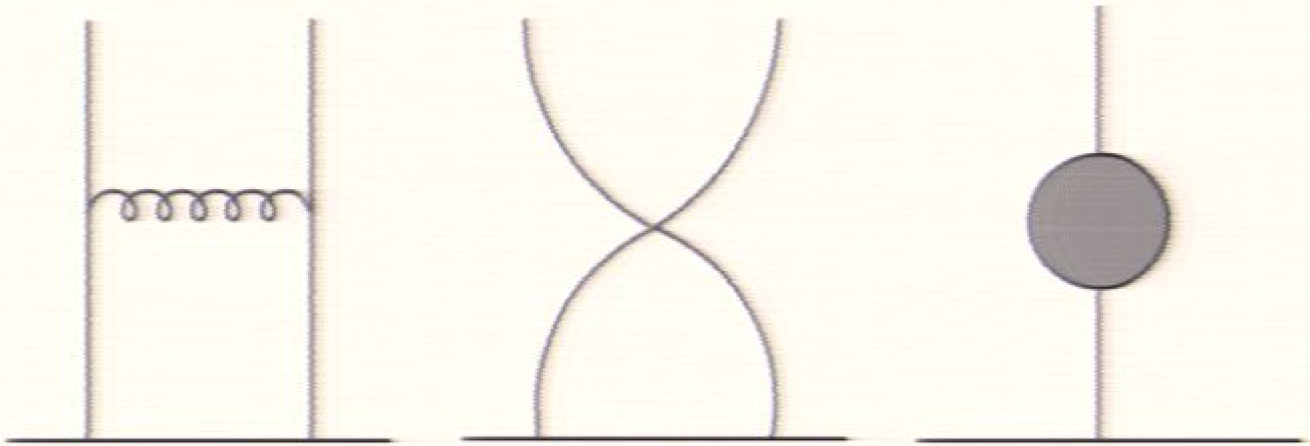

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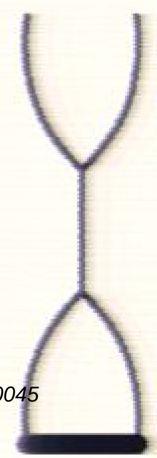

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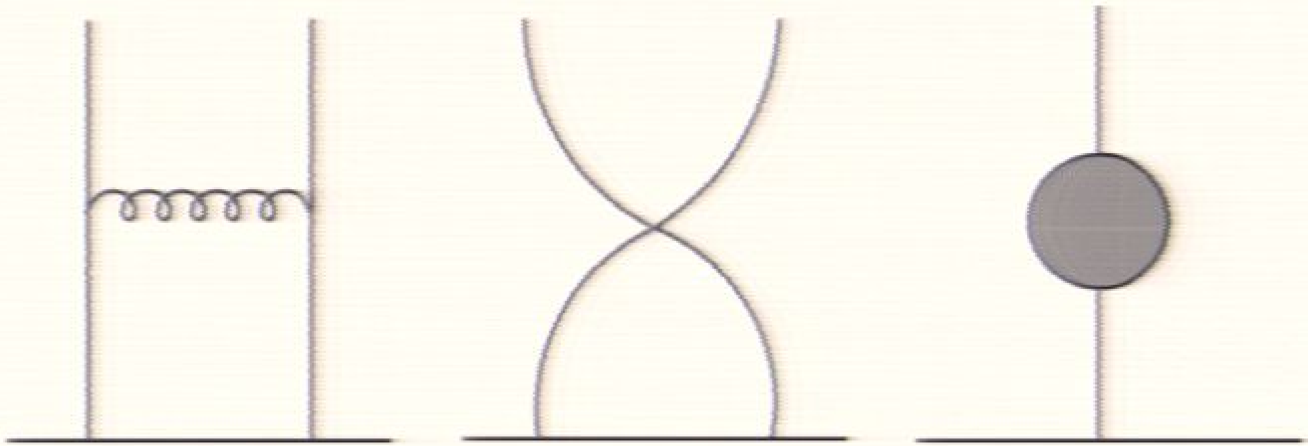

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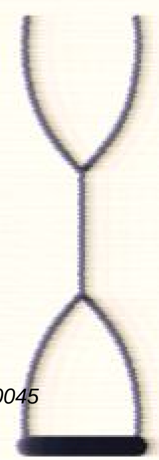

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Definition ($\mathcal{N} = 4$ SYM):

$$\chi(a_1, a_2 \ldots a_n) \equiv \sum_{j=0}^{L-1} (1 - P_{j+a_1, j+a_1+1})(1 - P_{j+a_2, j+a_2+1}) \ldots (1 - P_{j+a_n, j+a_n+1})$$

Useful properties (Not specific to $\mathcal{N} = 4$ SYM):

$$\chi(a_1, \ldots a_j, a_{j+1} \ldots a_n) = \chi(a_1, \ldots a_{j+1}, a_j \ldots a_n) \qquad |a_j - a_{j+1}| \geq 2$$

$$\chi(a_1, \ldots a_j, a_{j+1} \ldots a_n) = 2\chi(a_1, \ldots a_j \ldots a_n) \qquad a_j = a_{j+1} \qquad [\textit{reduction}]$$

Connected: $\chi(a_1, \ldots a_j \ldots a_n)$ if $|a_j - a_{j+1}| = 1 \;\; \forall \;\; 1 \leq j < n$.

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$$|p\rangle \equiv \sum_{j=1}^{L} e^{ipj} |XXX \ldots \overset{j}{\overset{\downarrow}{X}}YX \ldots XX\rangle\,, \quad \varepsilon(p) = \sqrt{1 + 16g^2 \sin^2 \frac{p}{2}} - 1, \quad g = \frac{\sqrt{\lambda}}{4\pi}$$

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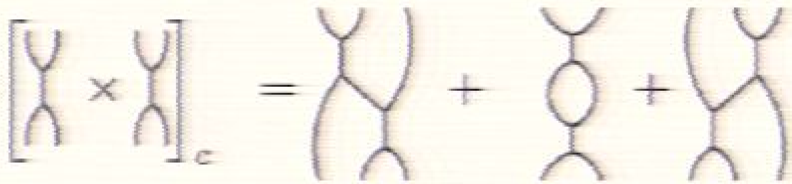
$[\chi(1)^2]_c =$



$= \chi(2,1)+2\chi(1)+\chi(1,2)$

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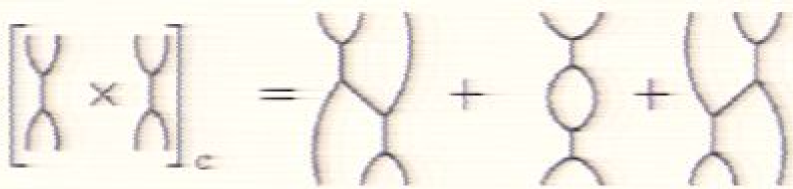
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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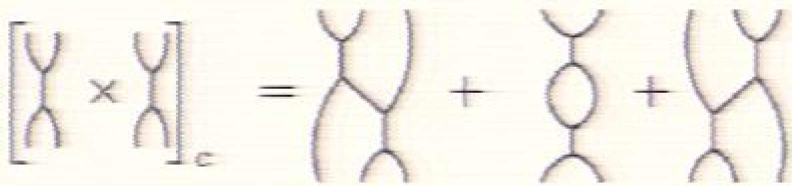
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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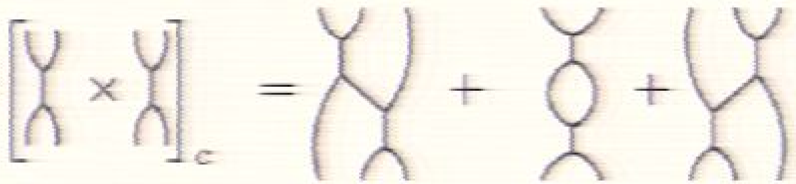

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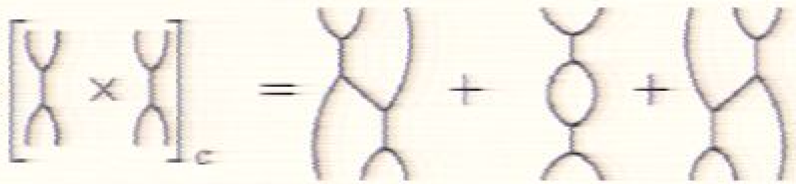
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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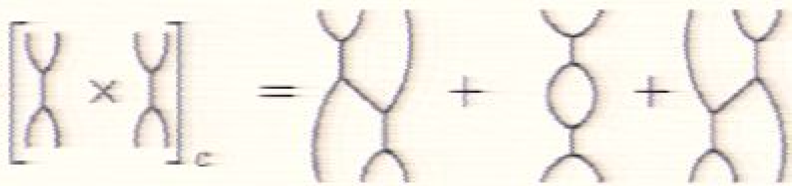
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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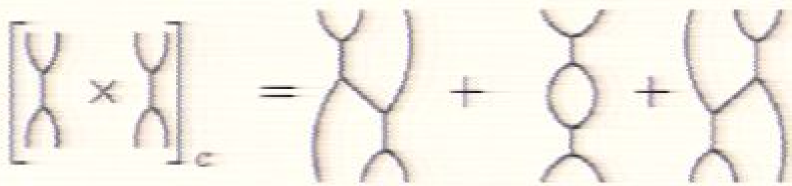
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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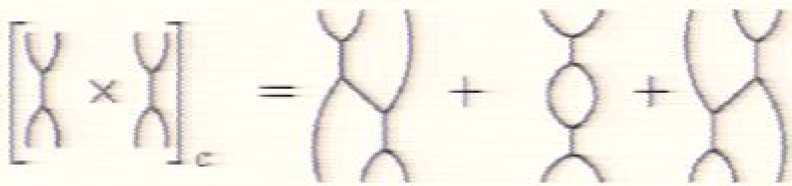
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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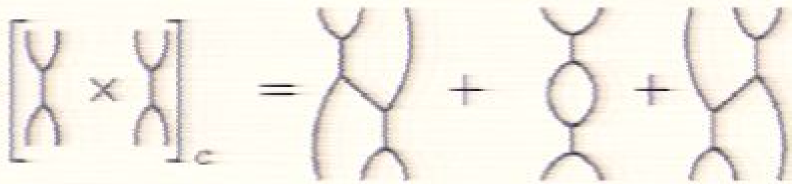

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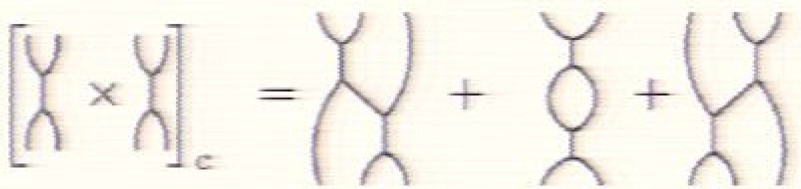

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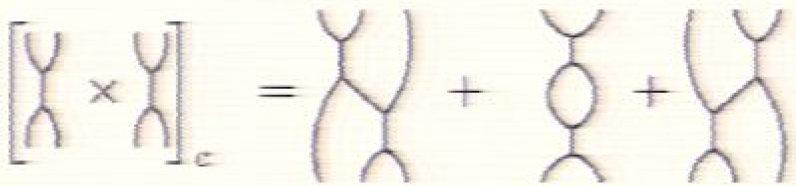

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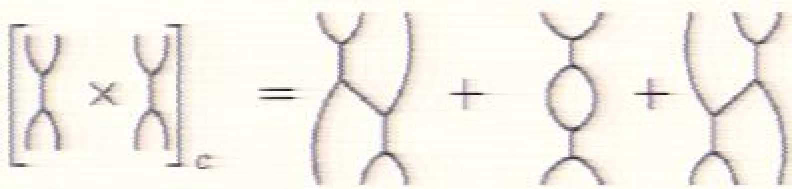
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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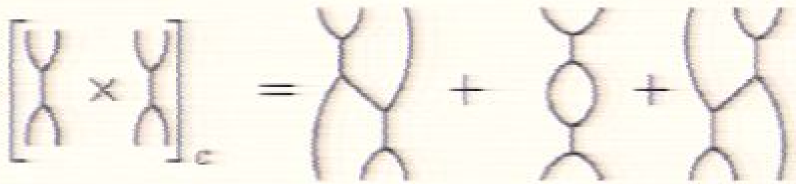
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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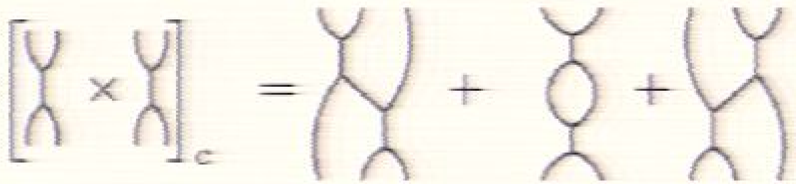

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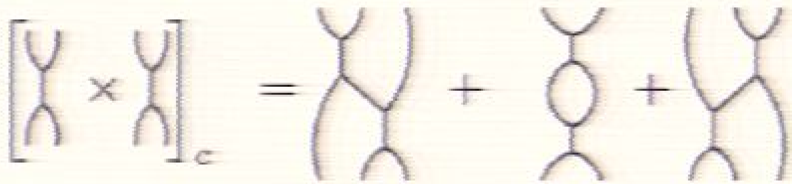

$= \chi(2,1) + 2\chi(1) + \chi(1,2)$

Resum:
$$\sum_{m=1}^{\infty} \frac{\Gamma(3/2)}{m!\Gamma(3/2-m)} g^{2m} \left[\chi(1)^m\right]_c = F_1(g^2)\,\chi(1) + F_2(g^2)\left[\chi(1,2) + \chi(2,1)\right]$$
$$+ F_3(g^2)\left[\chi(1,2,3) + \chi(3,2,1) + \chi(1,2,1) + \chi(2,1,2)\right] + \ldots$$

$$F_n(g^2) = \frac{(-1)^{n+1}\Gamma(n-1/2)}{2\sqrt{\pi}\,n!} (2g)^{2n}\ {}_2F_1(n-1/2, n; n+1; -8g^2) \qquad \text{(algebraic)}$$

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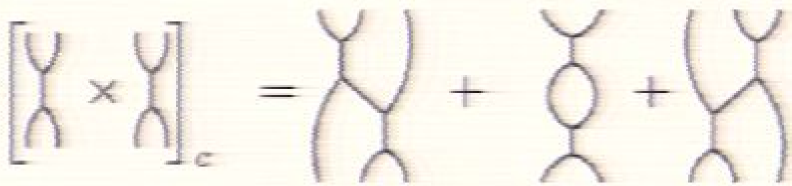

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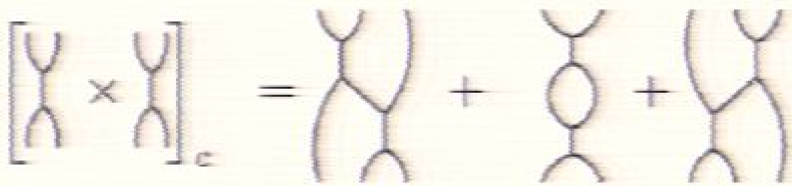

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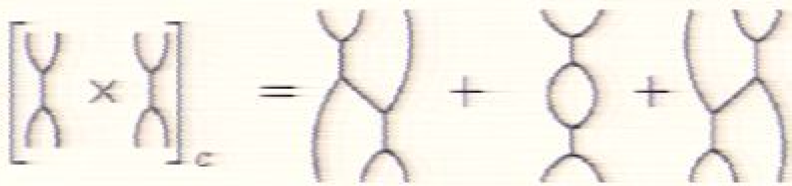

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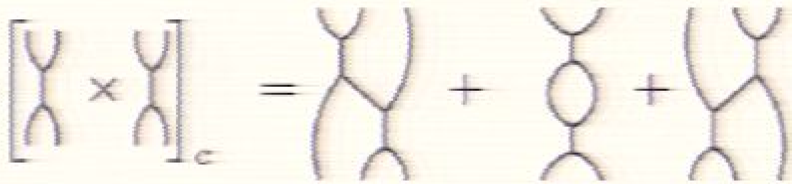

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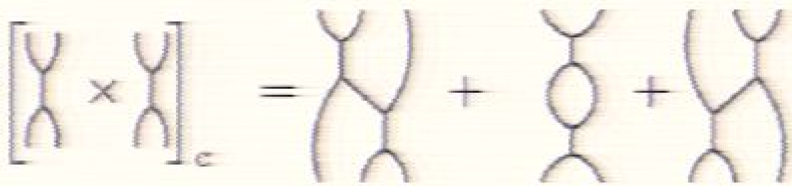

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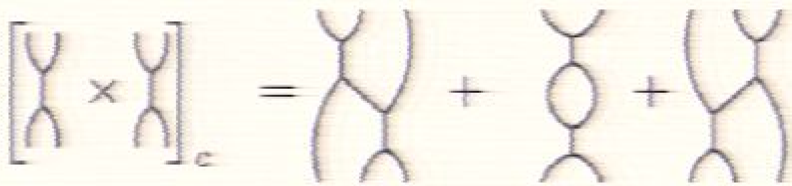

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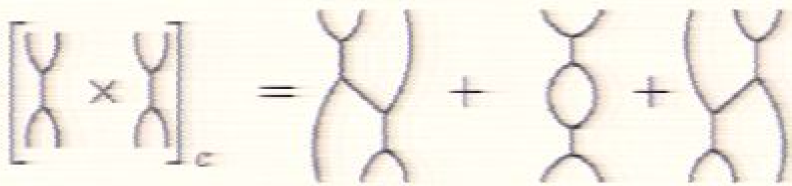
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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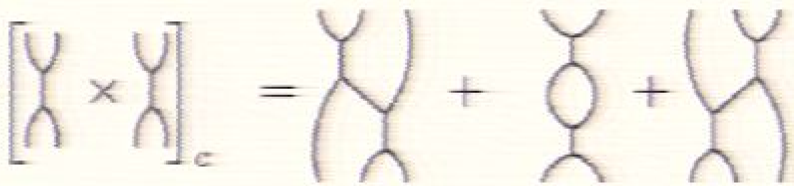

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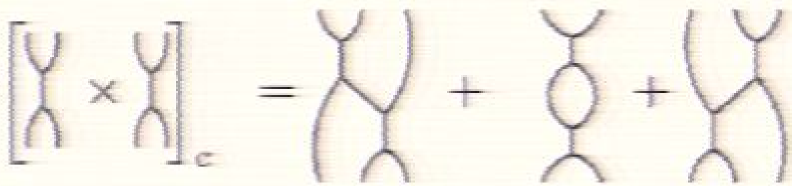
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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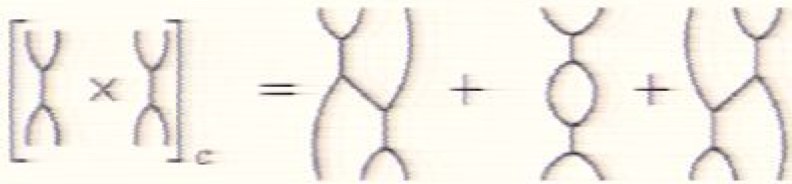

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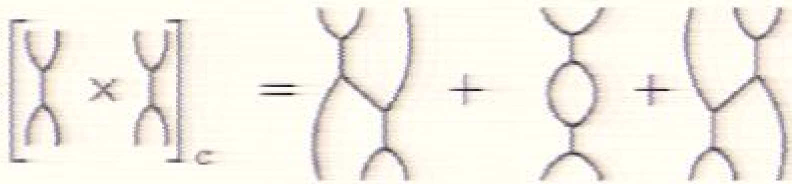
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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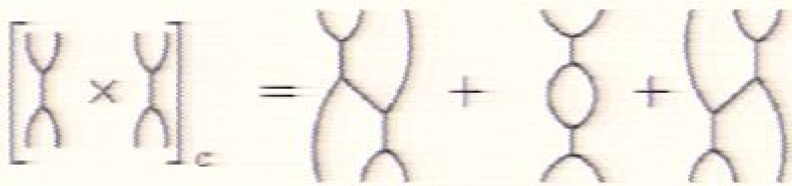

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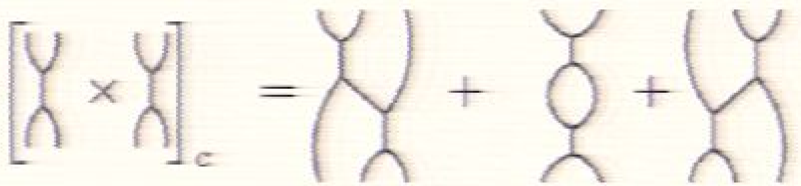
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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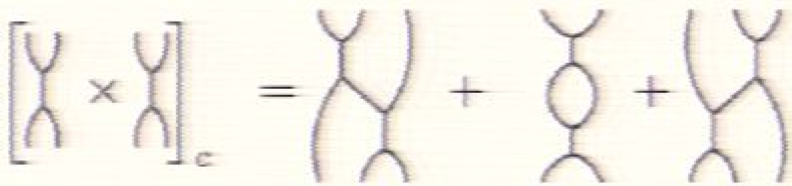
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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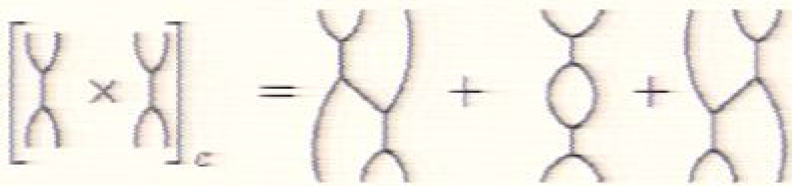
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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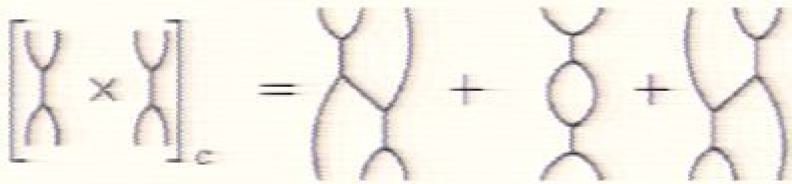
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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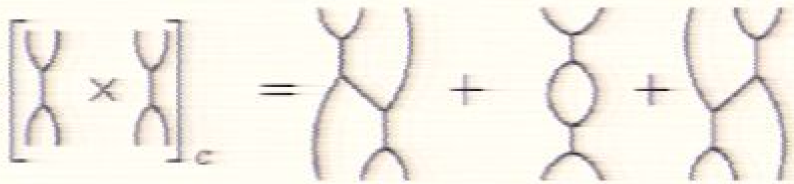
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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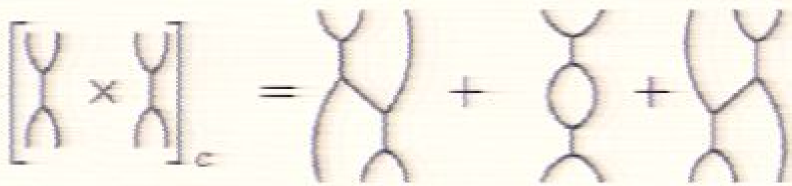
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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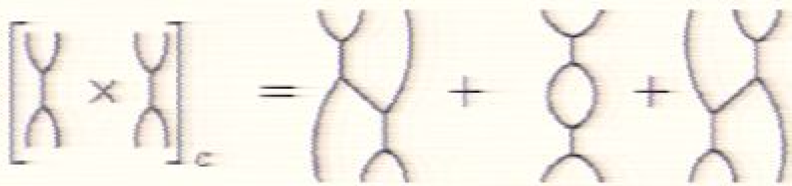
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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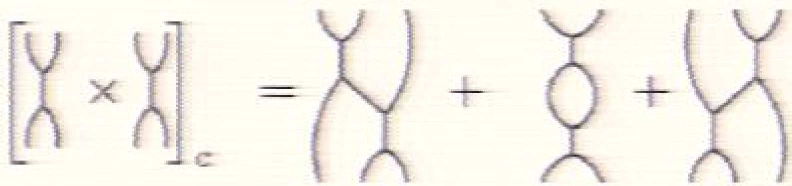
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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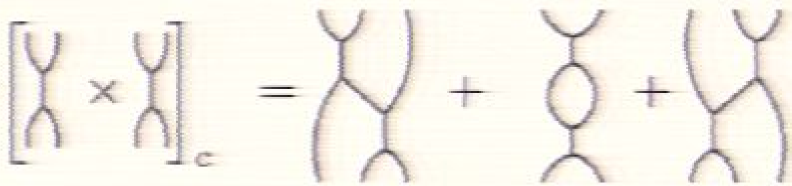
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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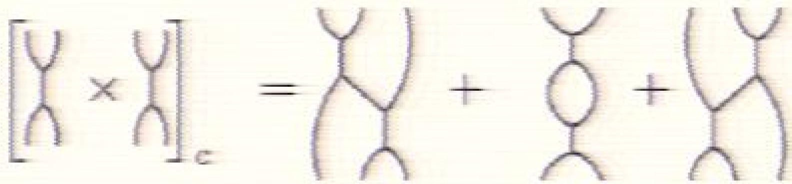

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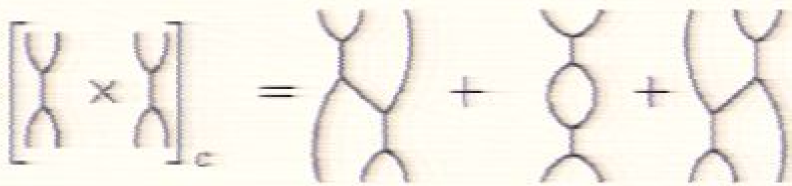
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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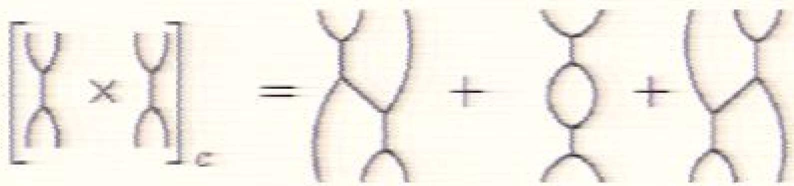

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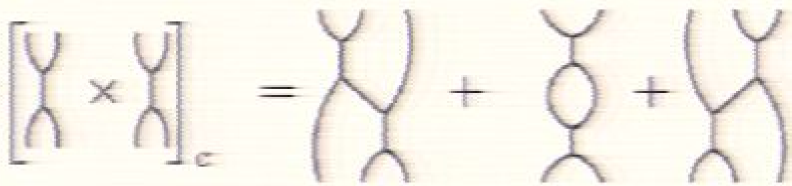

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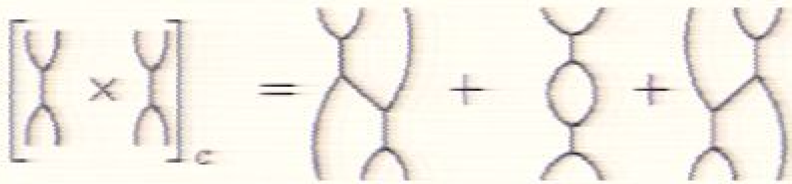
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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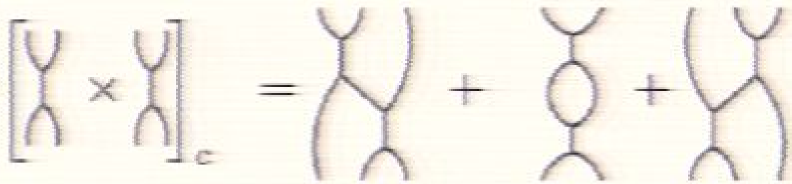

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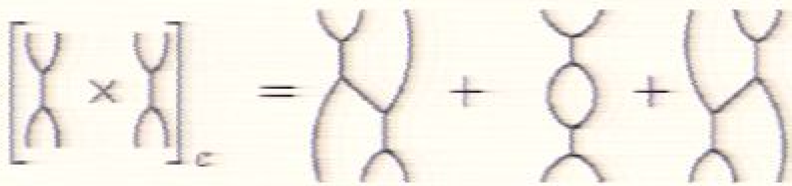
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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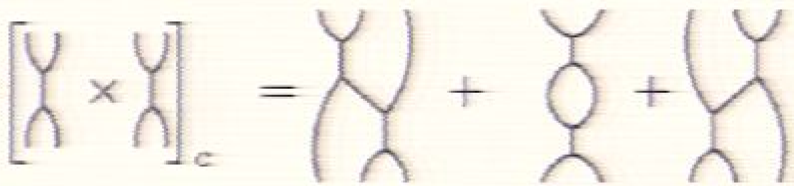
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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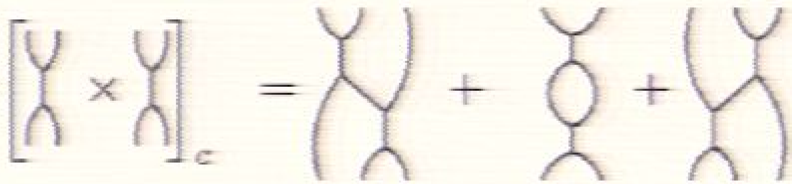
$[\chi(1)^2]_c =$  $= \chi(2,1)+2\chi(1)+\chi(1,2)$

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$$+F_3(g^2)\left[\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)\right]+\ldots$$

$$F_n(g^2) = \frac{(-1)^{n+1}\Gamma(n-1/2)}{2\sqrt{\pi}\,n!}(2g)^{2n}\;{}_2F_1(n-1/2,n;n+1;-8g^2) \qquad \text{(algebraic)}$$

Caveat: $\chi(a_1\ldots a_j, a_j\pm 1, a_j\ldots a_n) = \chi(a_1\ldots a_j\ldots a_n)$ $(SU(2)$ sector):

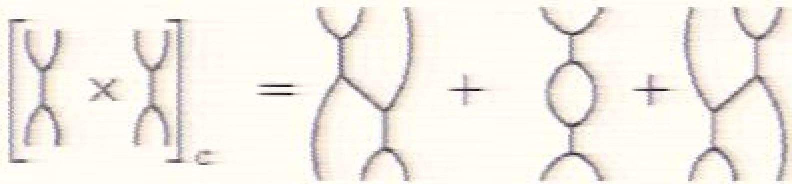
One-magnon state

$$|p\rangle \equiv \sum_{j=1}^{L} e^{ipj} |XXX \dots \overset{j}{\downarrow}{XYX} \dots XX\rangle\,, \quad \varepsilon(p) = \sqrt{1 + 16g^2 \sin^2 \frac{p}{2}} - 1, \quad g = \frac{\sqrt{\lambda}}{4\pi}$$

$$\varepsilon(p)|p\rangle = \left(\sqrt{1 + 4g^2\chi(1)} - 1\right)|p\rangle = \sum_{m=1}^{\infty} \frac{\Gamma(3/2)}{m!\Gamma(3/2 - m)} (2g)^{2m} \left[\chi(1)^m\right]_c |p\rangle\,,$$

Connected products:

$[\chi(1)^2]_c =$



$= \chi(2,1) + 2\chi(1) + \chi(1,2)$

Resum: $$\sum_{m=1}^{\infty} \frac{\Gamma(3/2)}{m!\Gamma(3/2 - m)} g^{2m} \left[\chi(1)^m\right]_c = F_1(g^2)\,\chi(1) + F_2(g^2)\left[\chi(1,2) + \chi(2,1)\right]$$

$$+ F_3(g^2)\left[\chi(1,2,3) + \chi(3,2,1) + \chi(1,2,1) + \chi(2,1,2)\right] + \dots$$

$$F_n(g^2) = \frac{(-1)^{n+1}\Gamma(n - 1/2)}{2\sqrt{\pi}\, n!} (2g)^{2n}\ {}_2F_1(n - 1/2, n; n+1; -8g^2) \qquad \text{(algebraic)}$$

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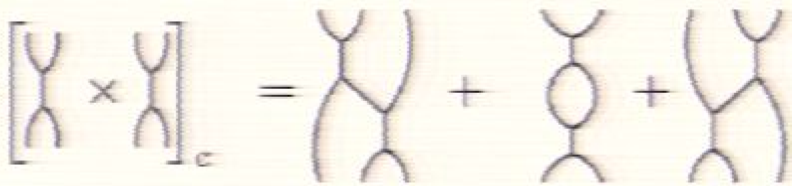
$[\chi(1)^2]_c =$  $= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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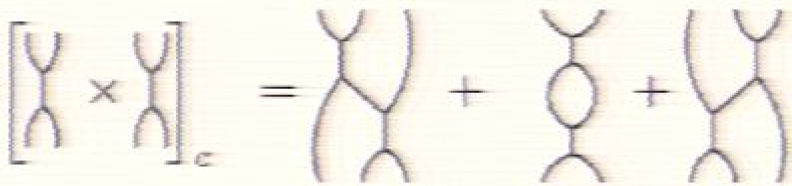

$= \chi(2,1) + 2\chi(1) + \chi(1,2)$

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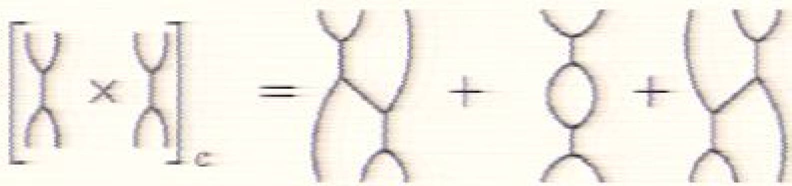

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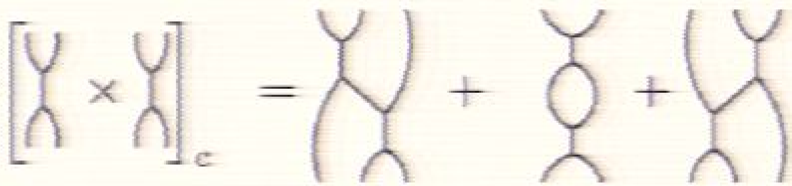

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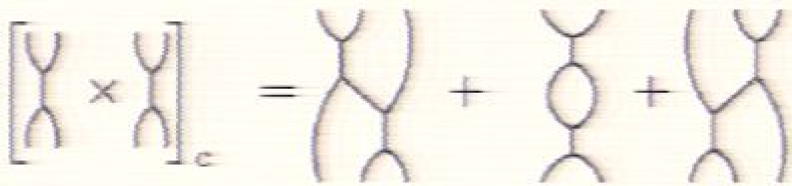

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Computing supergraphs: Feynman rules

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Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

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Computing supergraphs: Feynman rules

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Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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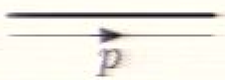
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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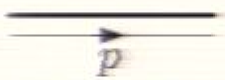
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

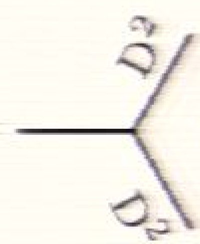
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

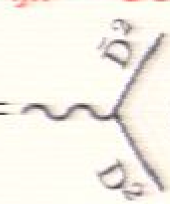
Vertices:

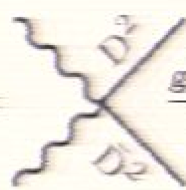
$V_{\phi^i \phi^j \phi^k} =$ 

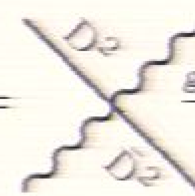
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

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Computing supergraphs: Feynman rules

Fields (all in adjoint):

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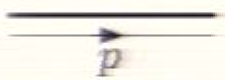
Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

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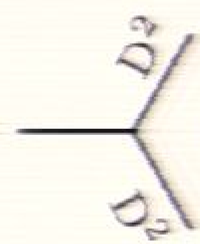
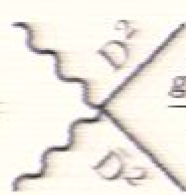
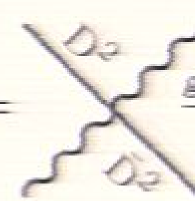
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

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Computing supergraphs: Feynman rules

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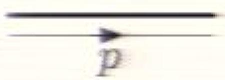
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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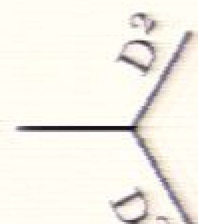
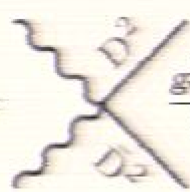
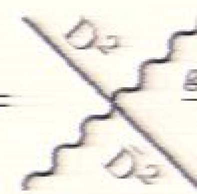
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

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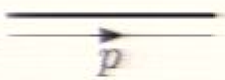
Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

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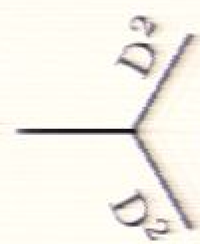
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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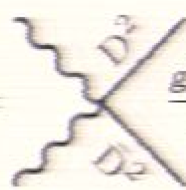
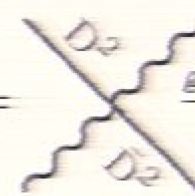
$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

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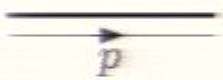
Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

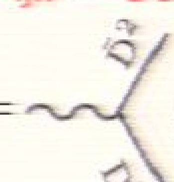
Vertices:

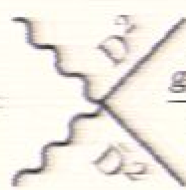
$V_{\phi^i \phi^j \phi^k} =$ 

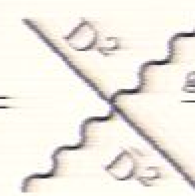
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g_{\rm YM}^2}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

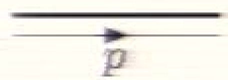
$\frac{g_{\rm YM}^2}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

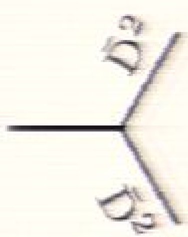
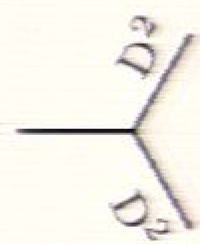
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

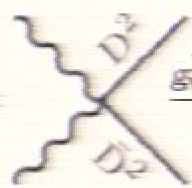
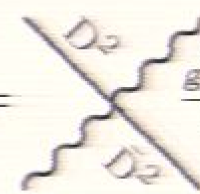
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

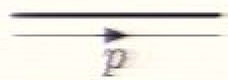
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

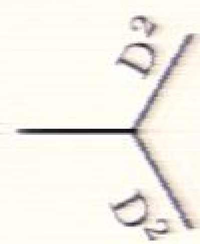
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

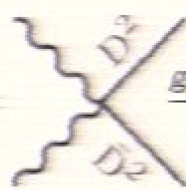
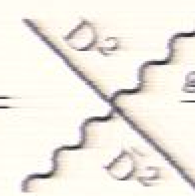
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

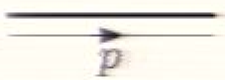
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

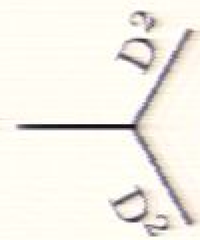
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

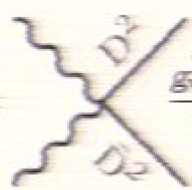
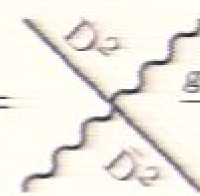
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

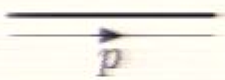
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

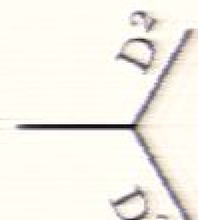
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

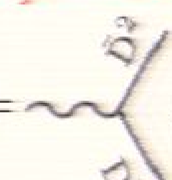
Vertices:

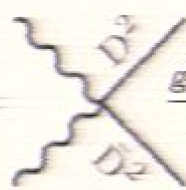
$V_{\phi^i \phi^j \phi^k} =$ 

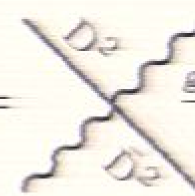
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

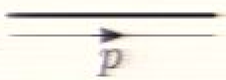
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

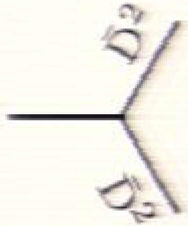
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

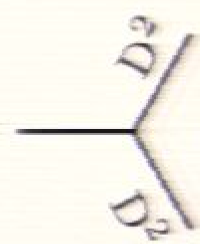
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

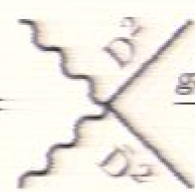
$V_{\phi^i \phi^j \phi^k} =$ 

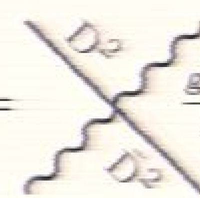
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}} \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

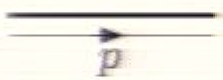
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

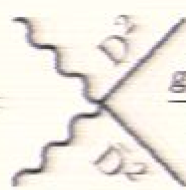
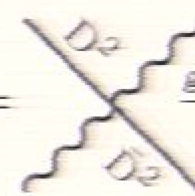
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

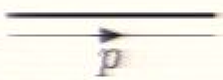
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

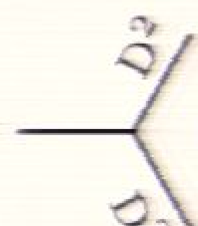
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

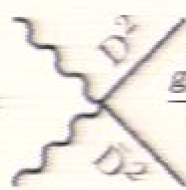
$V_{\phi^i \phi^j \phi^k} =$ 

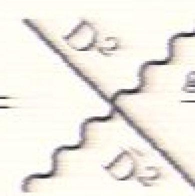
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

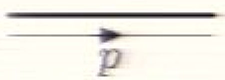
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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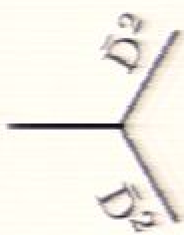
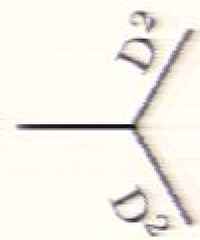
$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

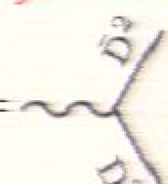
Vertices:

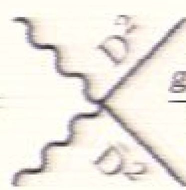
$V_{\phi^i \phi^j \phi^k} =$ 

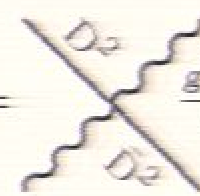
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

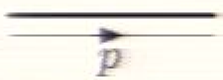
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

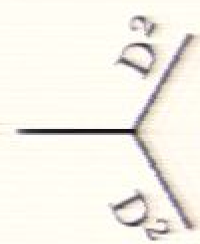
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

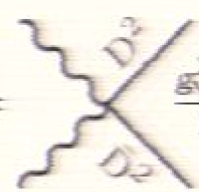
$V_{\phi^i \phi^j \phi^k} =$ 

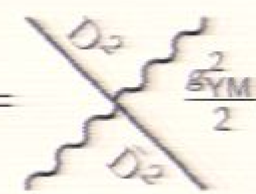
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

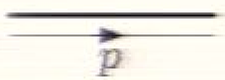
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

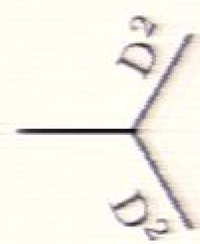
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

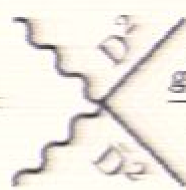
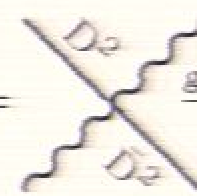
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g_{\mathrm{YM}}^2}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g_{\mathrm{YM}}^2}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

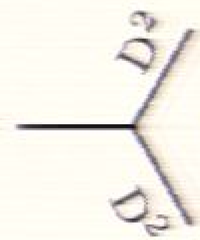
Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

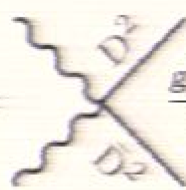
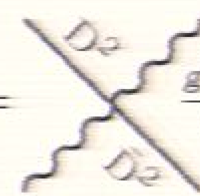
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

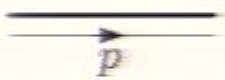
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

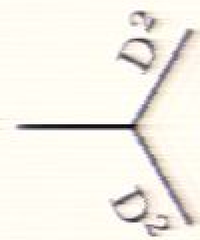
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

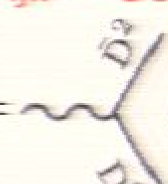
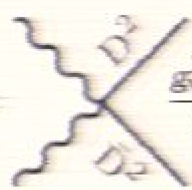
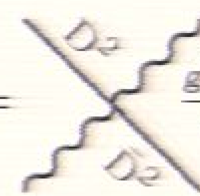
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

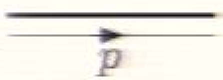
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

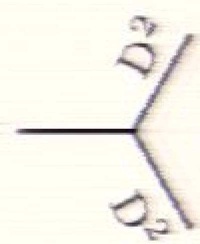
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 

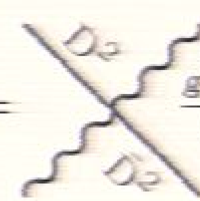
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

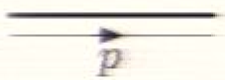
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

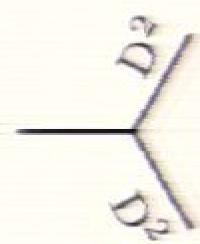
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

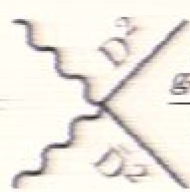
$V_{\phi^i \phi^j \phi^k} =$ 

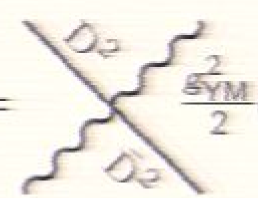
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

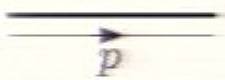
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^{c}{}_d \rangle =$ 

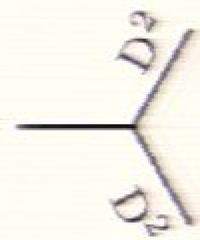
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

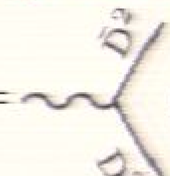
Vertices:

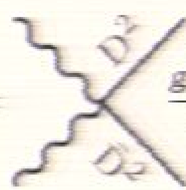
$V_{\phi^i \phi^j \phi^k} =$ 

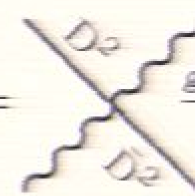
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

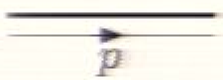
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

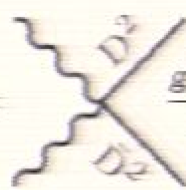
$V_{\phi^i \phi^j \phi^k} =$ 

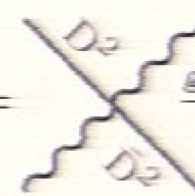
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

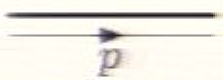
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \, \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b \, V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 

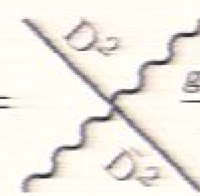
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

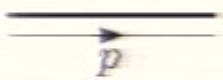
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

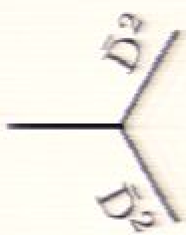
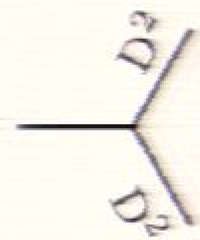
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

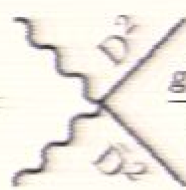
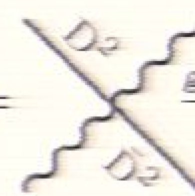
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowright + G_{ikj} \circlearrowleft)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowright + G^{ikj} \circlearrowleft)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

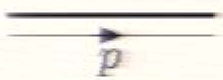
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

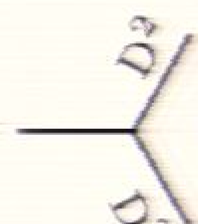
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

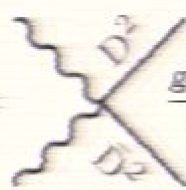
$V_{\phi^i \phi^j \phi^k} =$ 

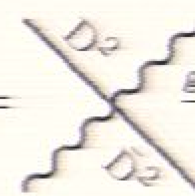
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

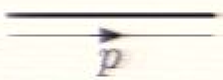
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

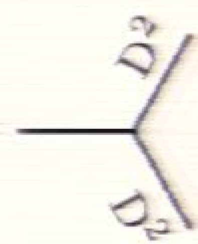
Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

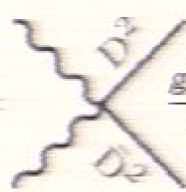
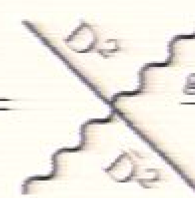
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

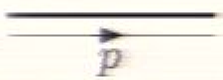
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

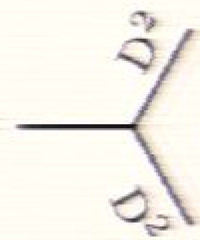
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

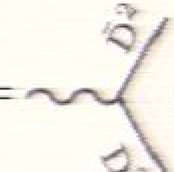
Vertices:

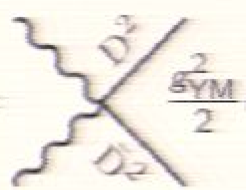
$V_{\phi^i \phi^j \phi^k} =$ 

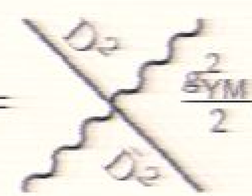
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

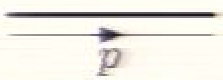
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

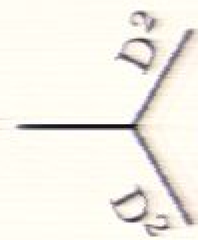
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

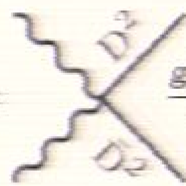
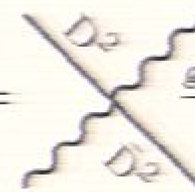
$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 
$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

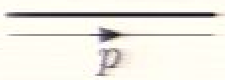
$V_{\bar{\phi}_j V \phi^i} =$ 
$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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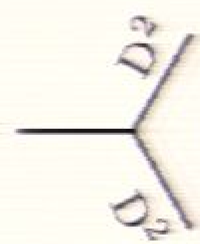
Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$,

$V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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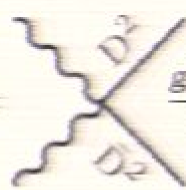
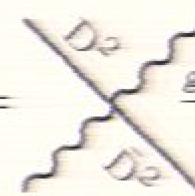
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$,

$V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$,

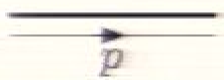
$V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

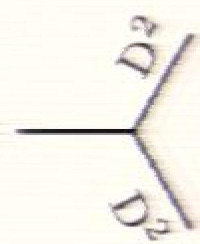
Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$,

$V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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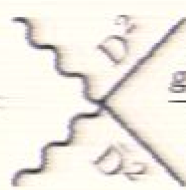
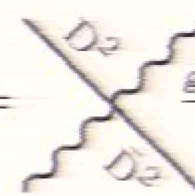
$V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$,

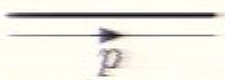
$V_{V \bar{\phi}_j V \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

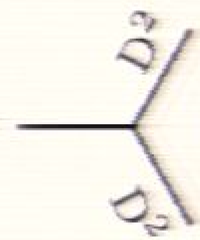
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 

$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

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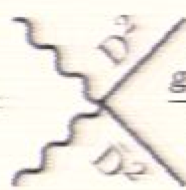
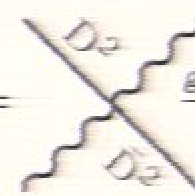
$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g_{\rm YM}^2}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

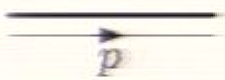
$\frac{g_{\rm YM}^2}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

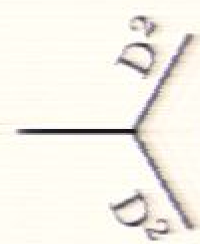
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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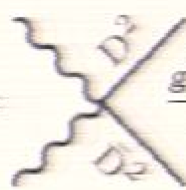
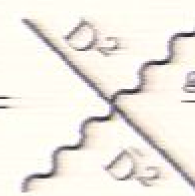
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

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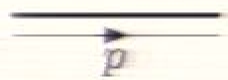
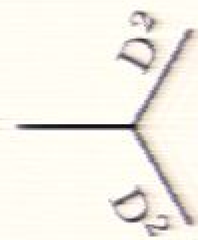
$\langle \phi^{i\,a}{}_b \bar\phi_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar\phi_i \bar\phi_j \bar\phi_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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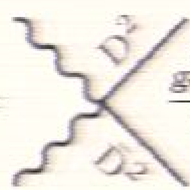
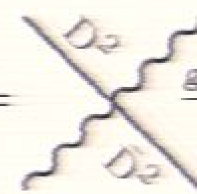
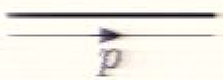
$V_{\bar\phi_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar\phi_j \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar\phi_j V \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

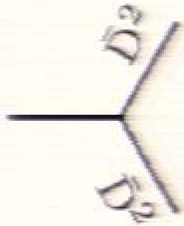
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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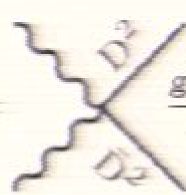
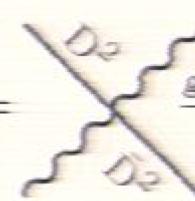
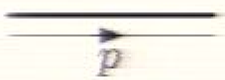
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

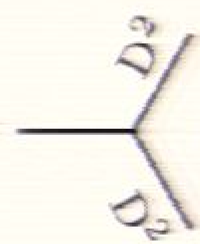
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

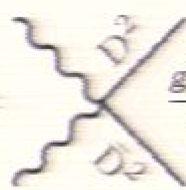
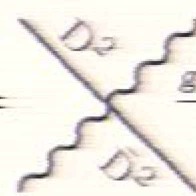
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 

$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar\phi_i \bar\phi_j \bar\phi_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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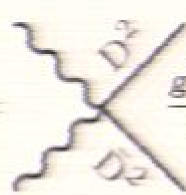
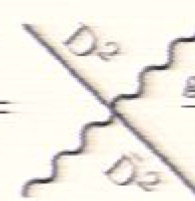
$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar\phi_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar\phi_i V \phi^j} =$ 

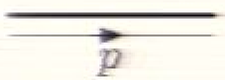
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

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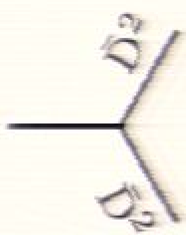
Vertices:

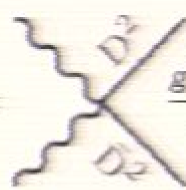
$V_{\phi^i \phi^j \phi^k} =$ 

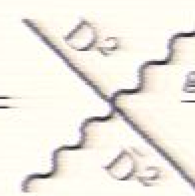
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

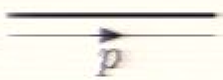
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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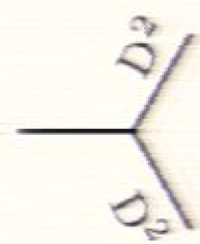
Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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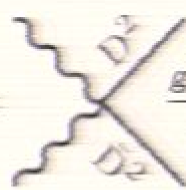
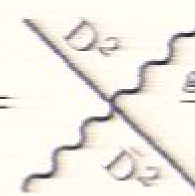
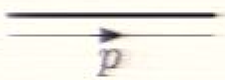
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

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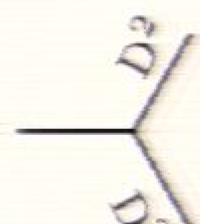
$V_{\phi^i \phi^j \phi^k} =$ 

$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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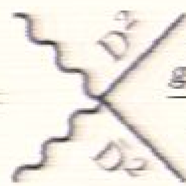
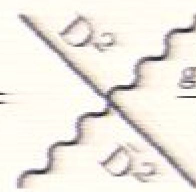
$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

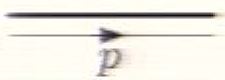
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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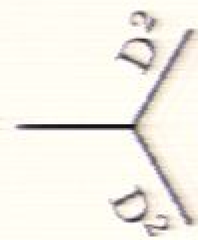
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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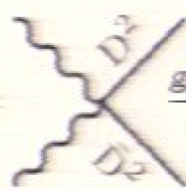
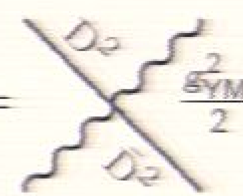
$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

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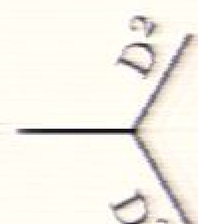
$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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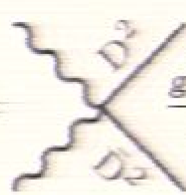
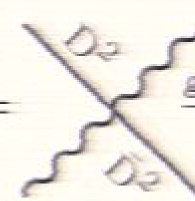
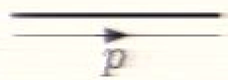
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

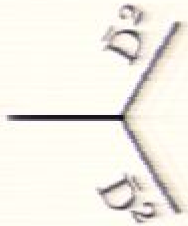
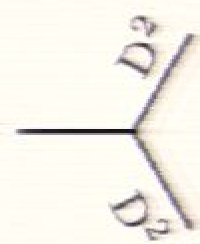
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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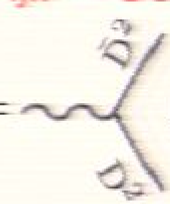
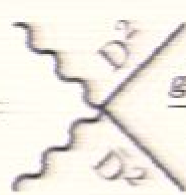
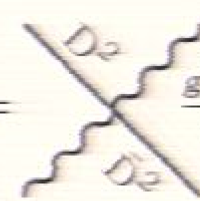
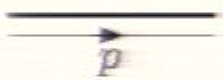
$V_{\bar{\phi}_j V \phi^i} =$  $g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$  $\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

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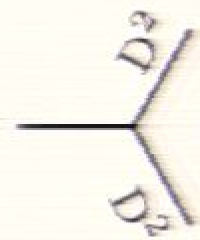
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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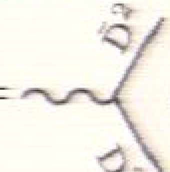
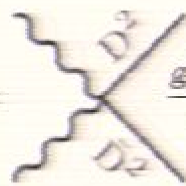
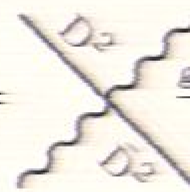
$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

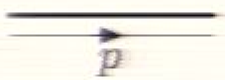
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

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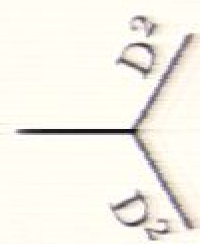
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

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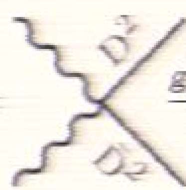
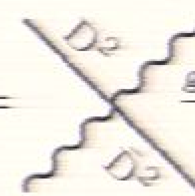
$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

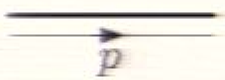
$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

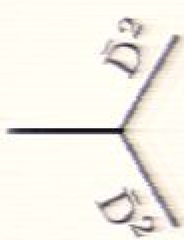
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

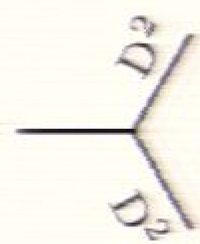
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

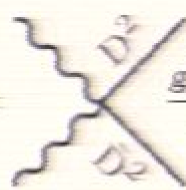
$V_{\phi^i \phi^j \phi^k} =$ 

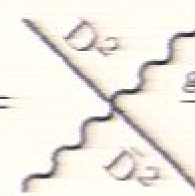
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

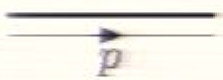
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

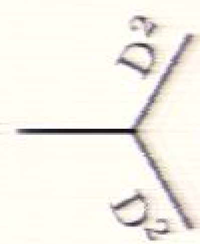
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

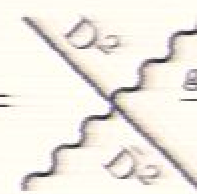
$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 
$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

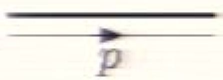
$V_{\bar{\phi}_j V \phi^i} =$ 
$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 
$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

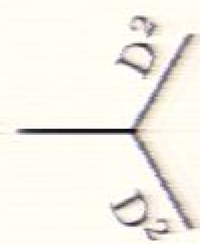
Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

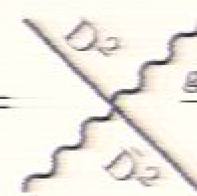
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

$V_{\phi^i \phi^j \phi^k} =$  $i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$  $i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$  $g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$  $\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

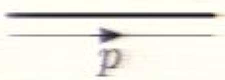
Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

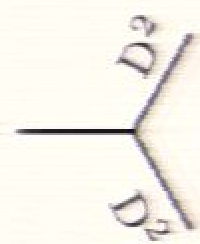
$$\langle \phi^{j\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle = \underset{p}{\longrightarrow} = \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$$



$$\langle V^a{}_b V^c{}_d \rangle = \underset{p}{\rightsquigarrow} = -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$$

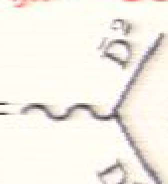
Vertices:

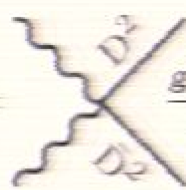
$$V_{\phi^i \phi^j \phi^k} = \; i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright), \quad V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} = \; i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$$

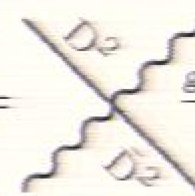


$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$$V_{\bar{\phi}_j V \phi^i} = \; g_{\rm YM} \delta^j_i, \quad V_{V^2 \bar{\phi}_j \phi^i} = \; \frac{g^2_{\rm YM}}{2} \delta^j_i, \quad V_{V \bar{\phi}_j V \phi^i} = \; \frac{g^2_{\rm YM}}{2} \delta^j_i$$





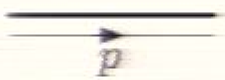


Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

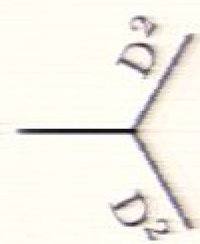
Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$  $= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$  $= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

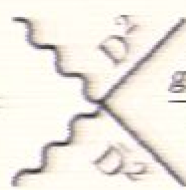
$V_{\phi^i \phi^j \phi^k} =$ 

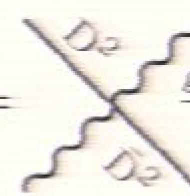
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

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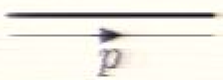
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

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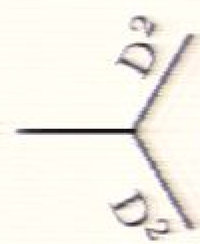
Vertices:

$V_{\phi^i \phi^j \phi^k} =$ 

$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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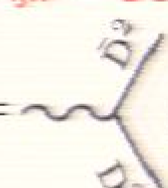
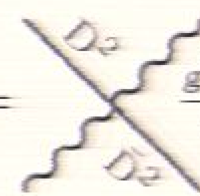
$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

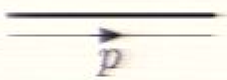
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

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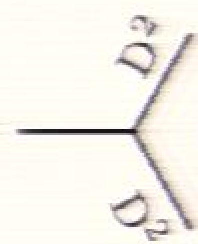
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

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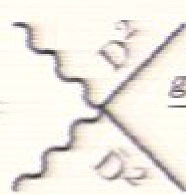
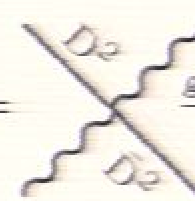
$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

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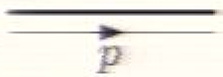
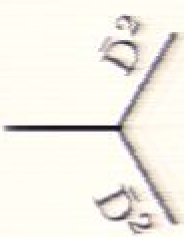
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

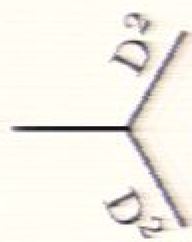
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

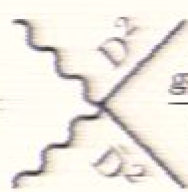
$V_{\phi^i \phi^j \phi^k} =$ 

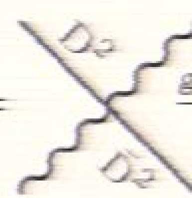
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_i \phi^j} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_i V \phi^j} =$ 

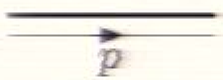
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i) Vector superfields: V

Propagators:

$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

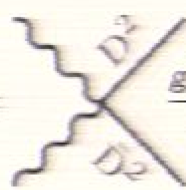
$V_{\phi^i \phi^j \phi^k} =$ 

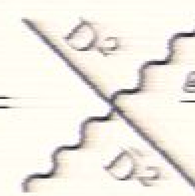
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\rm YM}\, \epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\rm YM} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\rm YM}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

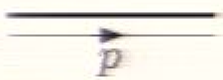
$\frac{g^2_{\rm YM}}{2} \delta^j_i$

Computing supergraphs: Feynman rules

Fields (all in adjoint):

Chiral superfields: X, Y, Z (or ϕ^i)   Vector superfields: V

Propagators:

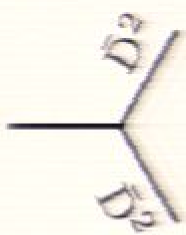
$\langle \phi^{i\,a}{}_b \bar{\phi}_j{}^c{}_d \rangle =$ 

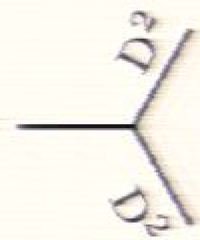
$= \delta^i{}_j \frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

$\langle V^a{}_b V^c{}_d \rangle =$ 

$= -\frac{\delta^a{}_d \delta^c{}_b}{p^2} \delta^4(\theta_1 - \theta_2)$

Vertices:

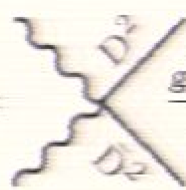
$V_{\phi^i \phi^j \phi^k} =$ 

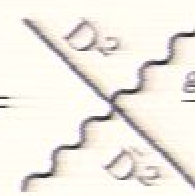
$i(G_{ijk} \circlearrowleft + G_{ikj} \circlearrowright)$, $V_{\bar{\phi}_i \bar{\phi}_j \bar{\phi}_k} =$ 

$i(G^{ijk} \circlearrowleft + G^{ikj} \circlearrowright)$

$\mathcal{N} = 4$: $G_{ijk} = g_{\mathrm{YM}}\,\epsilon_{ijk}$

$V_{\bar{\phi}_j V \phi^i} =$ 

$g_{\mathrm{YM}} \delta^j_i$, $V_{V^2 \bar{\phi}_j \phi^i} =$ 

$\frac{g^2_{\mathrm{YM}}}{2} \delta^j_i$, $V_{V \bar{\phi}_j V \phi^i} =$ 

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Computing supergraphs: Chiral Operators

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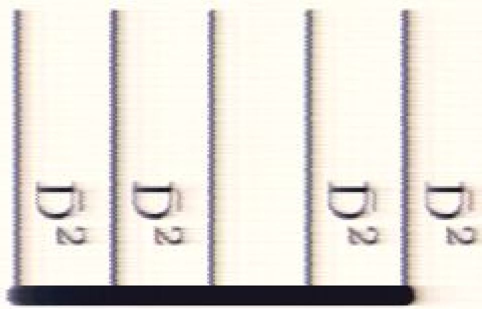

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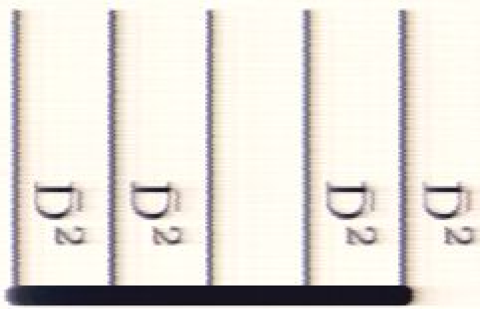

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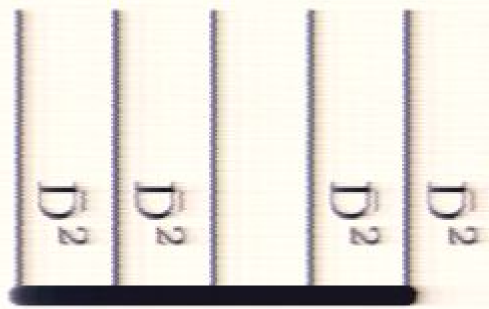

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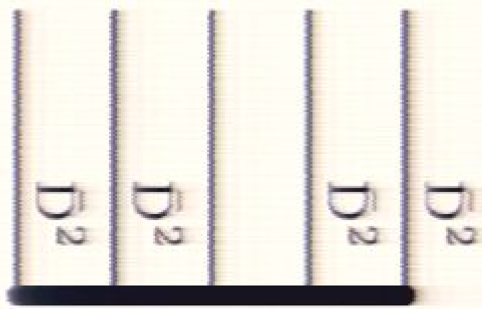
$\mathcal{O} = \ldots$ 

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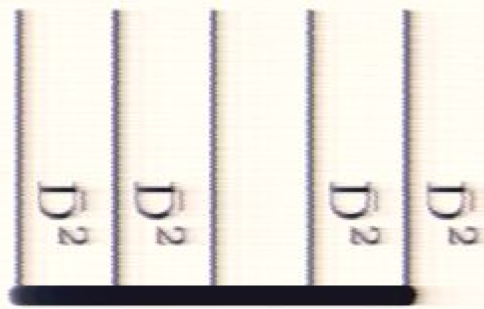
$\mathcal{O} = \ldots$  $\ldots$ One leg missing $\bar{D}^2$.

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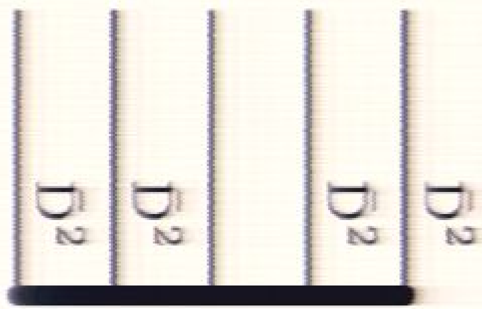
$\mathcal{O} = \ldots$ 

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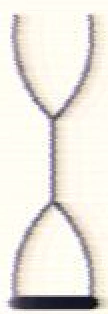
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1)\,, \quad \mathcal{D}_2 = -2\,[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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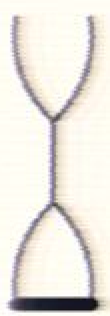
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1)\,, \quad \mathcal{D}_2 = -2[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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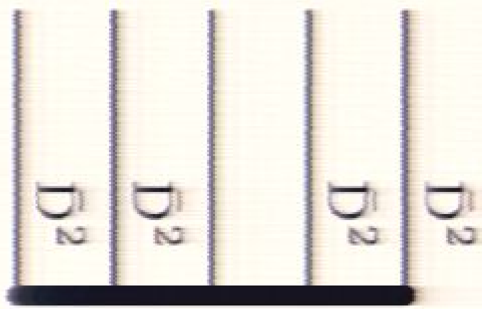
$\mathcal{O} = \ldots$  $\ldots$ One leg missing $\bar{D}^2$.

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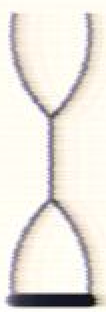
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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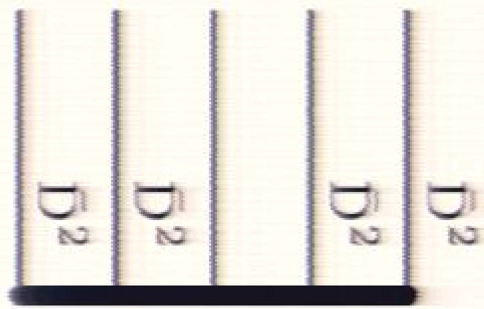
$\mathcal{O} = \ldots$ 

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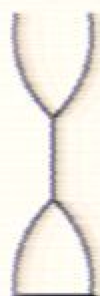
$\mathcal{D}_0 = L$,  $\mathcal{D}_1 = 2\chi(1)$, $\mathcal{D}_2 = -2[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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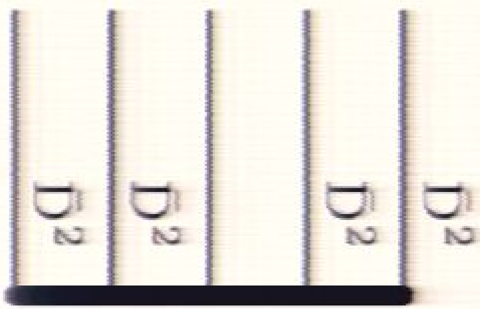
$\mathcal{O} = \ldots$ 

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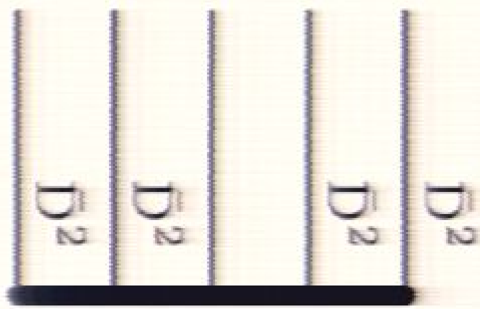
$\mathcal{O} = \ldots$  $\ldots$ One leg missing $\bar{D}^2$.

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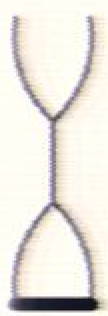
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2\,[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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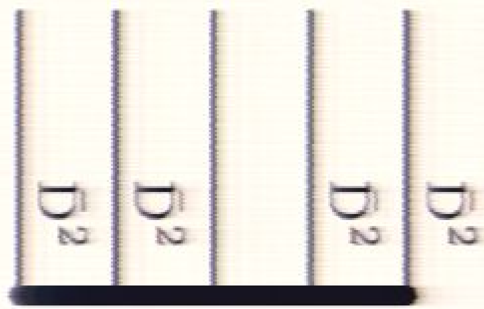

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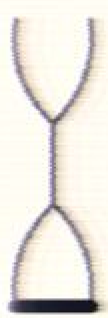

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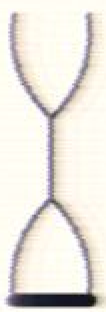
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2\left[\chi(1,2) + \chi(2,1)\right] - 4\chi(1)$

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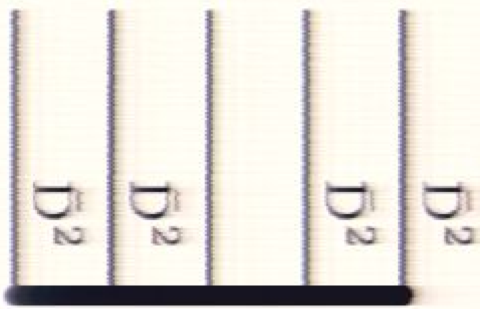
$\mathcal{O} = \ldots$  $\ldots$ One leg missing $\bar{D}^2$.

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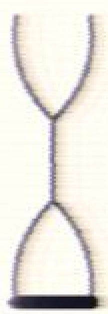
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2\left[\chi(1,2) + \chi(2,1)\right] - 4\chi(1)$

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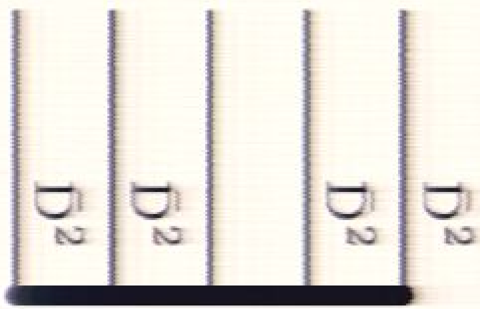
$\mathcal{O} = \ldots$ 

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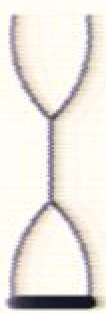
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1)\,, \quad \mathcal{D}_2 = -2\left[\chi(1,2) + \chi(2,1)\right] - 4\chi(1)$

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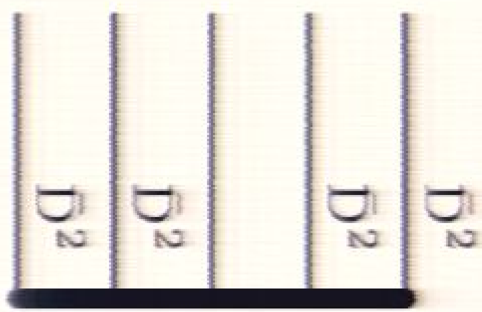
$\mathcal{O} = \dots$  $\cdots$ One leg missing $\bar{D}^2$.

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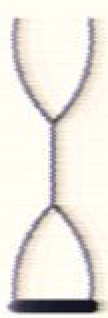
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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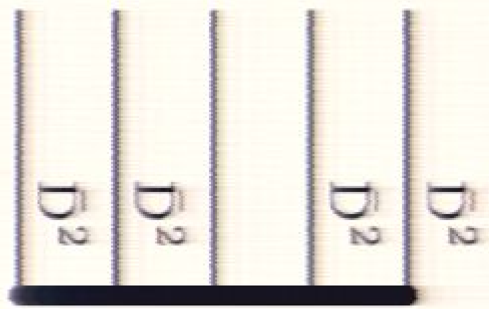
$\mathcal{O} = \ldots$  $\ldots$ One leg missing $\bar{D}^2$.

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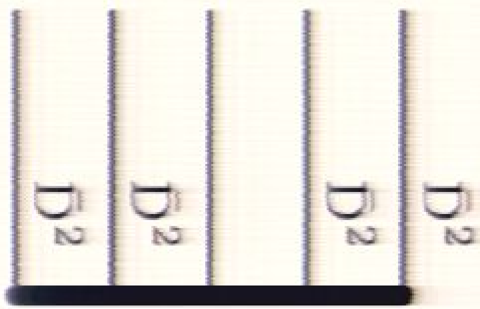
$\mathcal{O} = \ldots$  $\cdots$ One leg missing $\bar{D}^2$.

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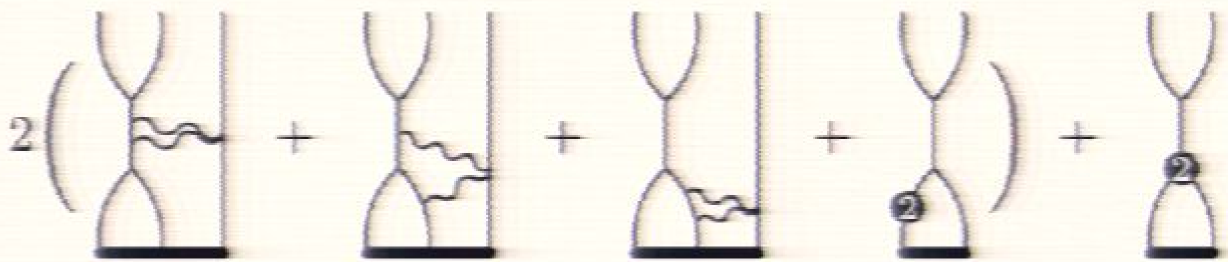

$$\mathcal{D}_3^{(1)} = 16\chi(1)$$

Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

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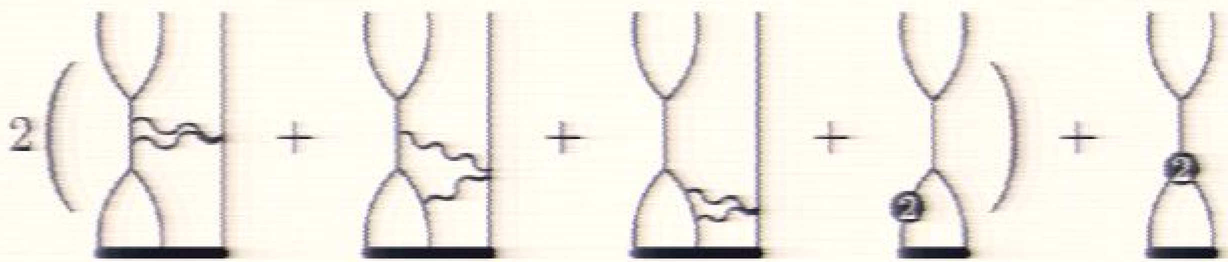

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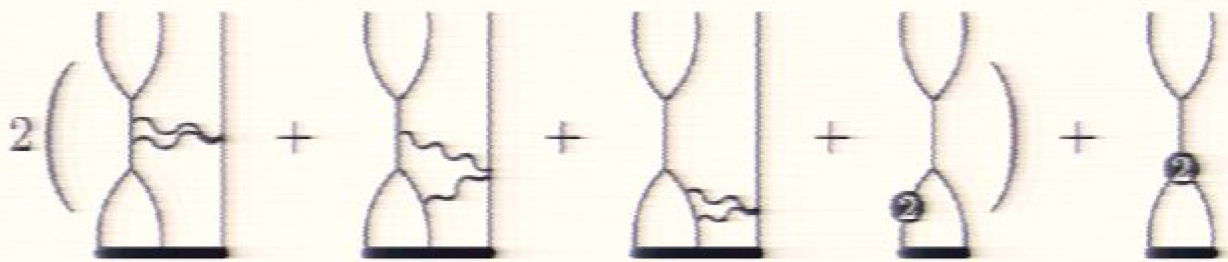

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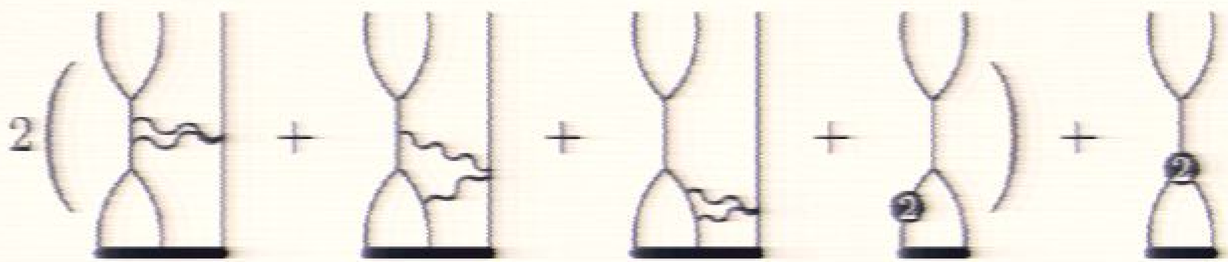

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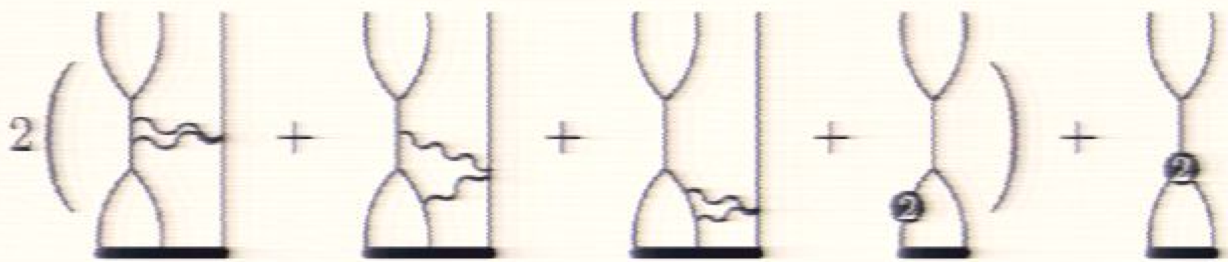

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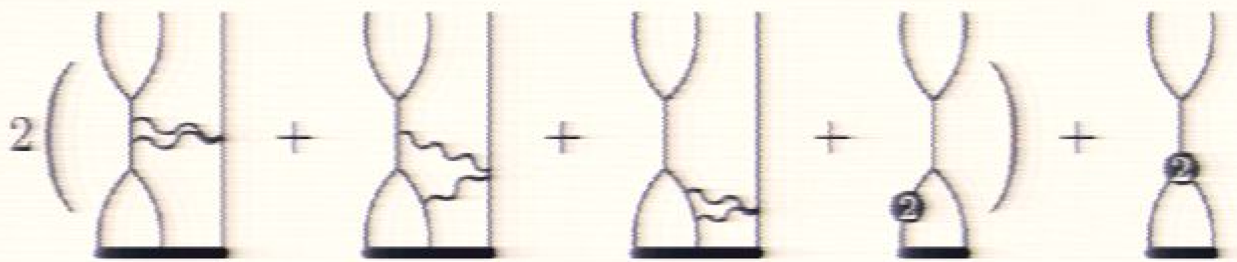

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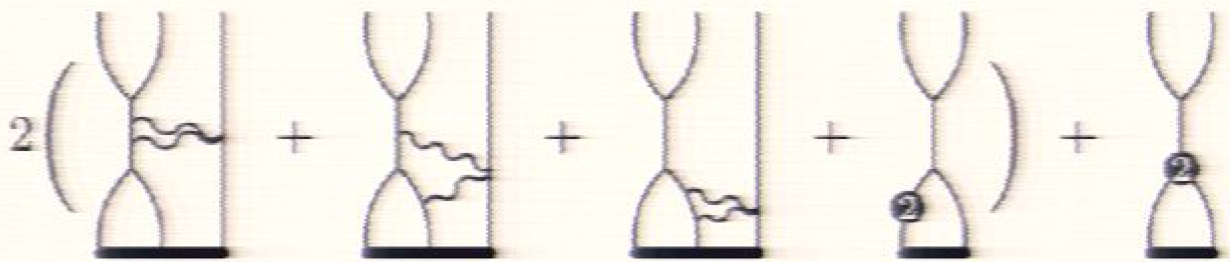

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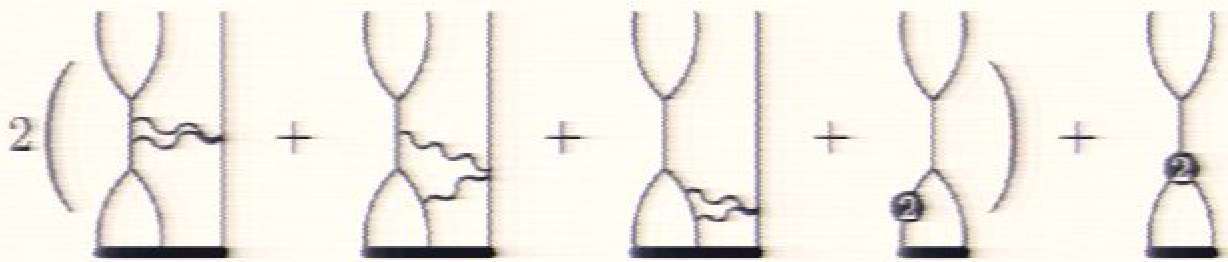

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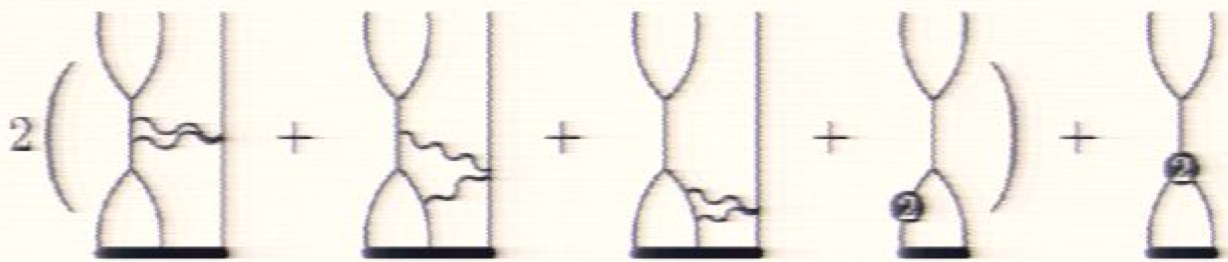

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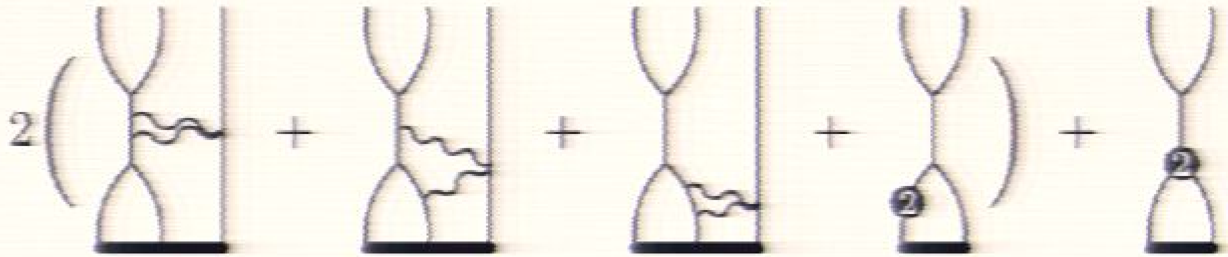

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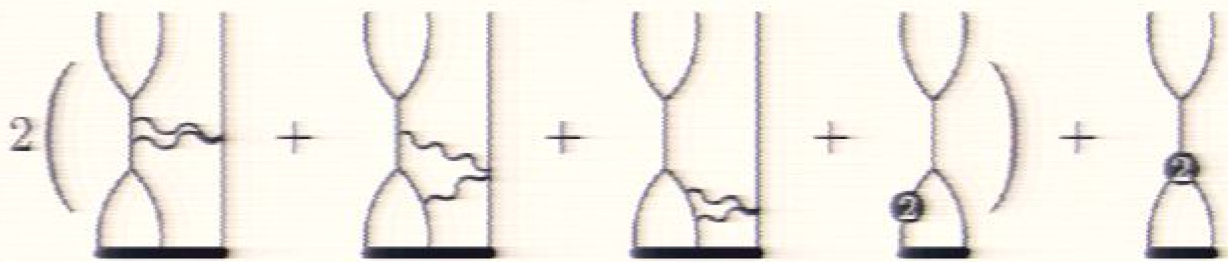

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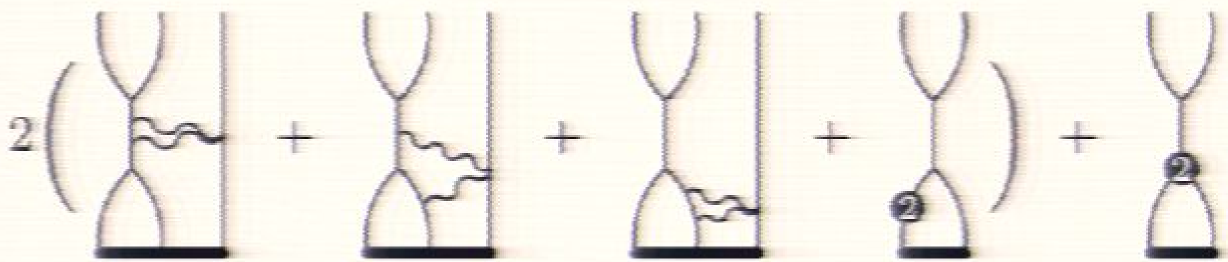

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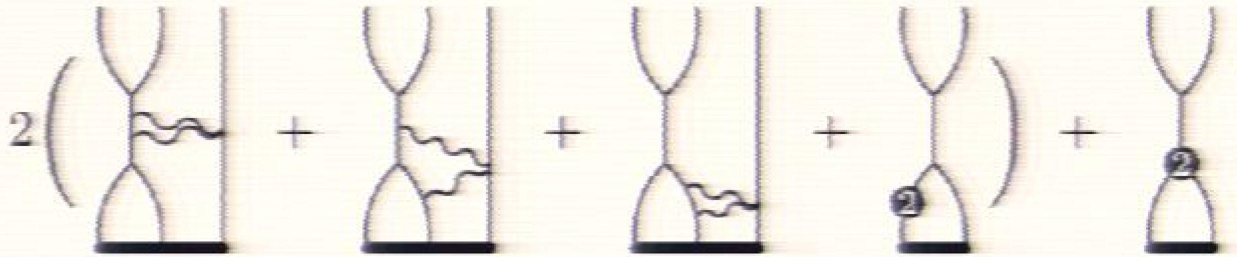

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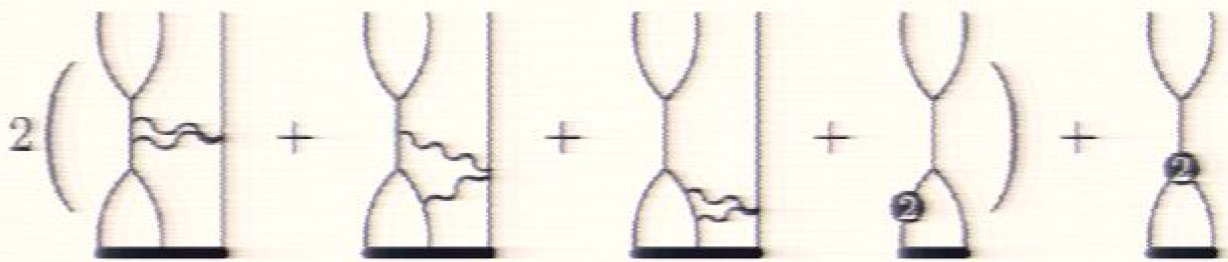

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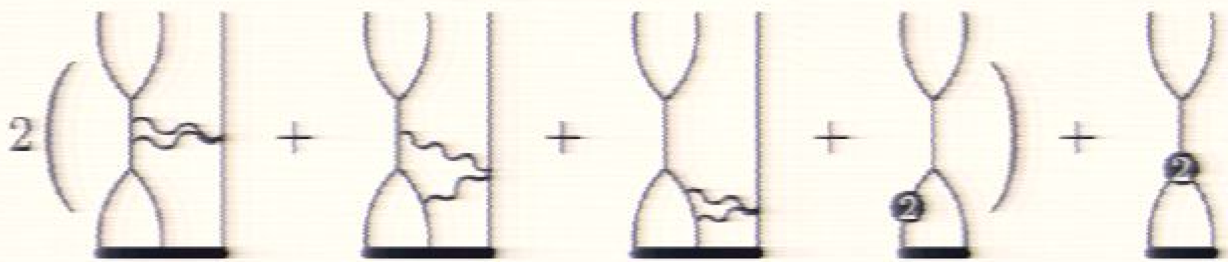

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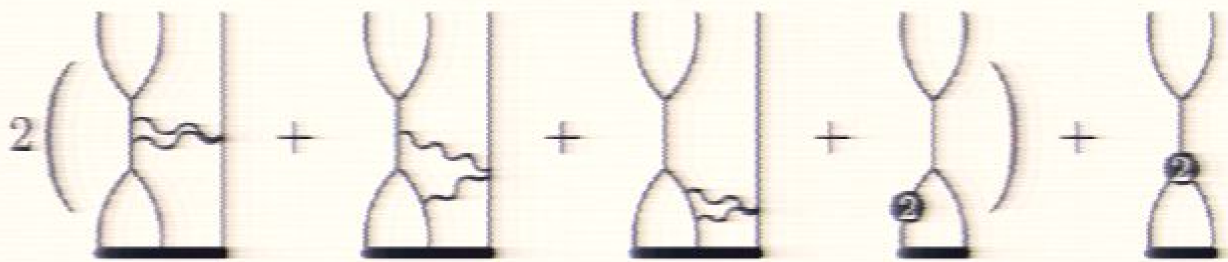

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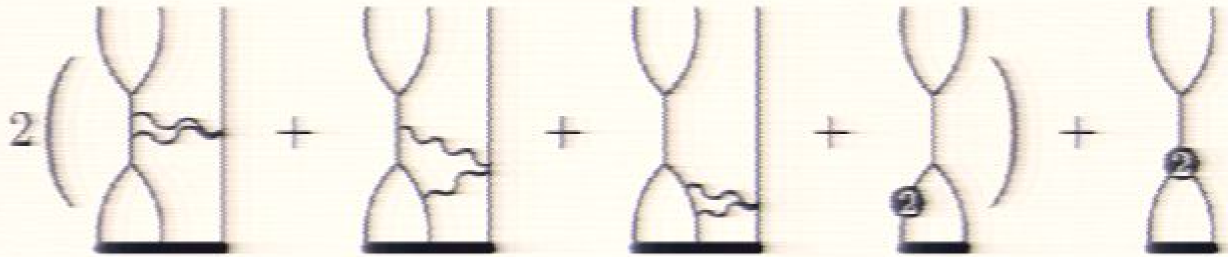

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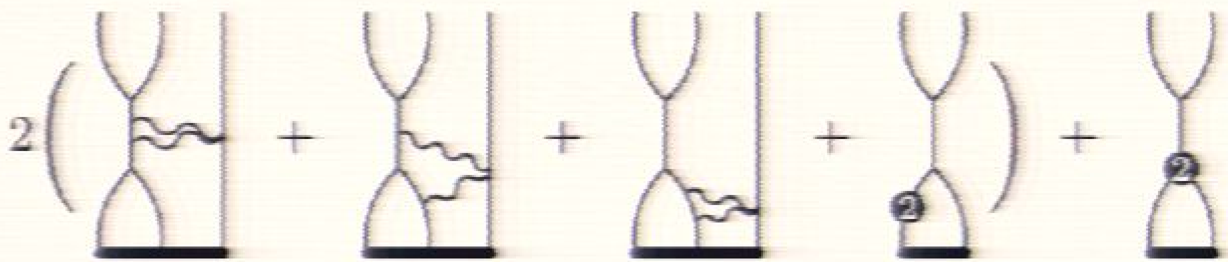

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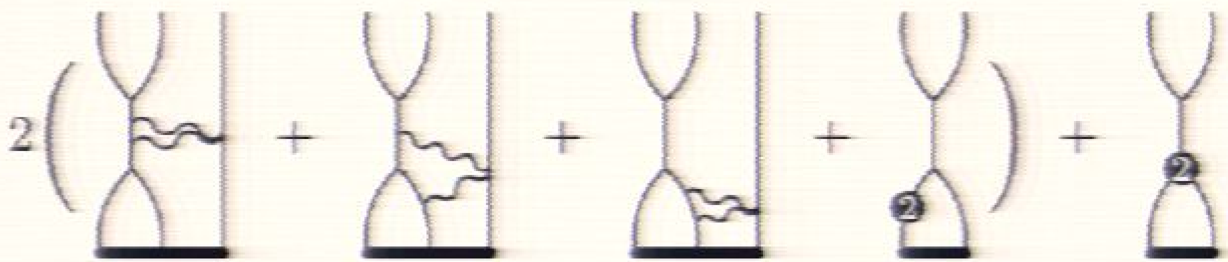

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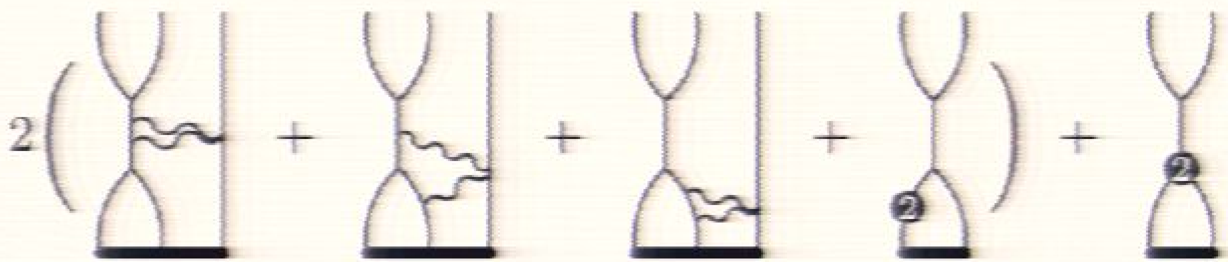

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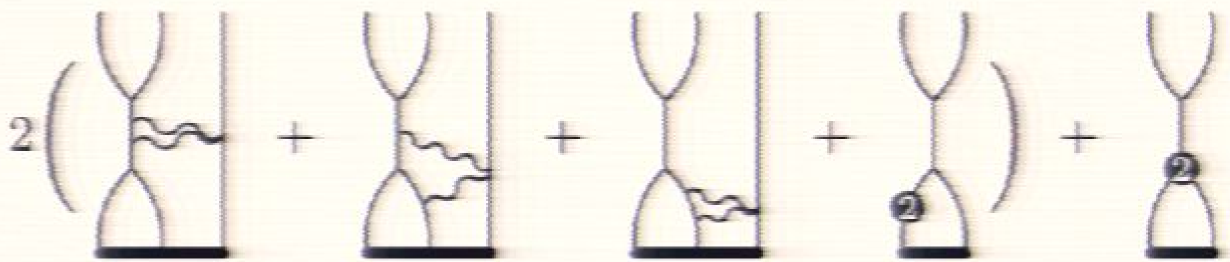

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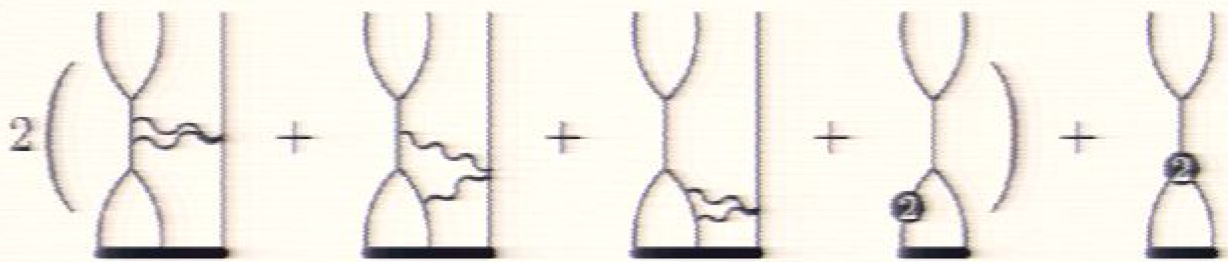

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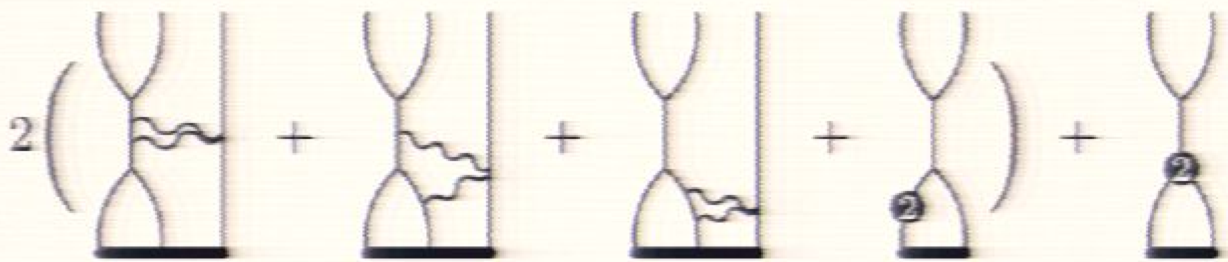

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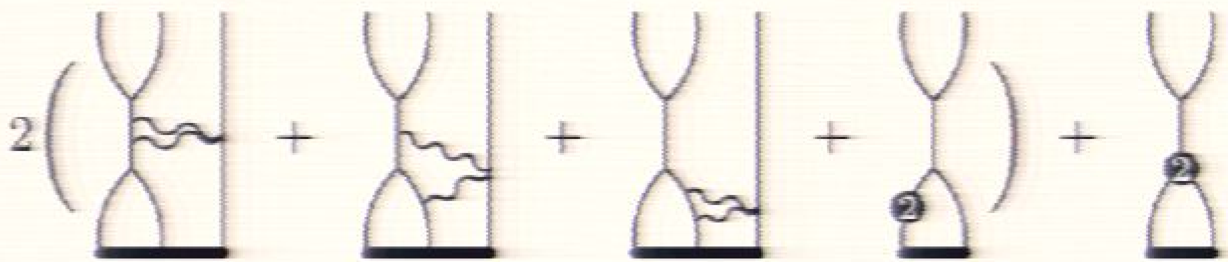

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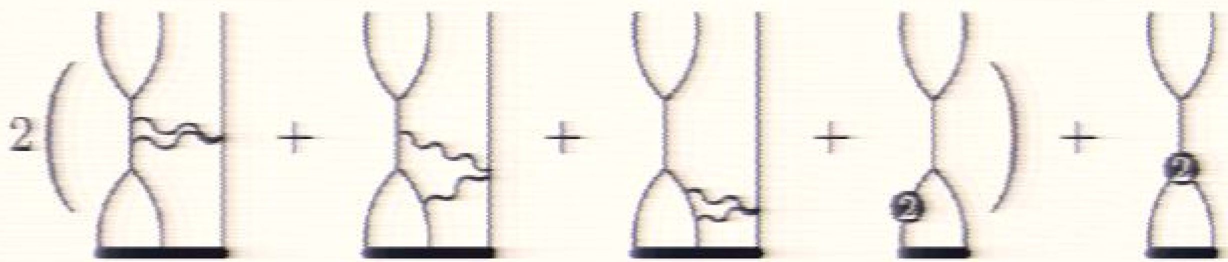

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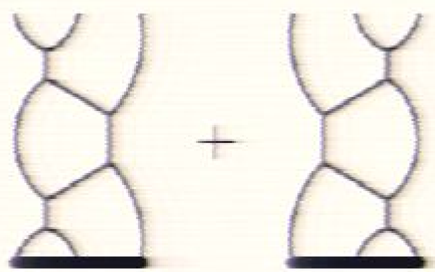

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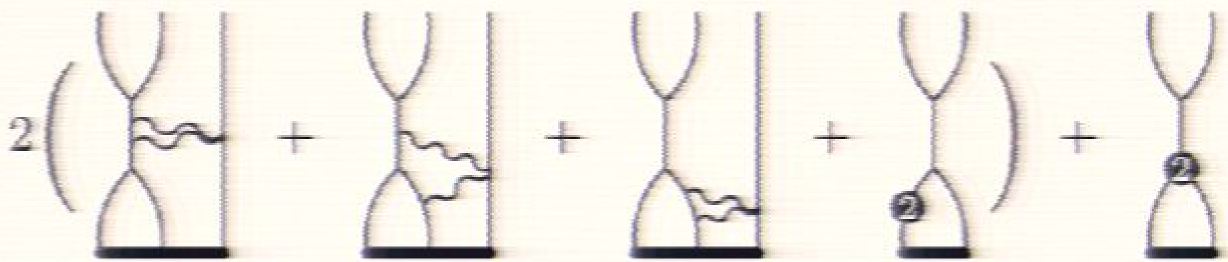

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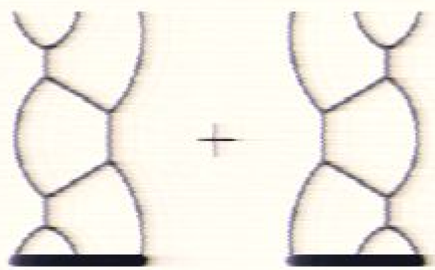

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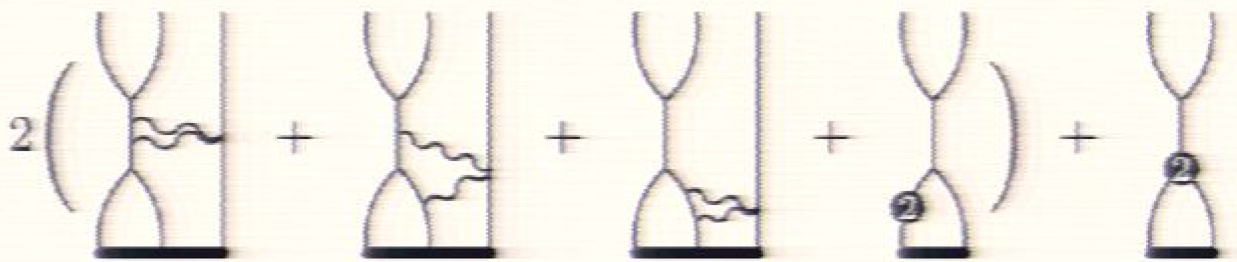

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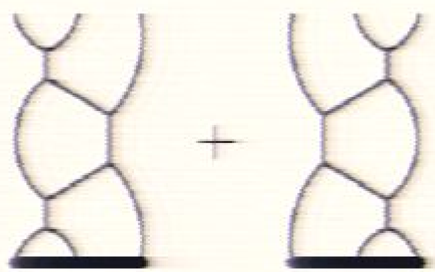

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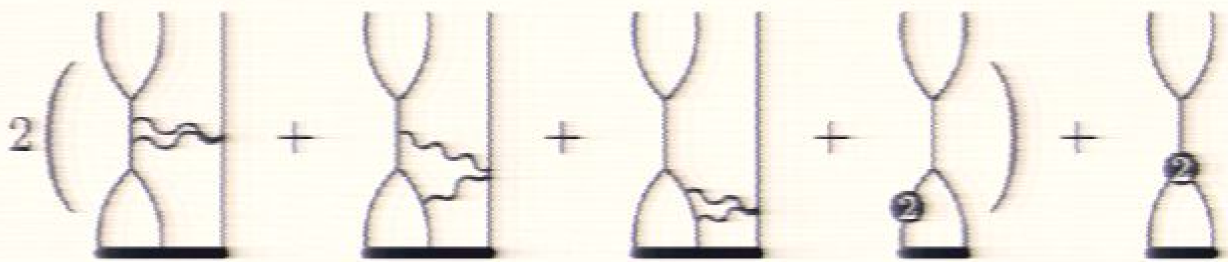

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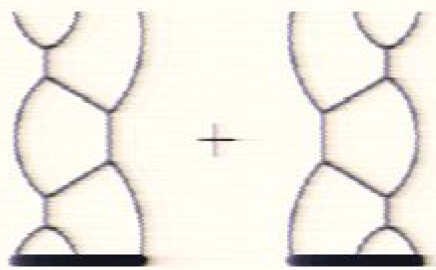

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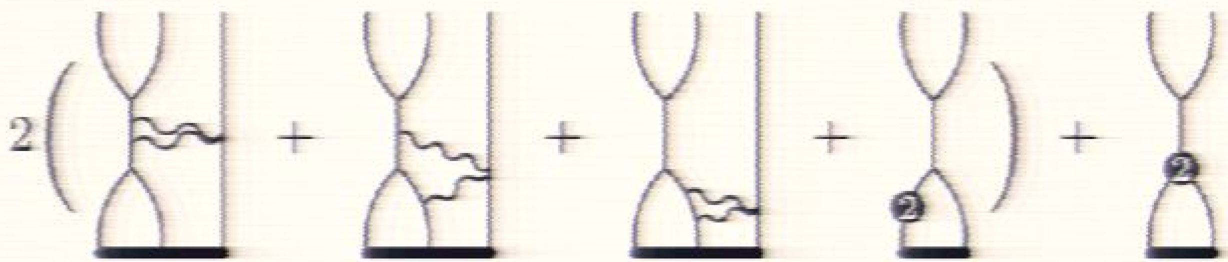
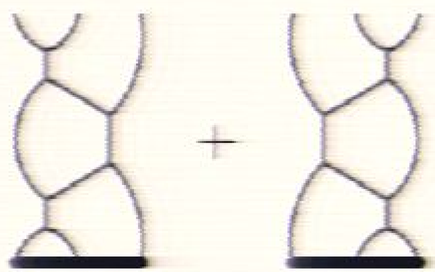


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

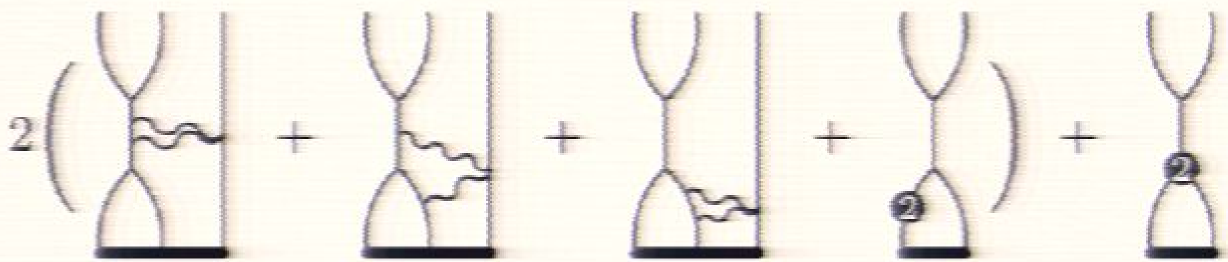
Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

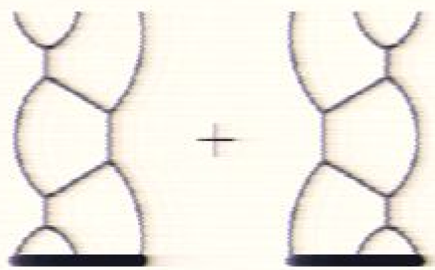
$$\mathcal{D}_3 \;=\; 4\left[\chi(1,2,3)+\chi(3,2,1)\right]-4\chi(1,3)+16\left(\chi(1,2)+\chi(2,1)\right)+24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1)=\chi(2,1,2)=\chi(1)$.

Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)}+\mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1)+4\chi(2,1,2)$$

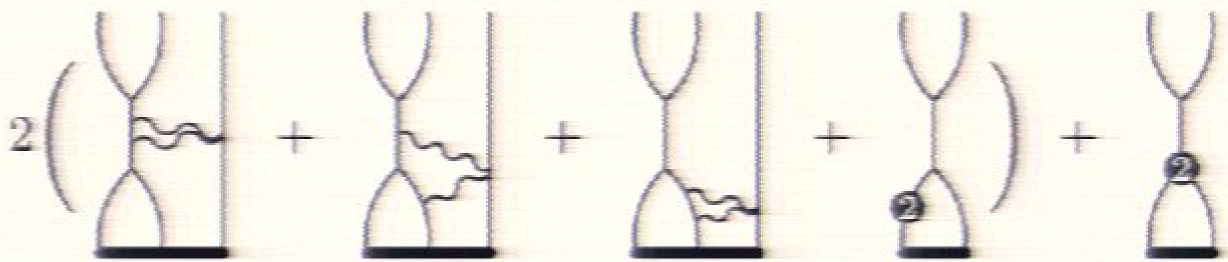
Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 \;=\; 4\big[\chi(1,2,3)+\chi(3,2,1)\big] - 4\chi(1,3) + 16\big(\chi(1,2)+\chi(2,1)\big) + 24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1) = \chi(2,1,2) = \chi(1)$.

Supergraphs: Sieg (2010)



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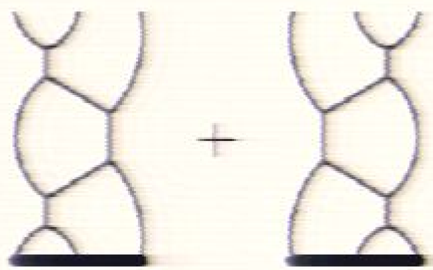

$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

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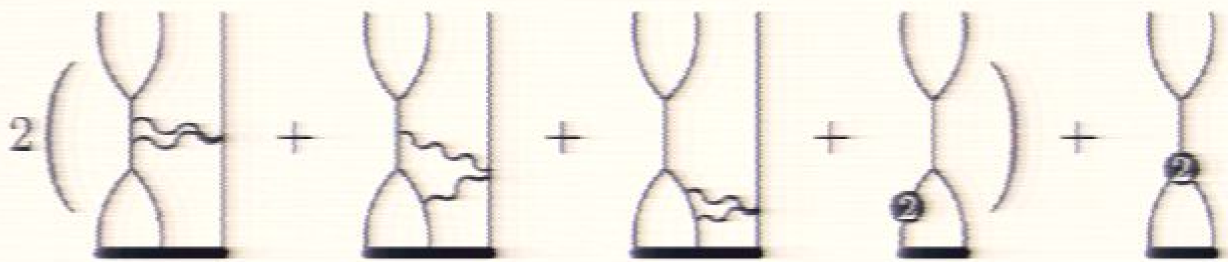

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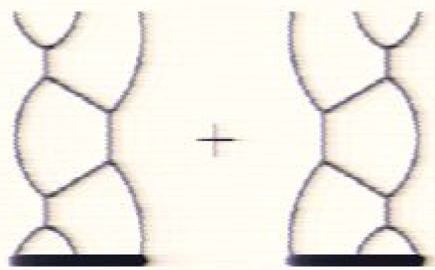

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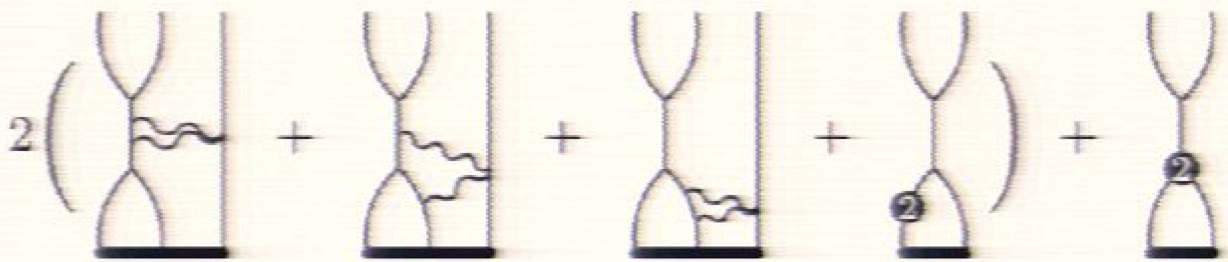

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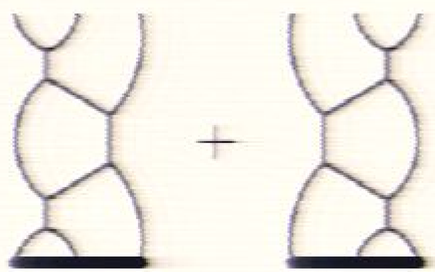

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$$\mathcal{D}_3 = 4[\chi(1,2,3)+\chi(3,2,1)] - 4\chi(1,3) + 16(\chi(1,2)+\chi(2,1)) + 24\chi(1)$$

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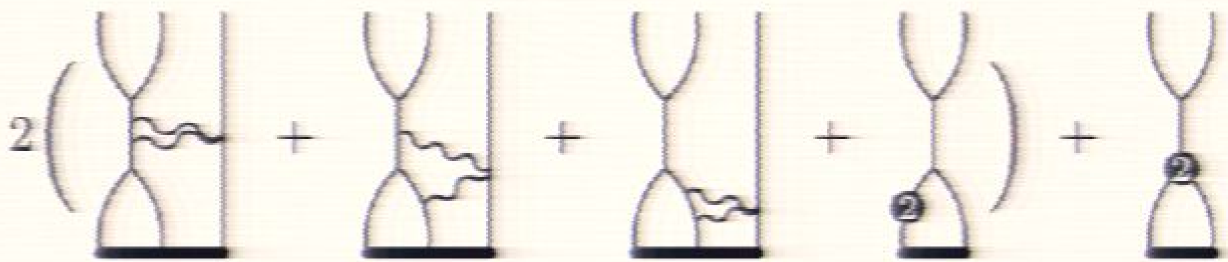
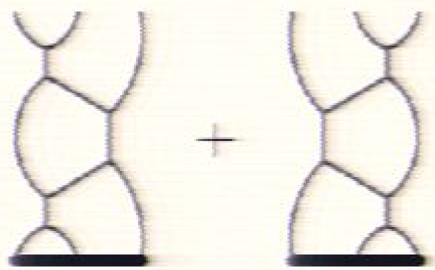


$\mathcal{D}_3^{(1)} = 16\chi(1)$



$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$

Three loops ($SU(2)$ sector)

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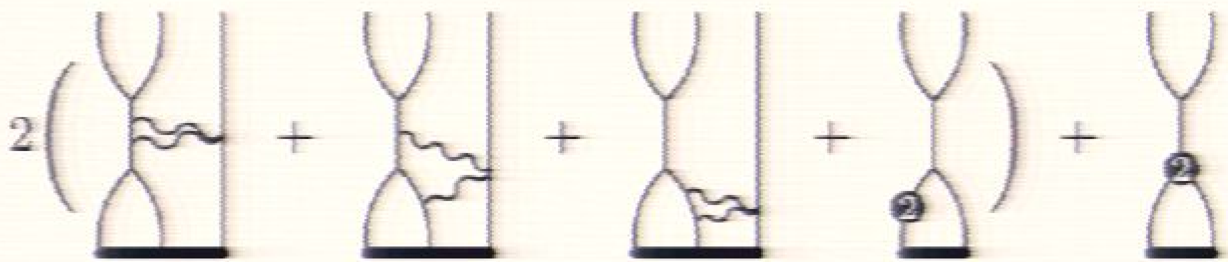
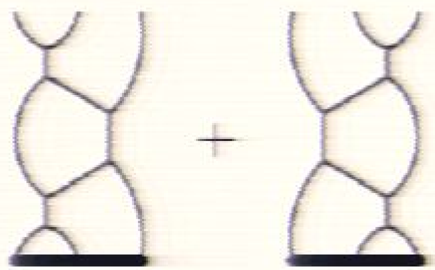


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



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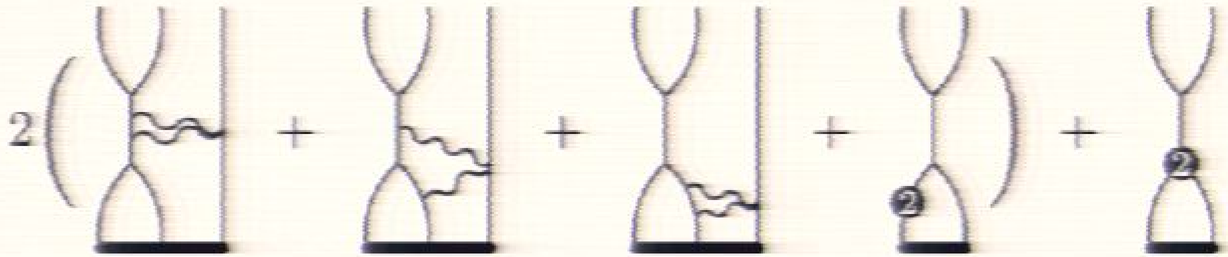
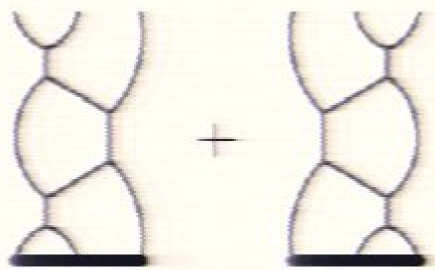


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



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Three loops (*SU*(2) sector)

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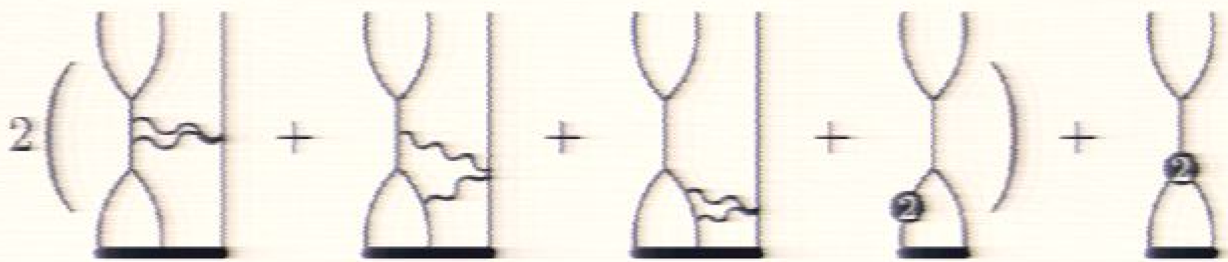
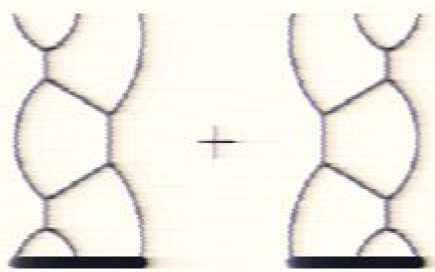


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

Three loops (*SU*(2) sector)

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$$\mathcal{D}_3 \;=\; 4\big[\chi(1,2,3)+\chi(3,2,1)\big] - 4\chi(1,3) + 16\big(\chi(1,2)+\chi(2,1)\big) + 24\chi(1)$$

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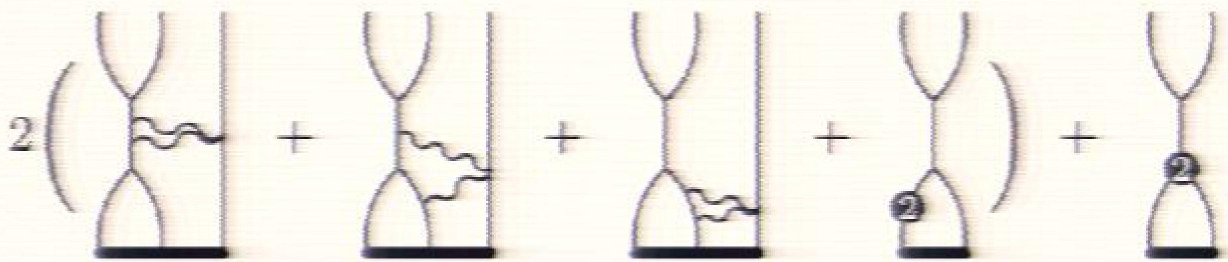
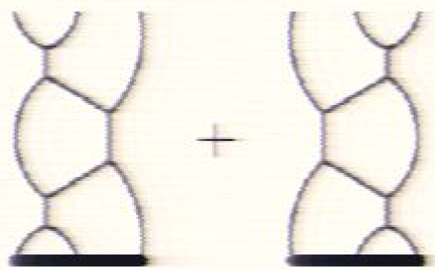
Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

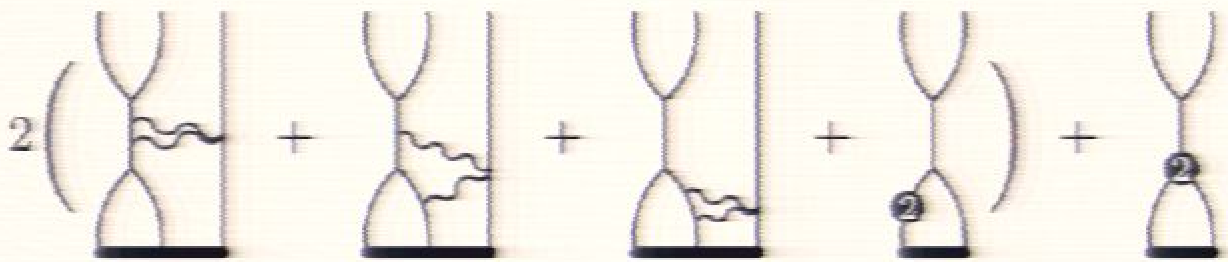
Three loops (SU(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

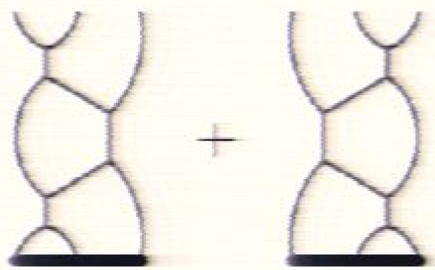
$$\mathcal{D}_3 \;=\; 4\left[\chi(1,2,3)+\chi(3,2,1)\right] - 4\chi(1,3) + 16\left(\chi(1,2)+\chi(2,1)\right) + 24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1) = \chi(2,1,2) = \chi(1)$.

Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 \;=\; 4\big[\chi(1,2,3)+\chi(3,2,1)\big] - 4\chi(1,3) + 16\big(\chi(1,2)+\chi(2,1)\big) + 24\chi(1)$$

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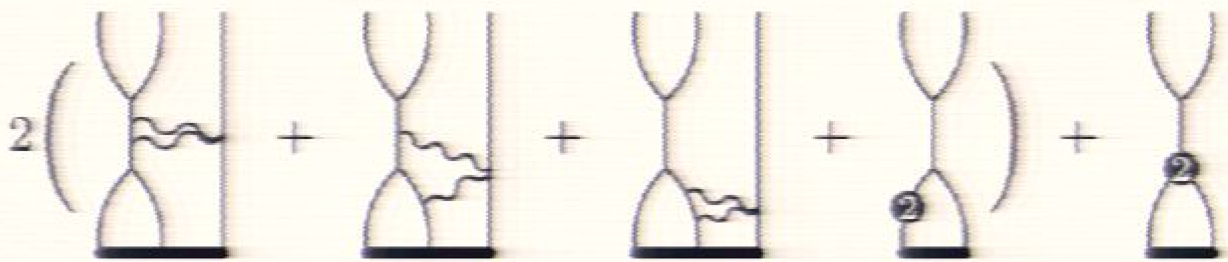
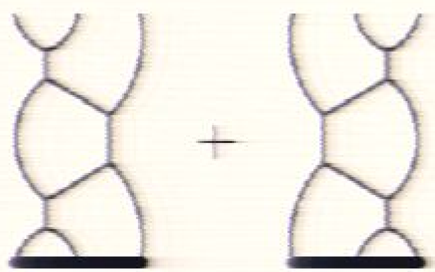
Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1) + 4\chi(1,2) + 4\chi(2,1) + \chi(1,2,3) + \chi(3,2,1) + \chi(1,2,1) + \chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 \;=\; 4\big[\chi(1,2,3)+\chi(3,2,1)\big] - 4\chi(1,3) + 16\big(\chi(1,2)+\chi(2,1)\big) + 24\chi(1)$$

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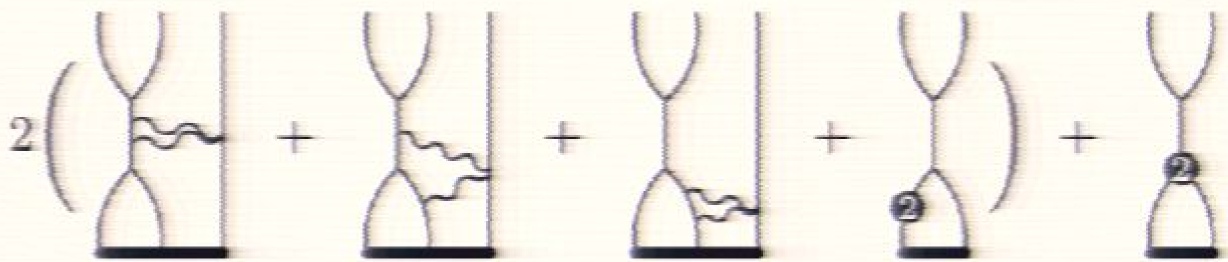
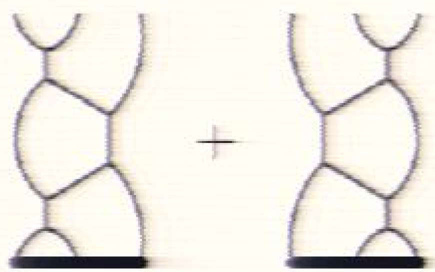


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1) + 4\chi(1,2) + 4\chi(2,1) + \chi(1,2,3) + \chi(3,2,1) + \chi(1,2,1) + \chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops ($SU(2)$ sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 \;=\; 4\left[\chi(1,2,3)+\chi(3,2,1)\right] - 4\chi(1,3) + 16\left(\chi(1,2)+\chi(2,1)\right) + 24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1) = \chi(2,1,2) = \chi(1)$.

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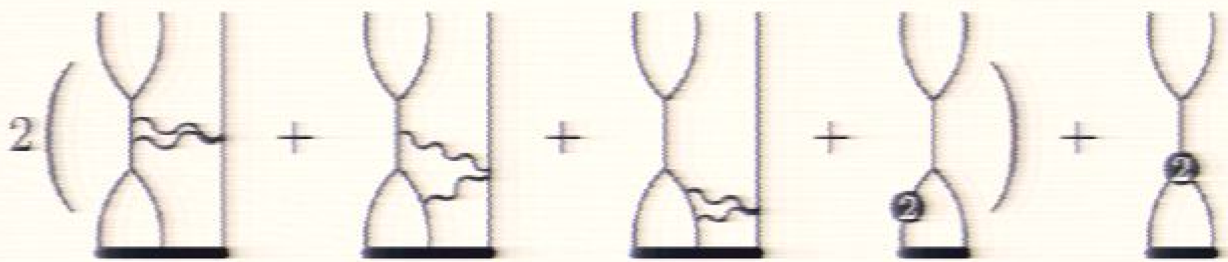

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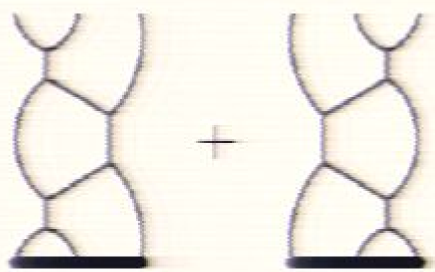


$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

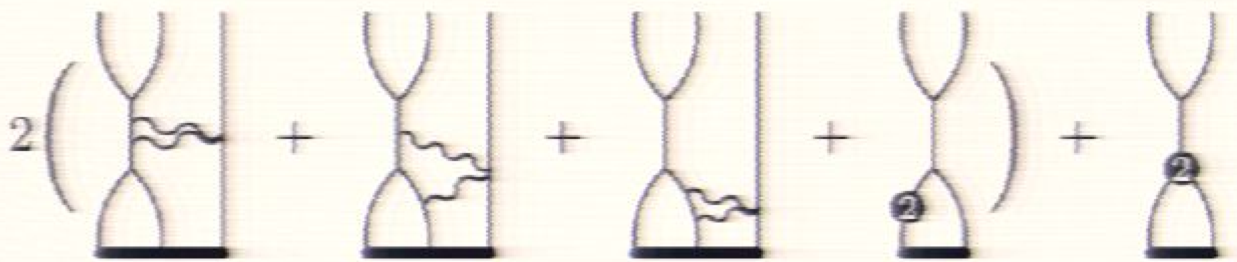
Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

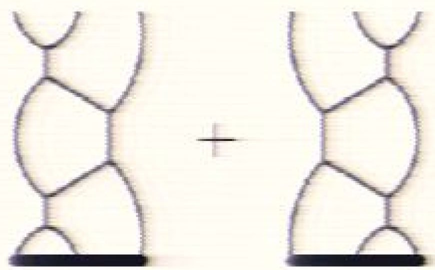
$$\mathcal{D}_3 \;=\; 4\left[\chi(1,2,3)+\chi(3,2,1)\right]-4\chi(1,3)+16\left(\chi(1,2)+\chi(2,1)\right)+24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1)=\chi(2,1,2)=\chi(1)$.

Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)}=16\chi(1)$$



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$$[\chi(1)^3]_c=4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops ($SU(2)$ sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 = 4\left[\chi(1,2,3)+\chi(3,2,1)\right] - 4\chi(1,3) + 16\left(\chi(1,2)+\chi(2,1)\right) + 24\chi(1)$$

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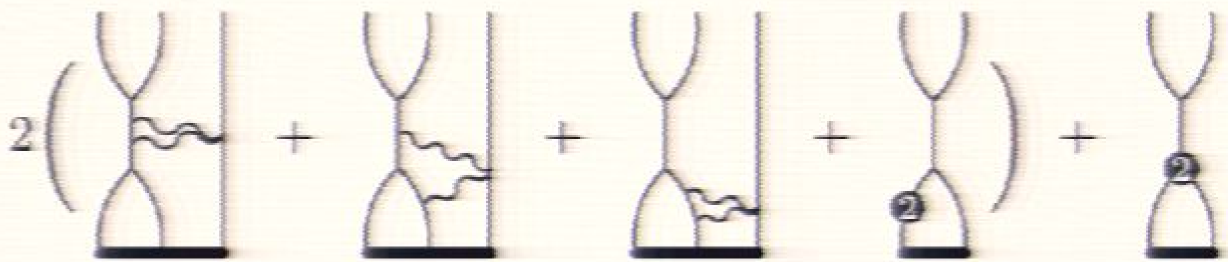
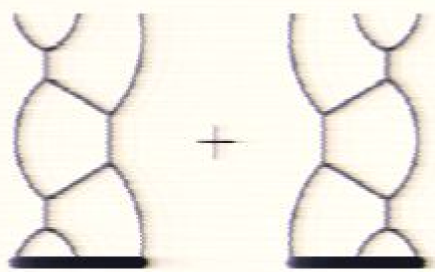


$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



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Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 \;=\; 4\big[\chi(1,2,3)+\chi(3,2,1)\big] - 4\chi(1,3) + 16\big(\chi(1,2)+\chi(2,1)\big) + 24\chi(1)$$

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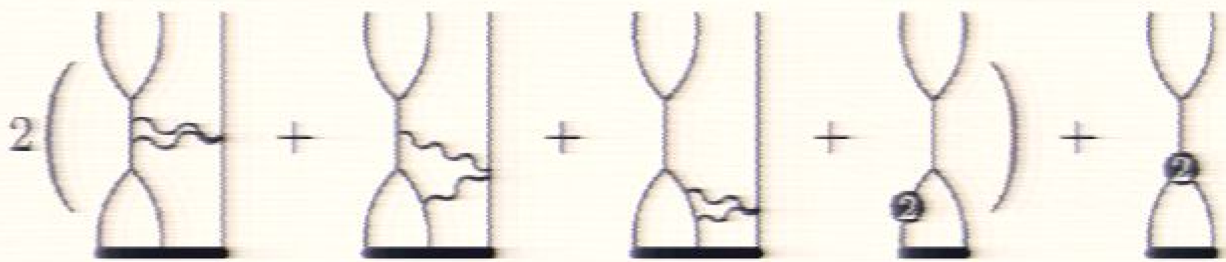
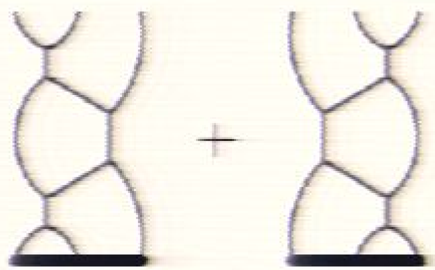


$\mathcal{D}_3^{(1)} = 16\chi(1)$



$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$

$$[\chi(1)^3]_c = 4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops (*SU*(2) sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

$$\mathcal{D}_3 = 4[\chi(1,2,3)+\chi(3,2,1)] - 4\chi(1,3) + 16(\chi(1,2)+\chi(2,1)) + 24\chi(1)$$

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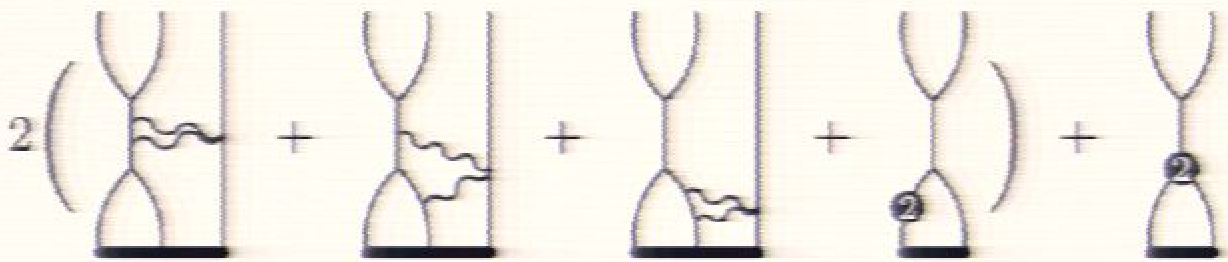

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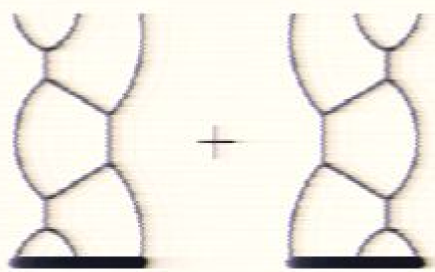


$$\mathcal{D}_3^{(1,2,1)} + \mathcal{D}_3^{(2,1,2)} = 4\chi(1,2,1) + 4\chi(2,1,2)$$

$$[\chi(1)^3]_c = 4\chi(1)+4\chi(1,2)+4\chi(2,1)+\chi(1,2,3)+\chi(3,2,1)+\chi(1,2,1)+\chi(2,1,2)$$

Supergraphs capture the $[\chi(1)^3]_c$ structure

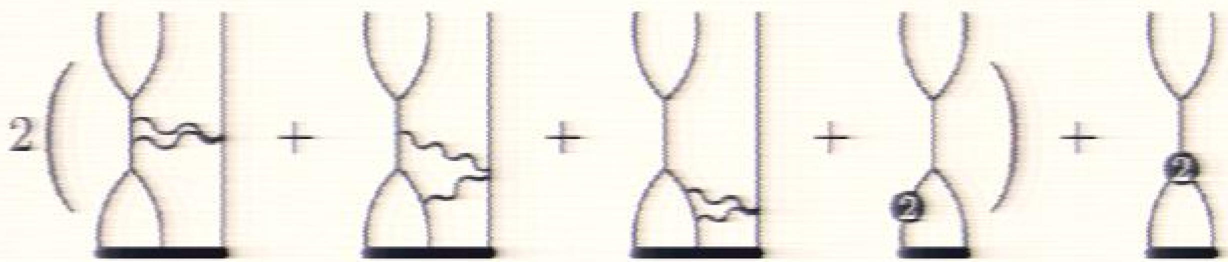
Three loops ($SU(2)$ sector)

Integrability: Beisert, Kristjansen, Staudacher (2003)

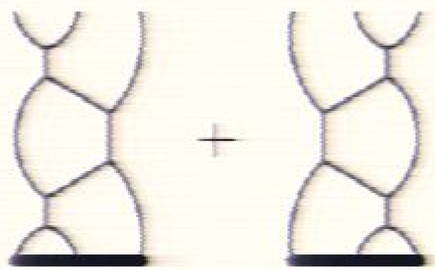
$$\mathcal{D}_3 \; = \; 4\left[\chi(1,2,3)+\chi(3,2,1)\right] - 4\chi(1,3) + 16\left(\chi(1,2)+\chi(2,1)\right) + 24\chi(1)$$

Consistent with $F_n(g^2)$ using $\chi(1,2,1) = \chi(2,1,2) = \chi(1)$.

Supergraphs: Sieg (2010)



$$\mathcal{D}_3^{(1)} = 16\chi(1)$$



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Supergraphs capture the $[\chi(1)^3]_c$ structure

Three loops (*SU*(2) sector)

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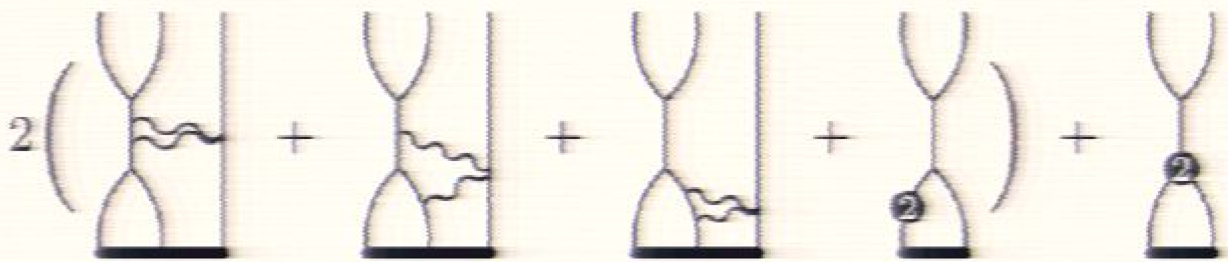
Consistent with $F_n(g^2)$ using $\chi(1,2,1) = \chi(2,1,2) = \chi(1)$.

Supergraphs: Sieg (2010)



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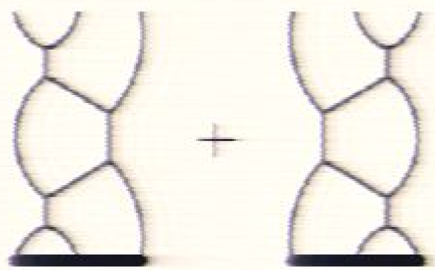

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Supergraphs capture the $[\chi(1)^3]_c$ structure

Conjecture

The all-loop sum of supergraphs with the connected chiral function $\chi(a_1, a_2 \dots a_j, \dots a_n)$ is given by

$$F_n(g^2)\chi(a_1, a_2 \dots a_j, \dots a_n)$$

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- This is a statement about supergraphs and can be applied outside the $SU(2)$ sector where

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Four loops ($SU(2)$ sector)

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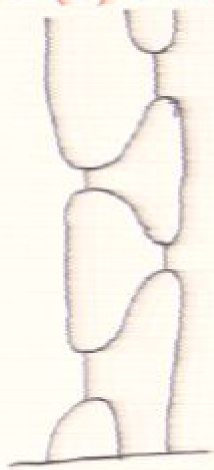
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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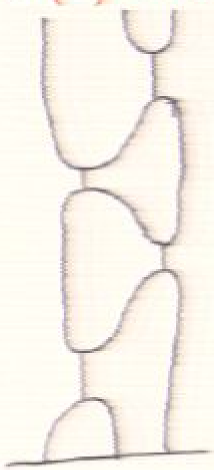

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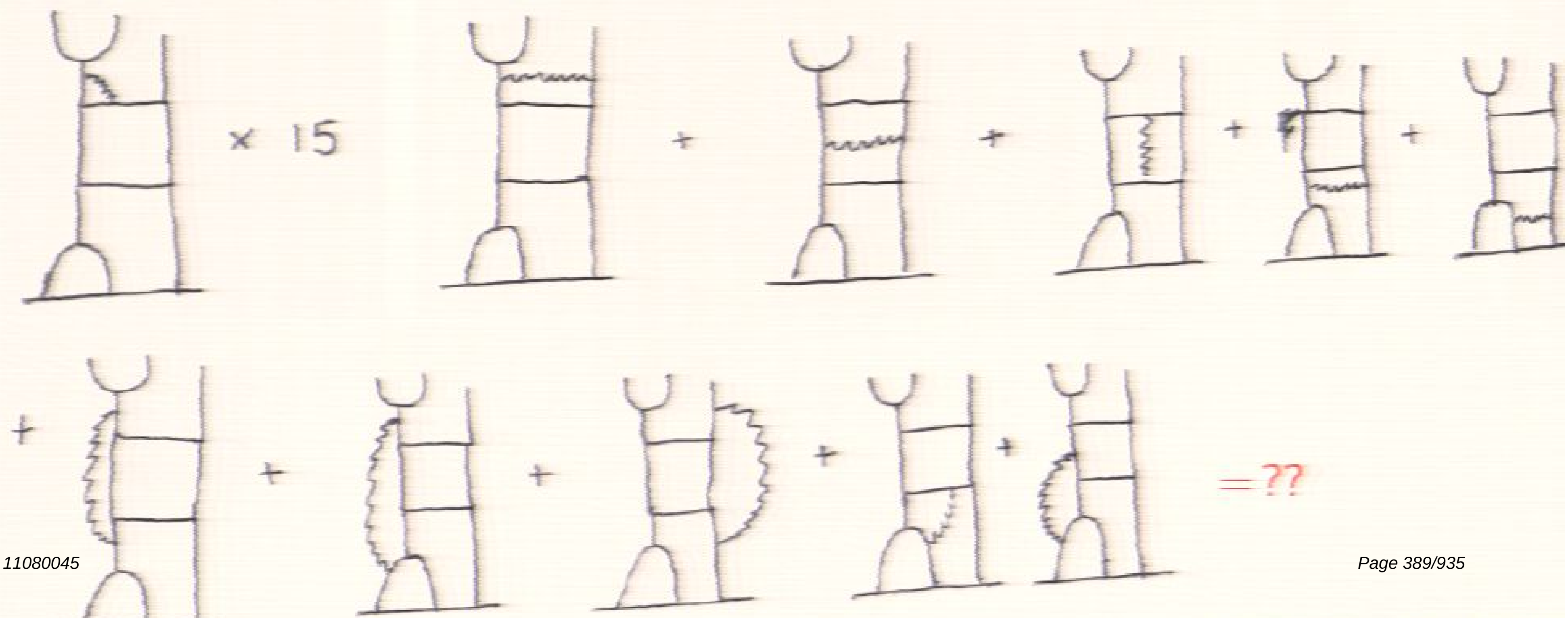

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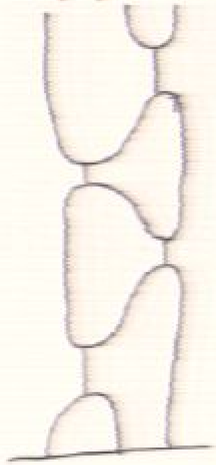
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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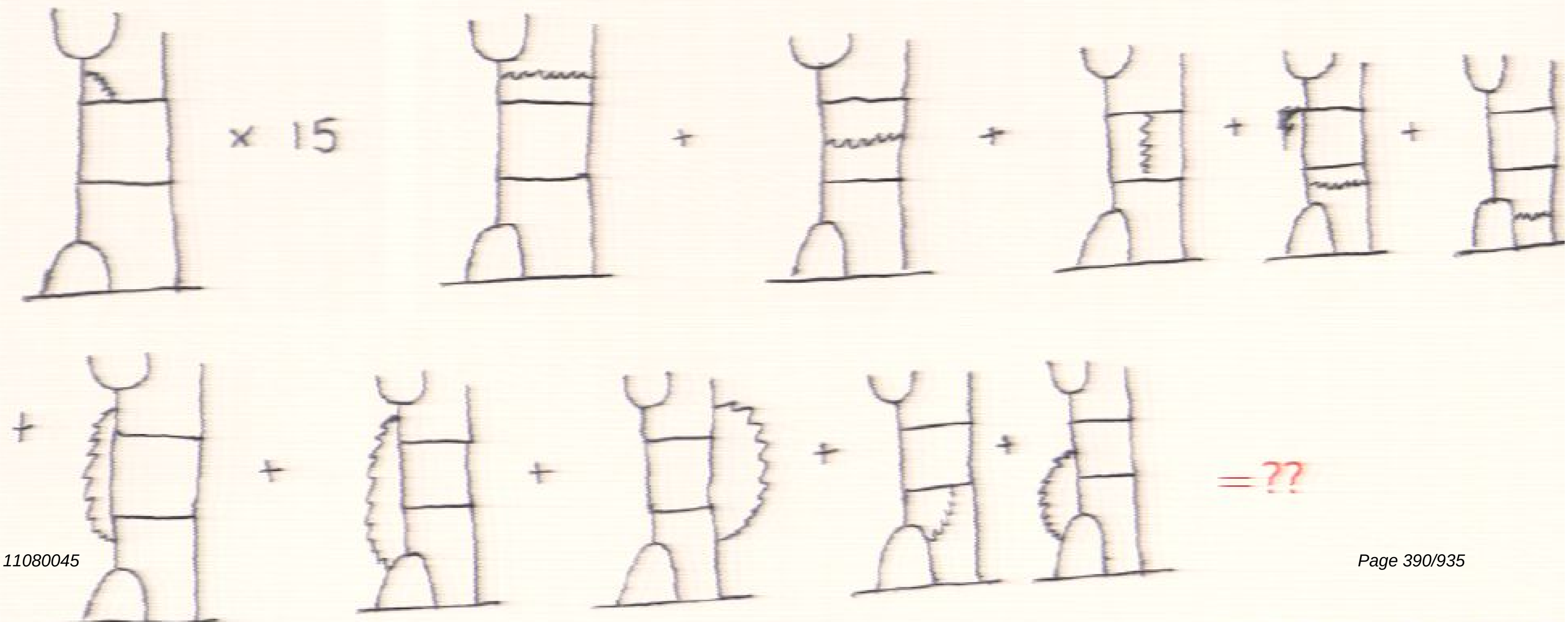

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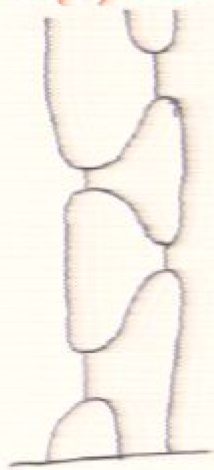

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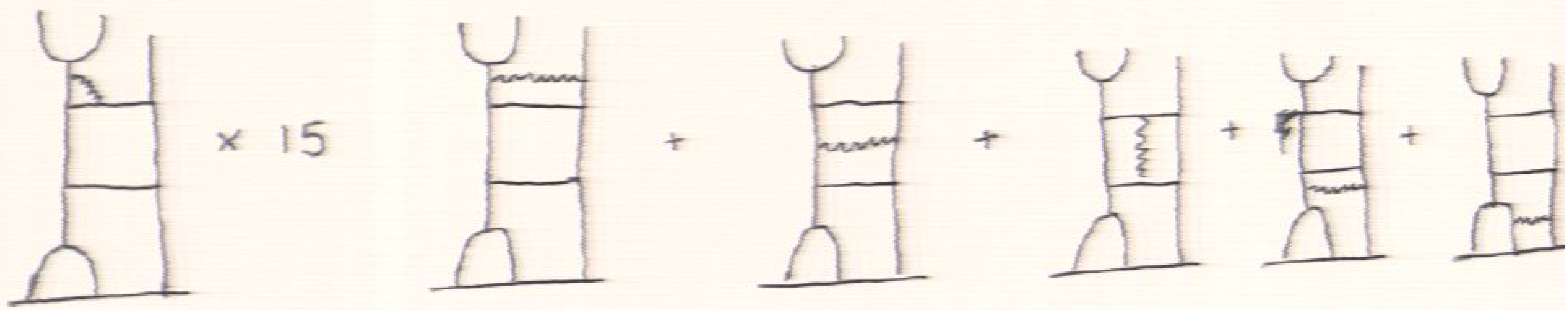

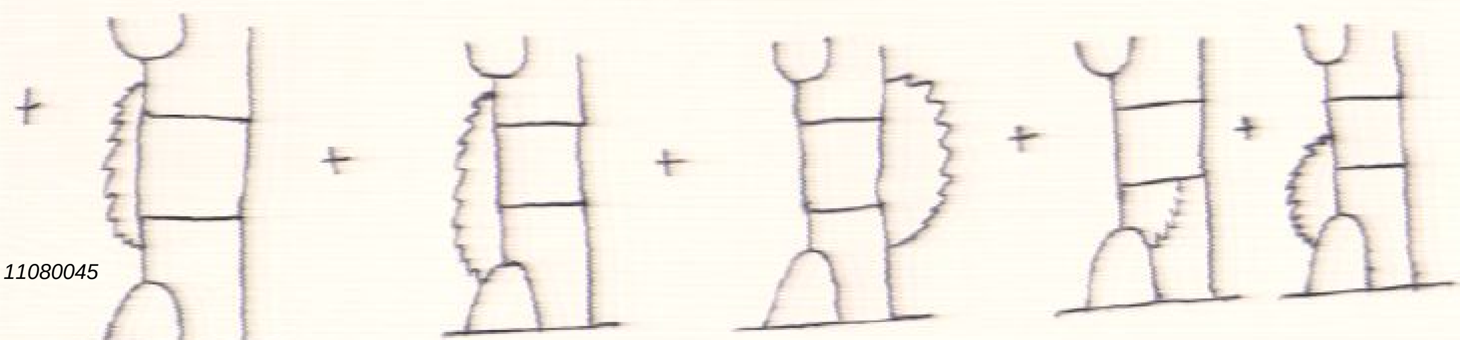

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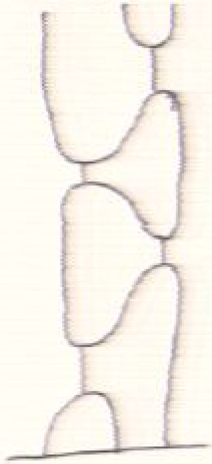
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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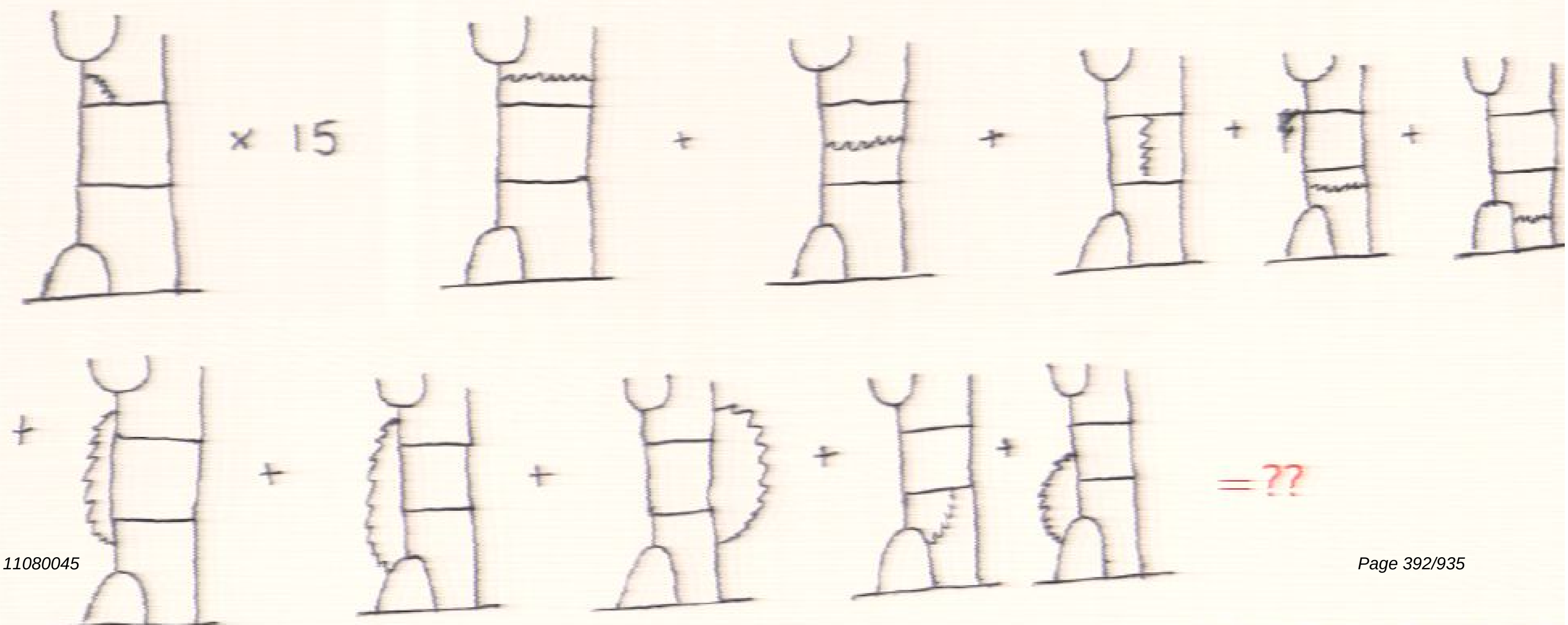

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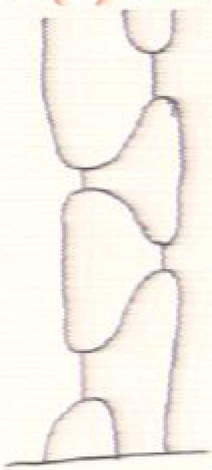
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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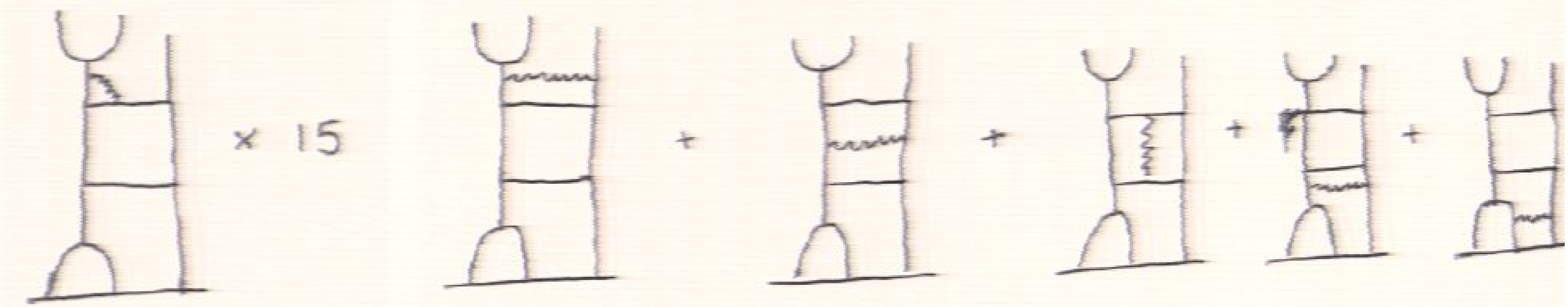

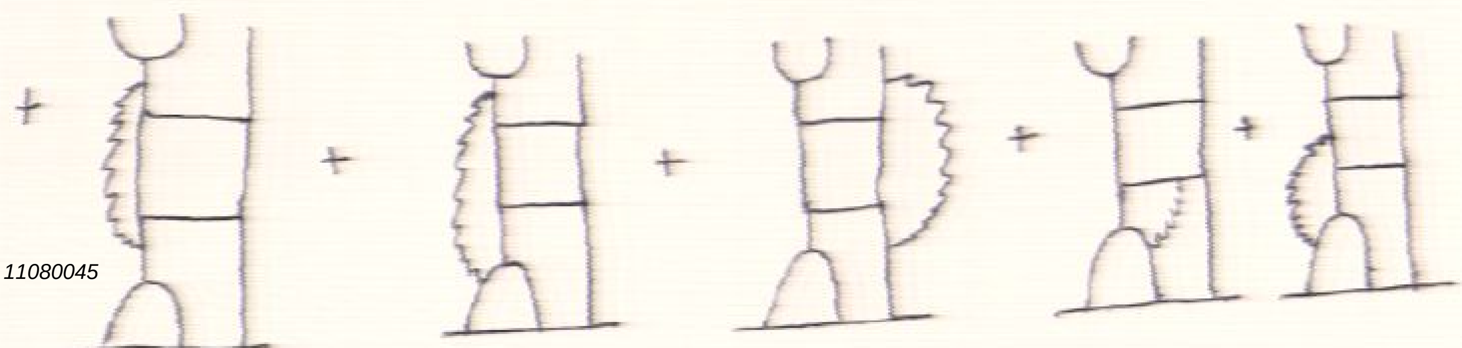

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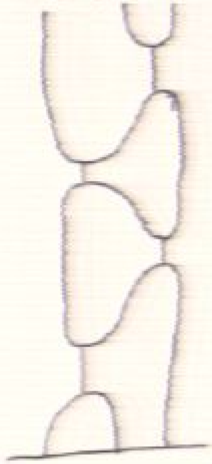
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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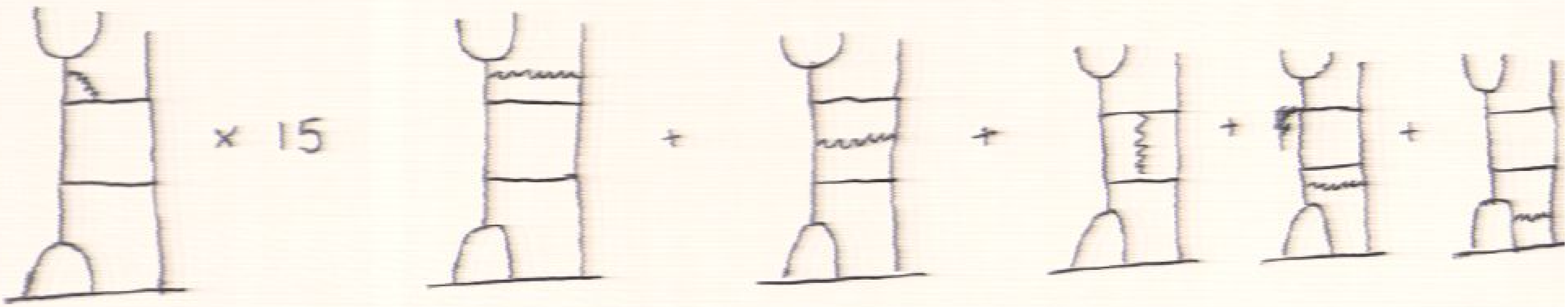

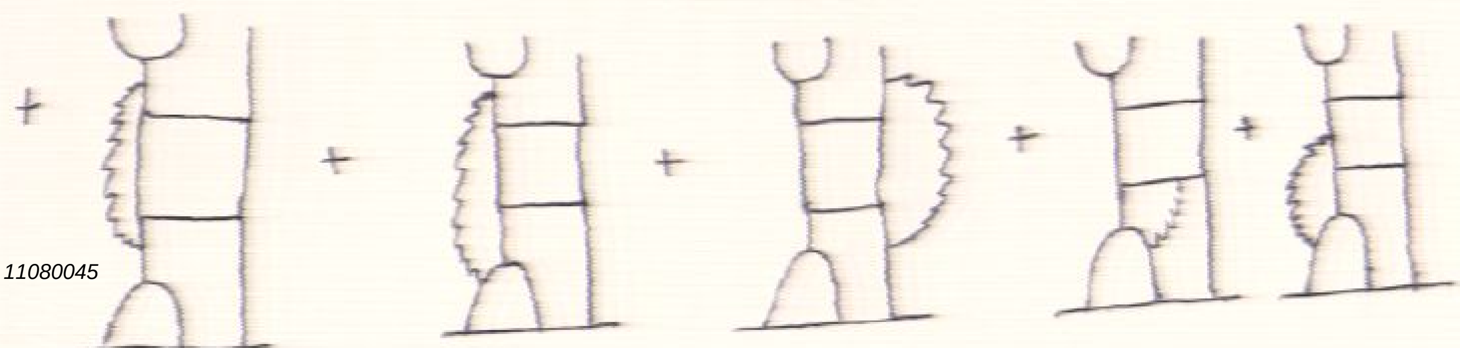

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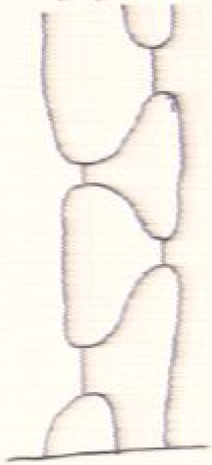

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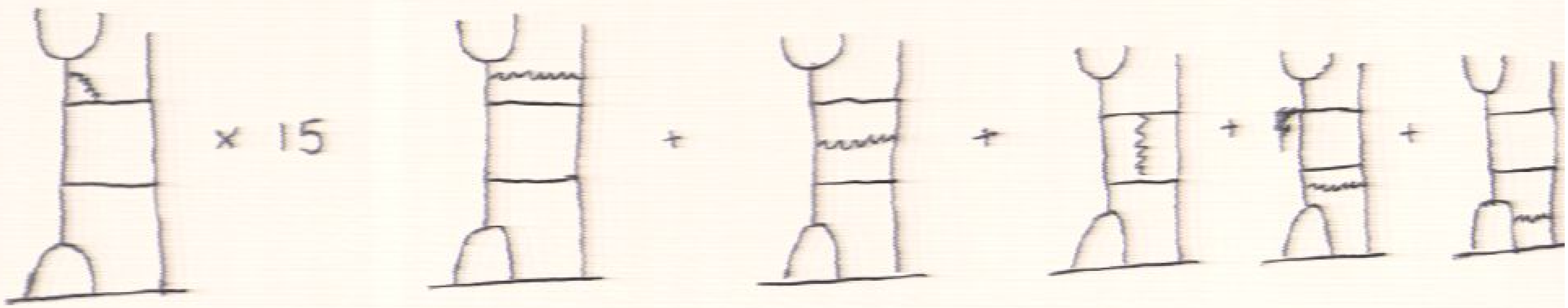

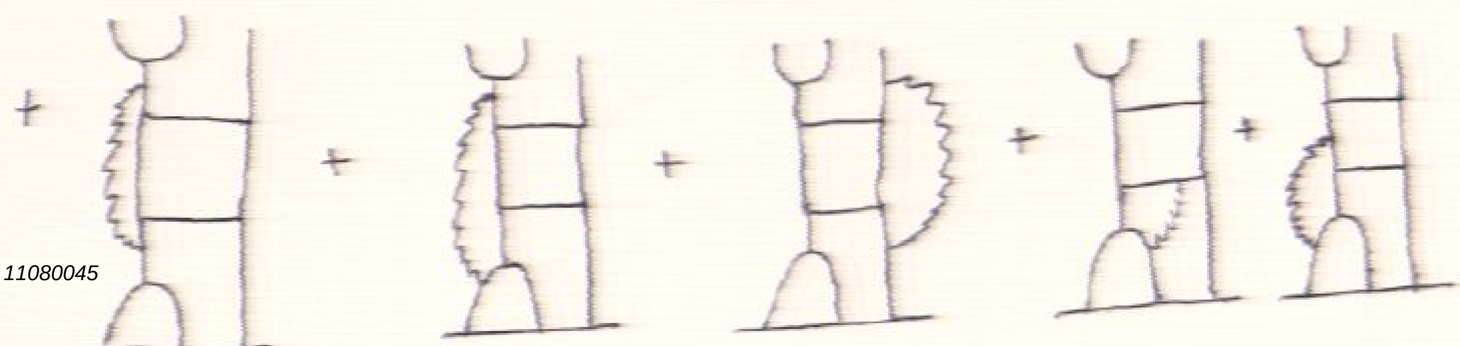

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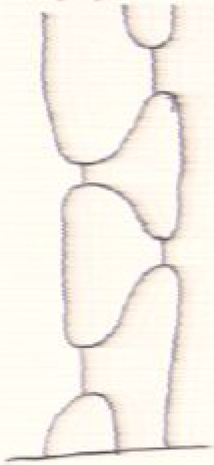

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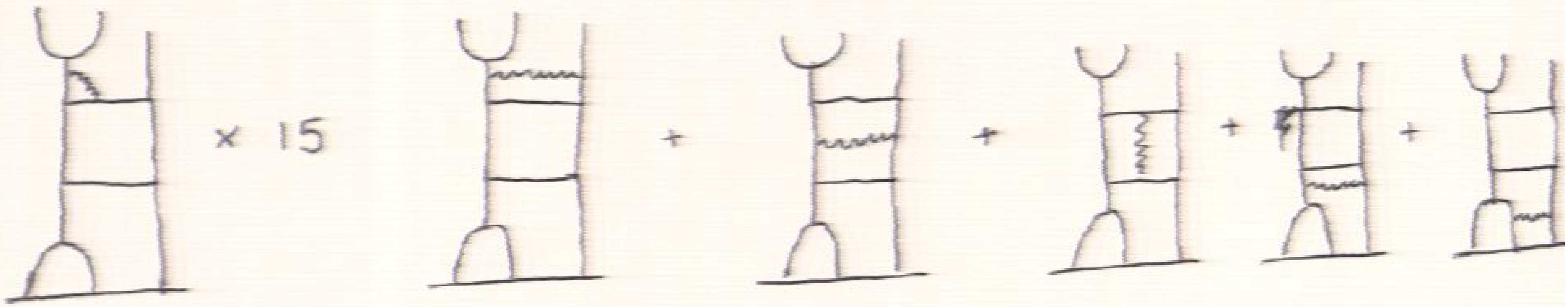

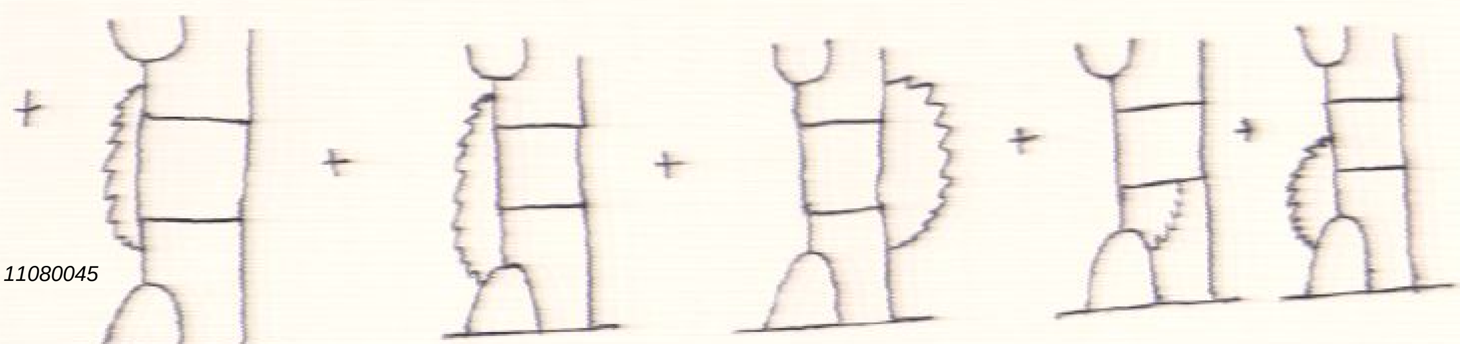

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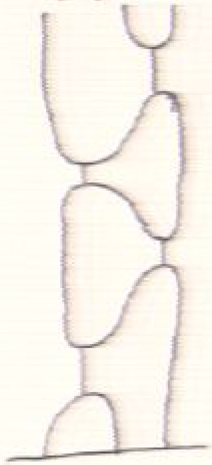

$\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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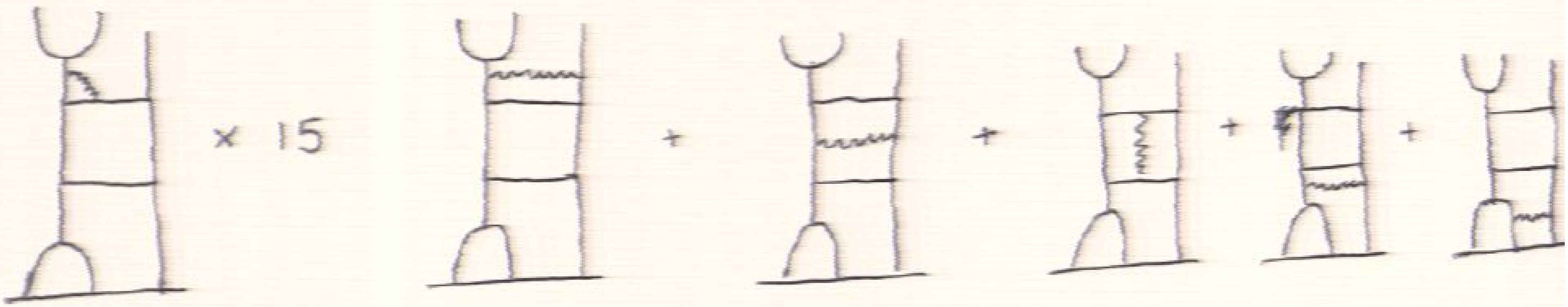

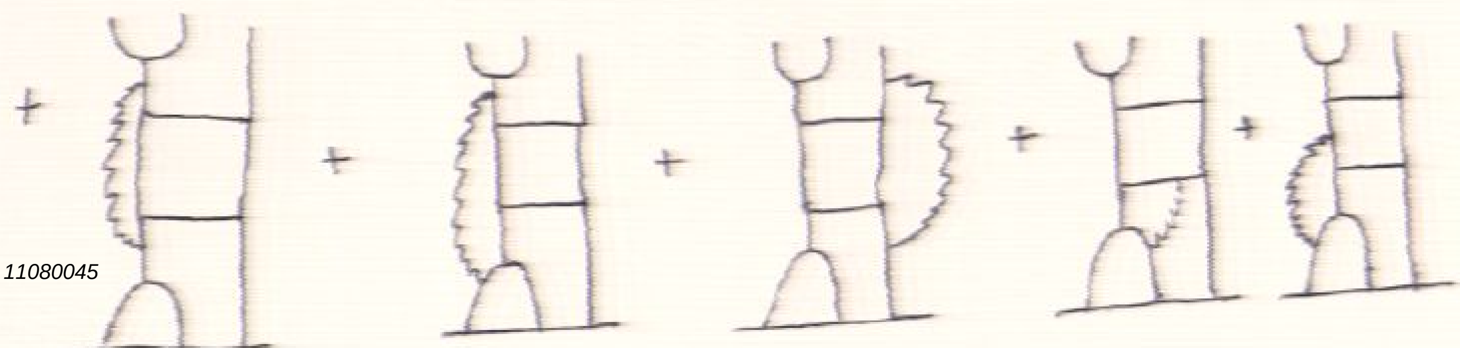

$= ??$

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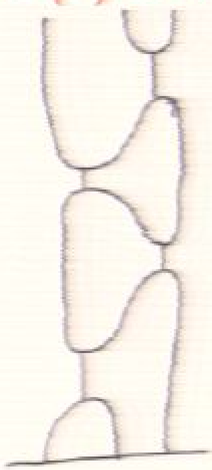

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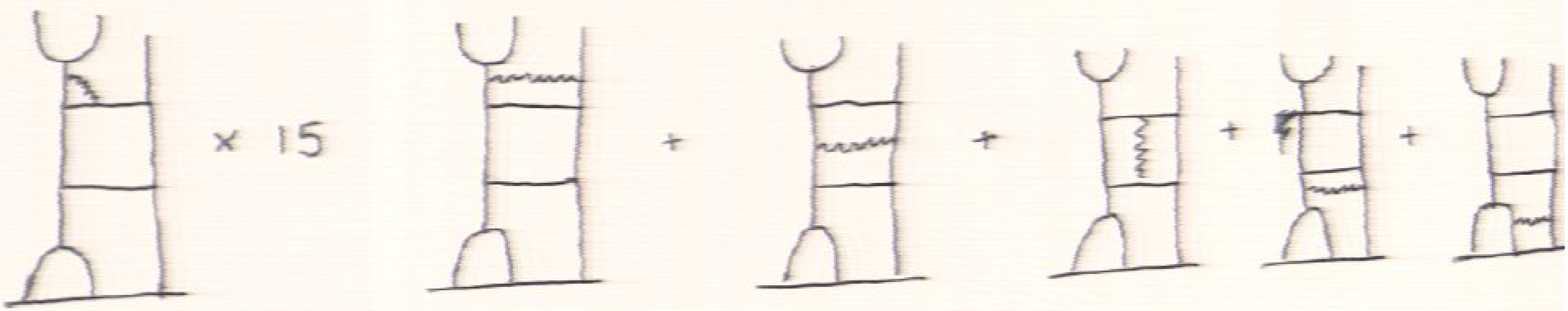

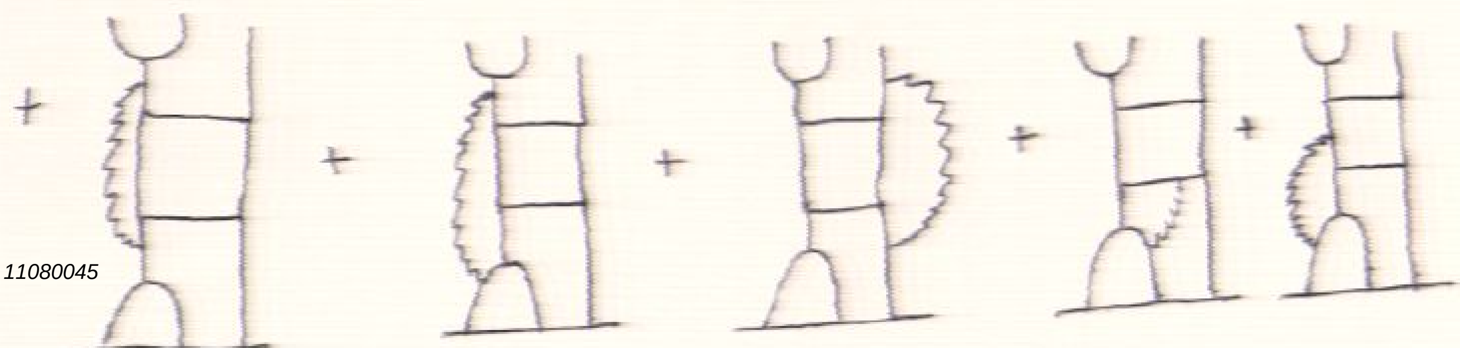

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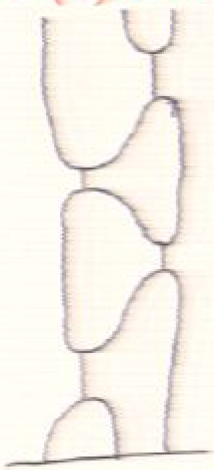
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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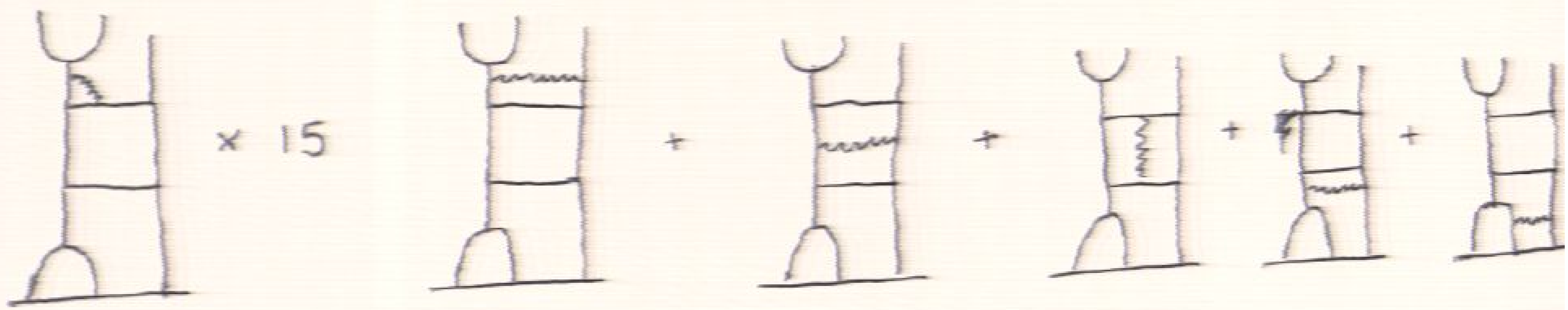
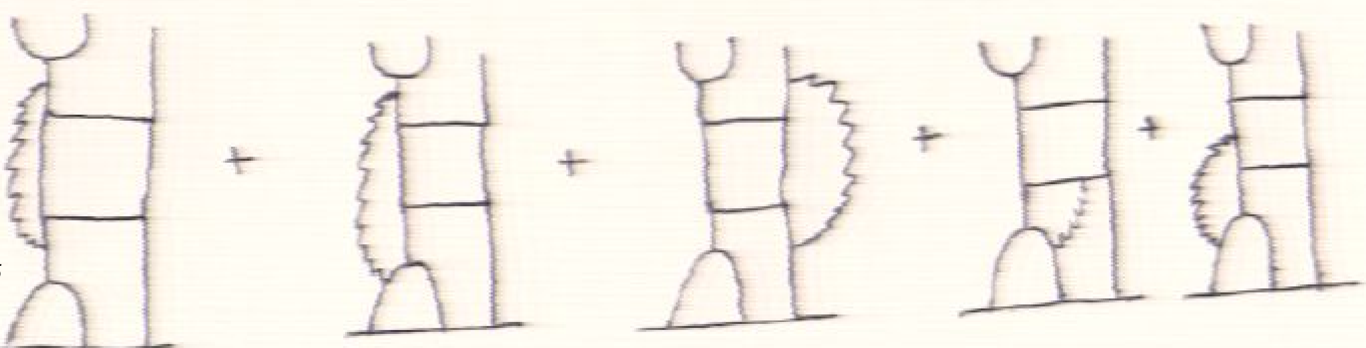


\+ 

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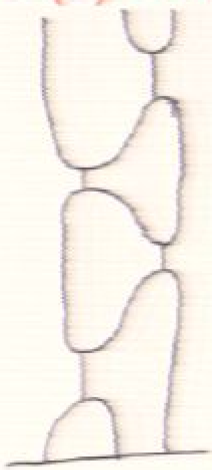

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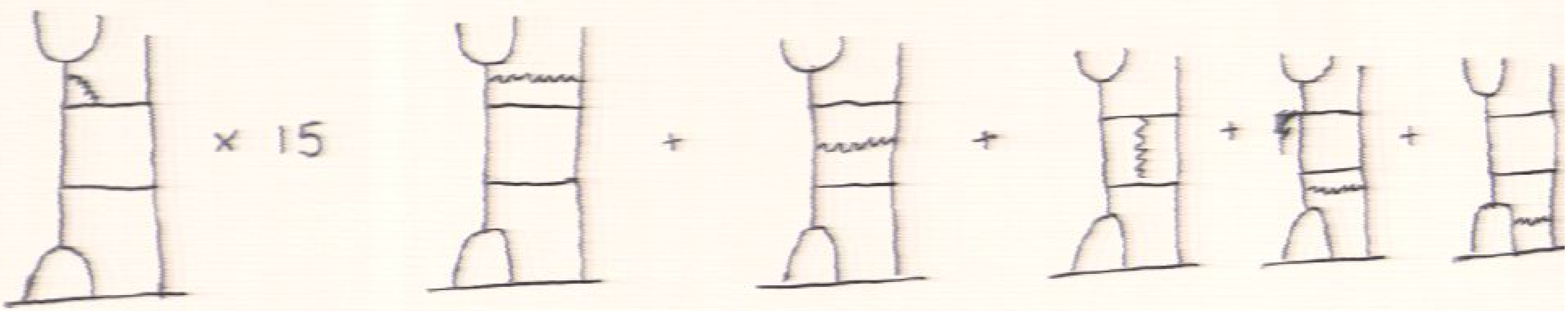

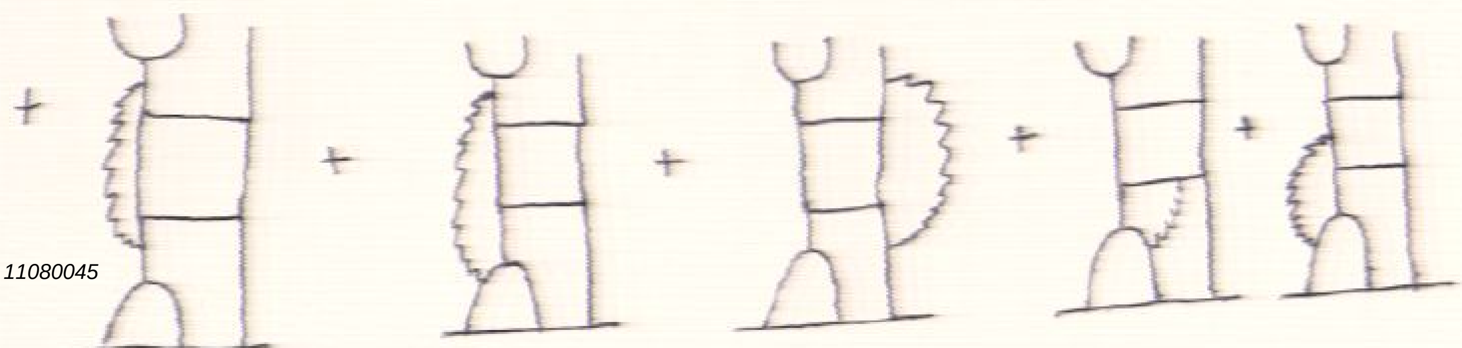

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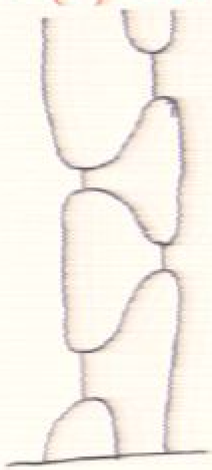

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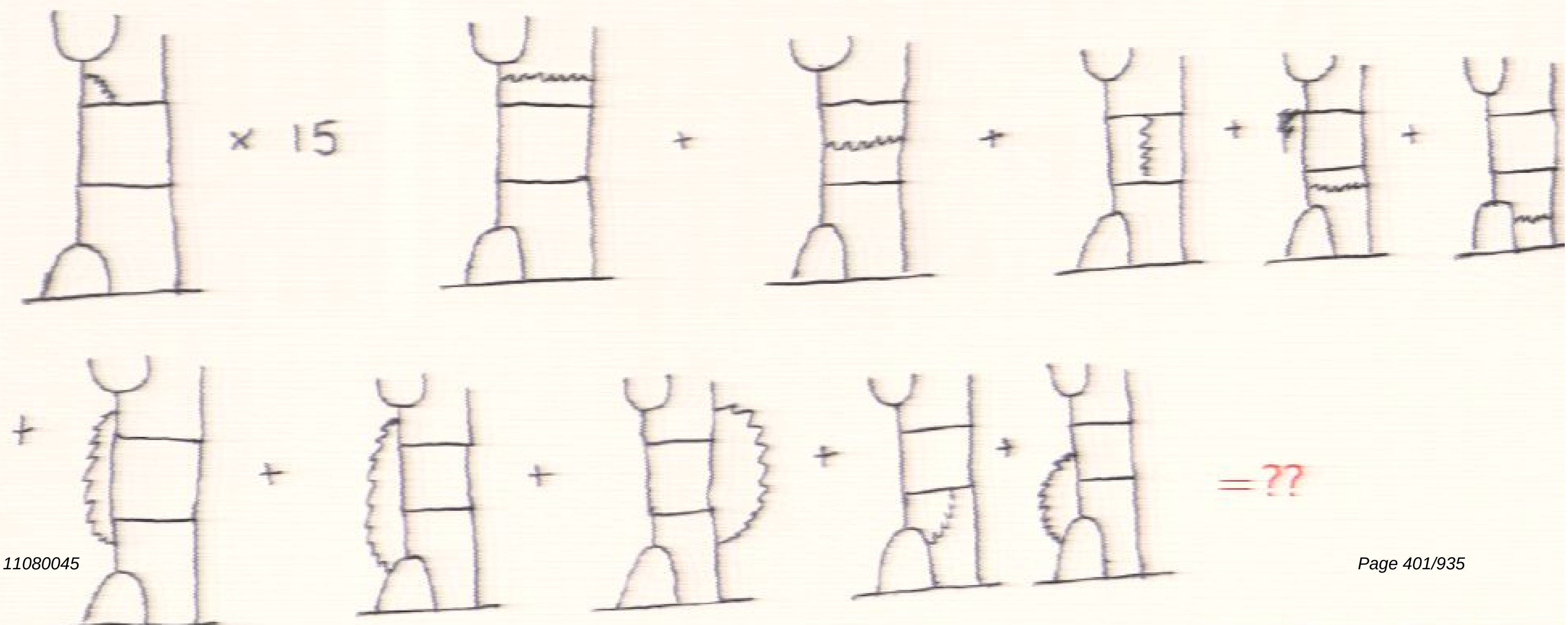

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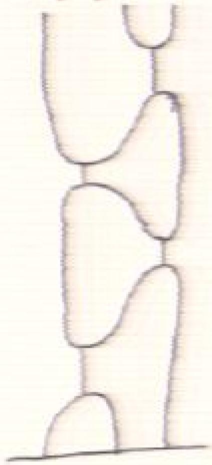

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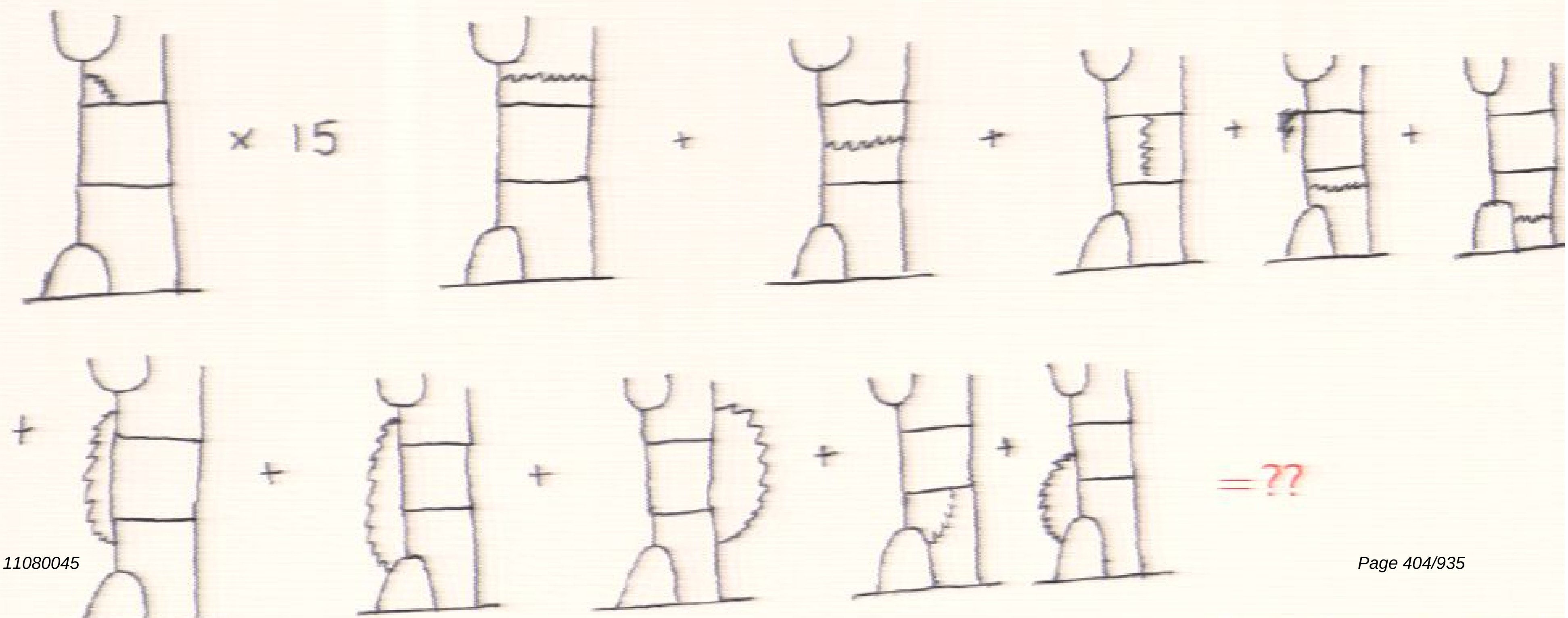

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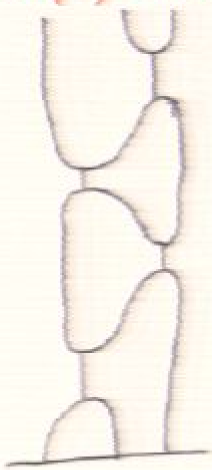

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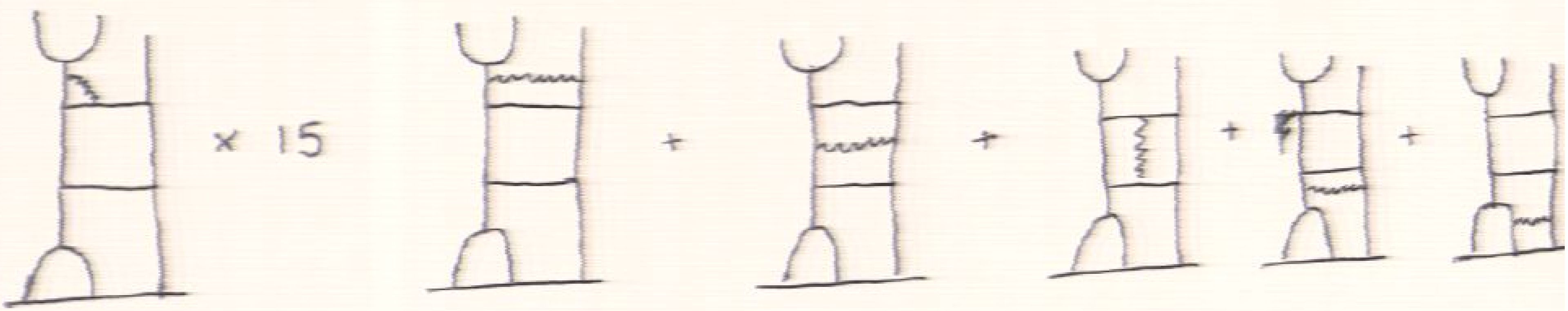

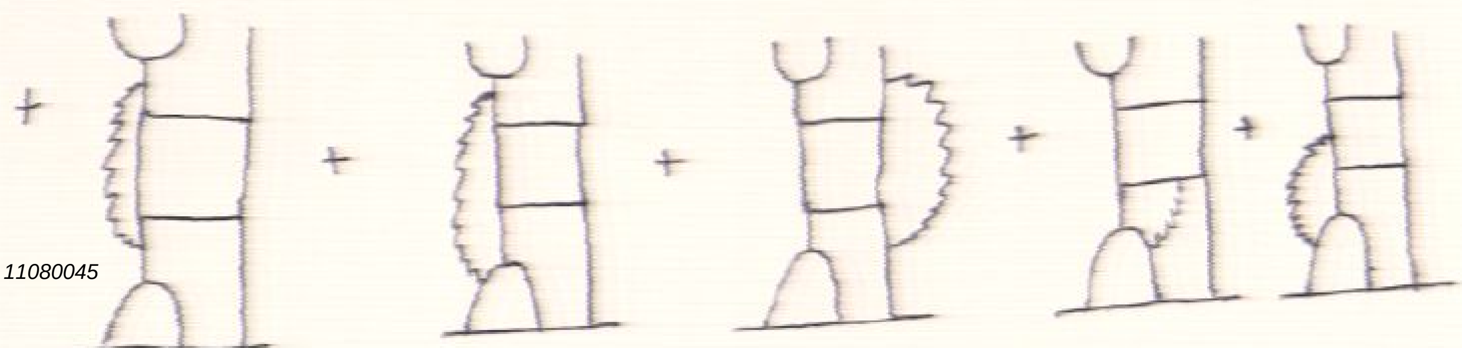

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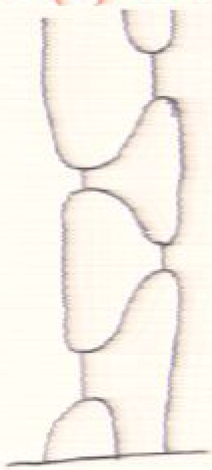

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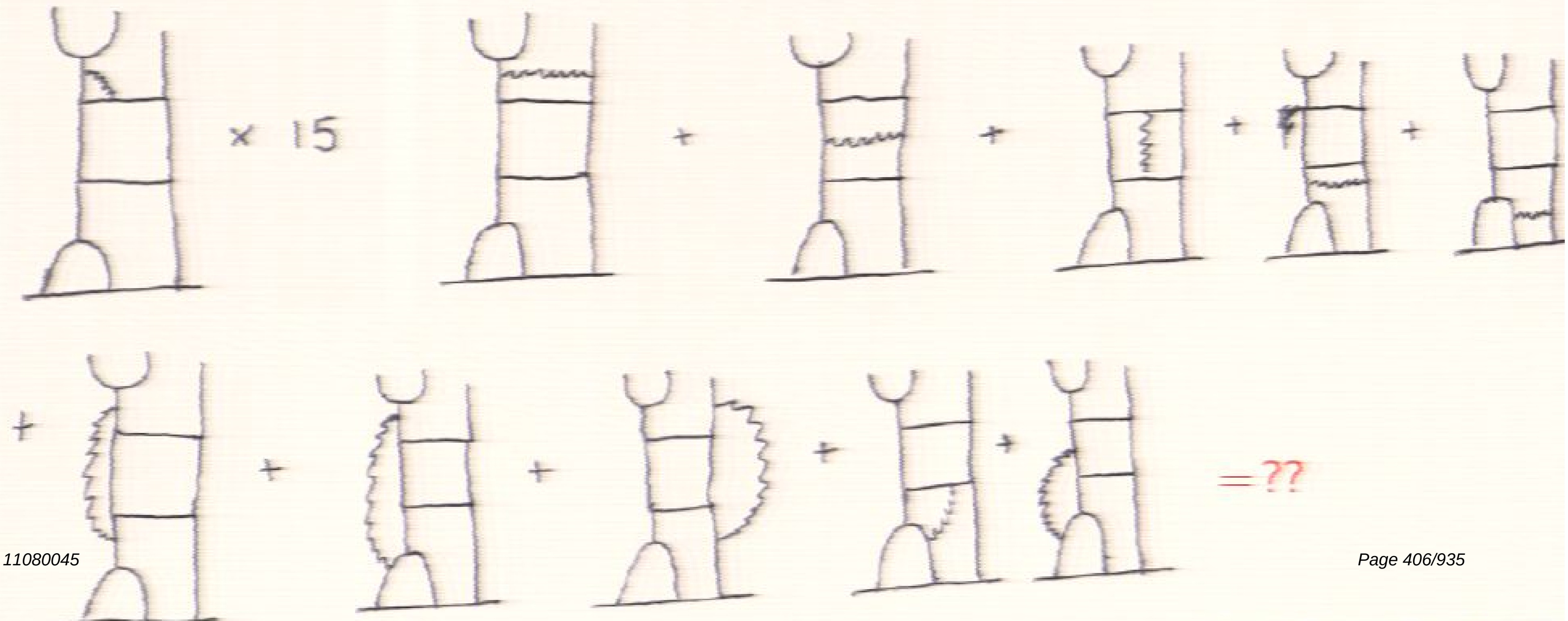

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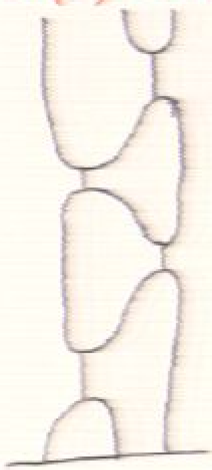
$\chi(1,2,1,2)$:  $\Delta^{(1,2,1,2)}\mathcal{D}_4 = -10\,\chi(1,2,1,2)$ Consistent with $F_4(g^2)$

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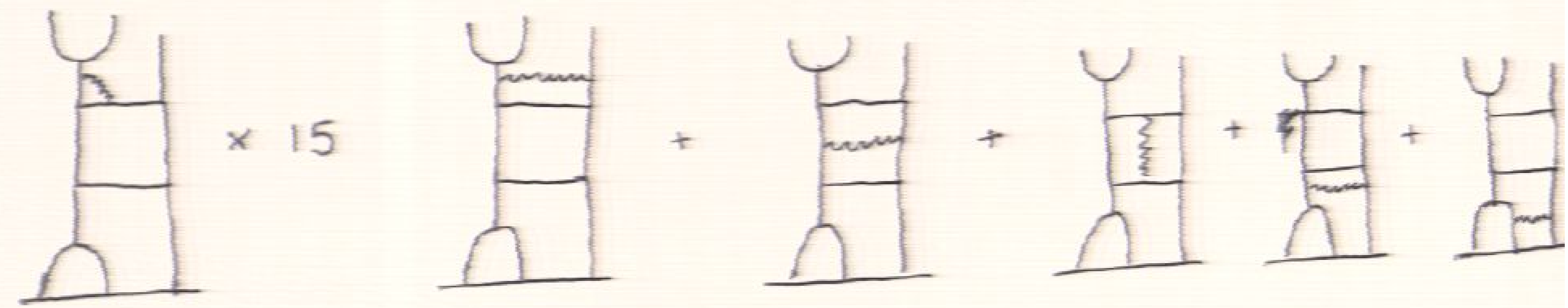

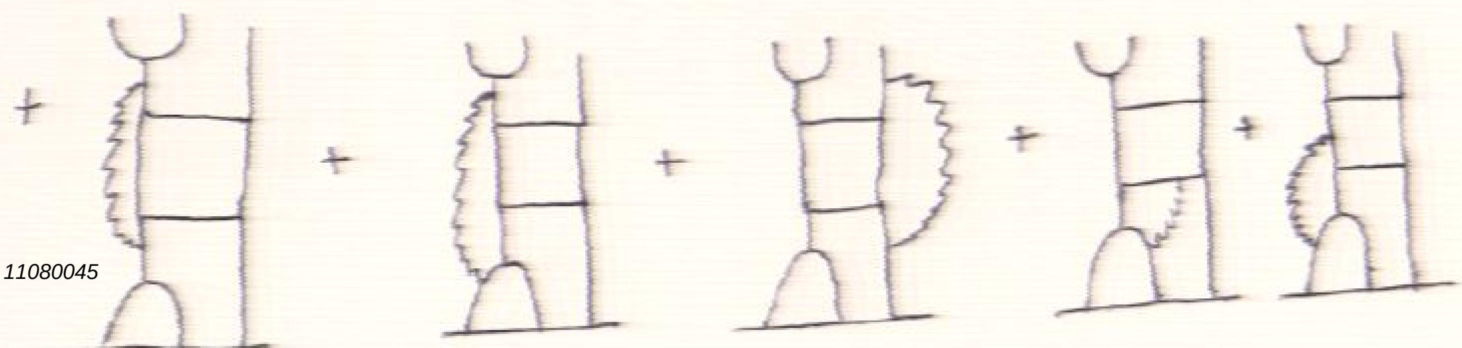

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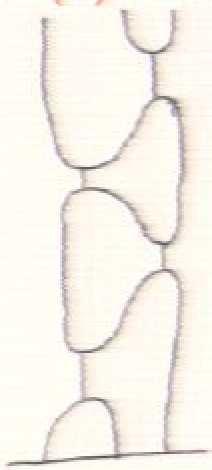

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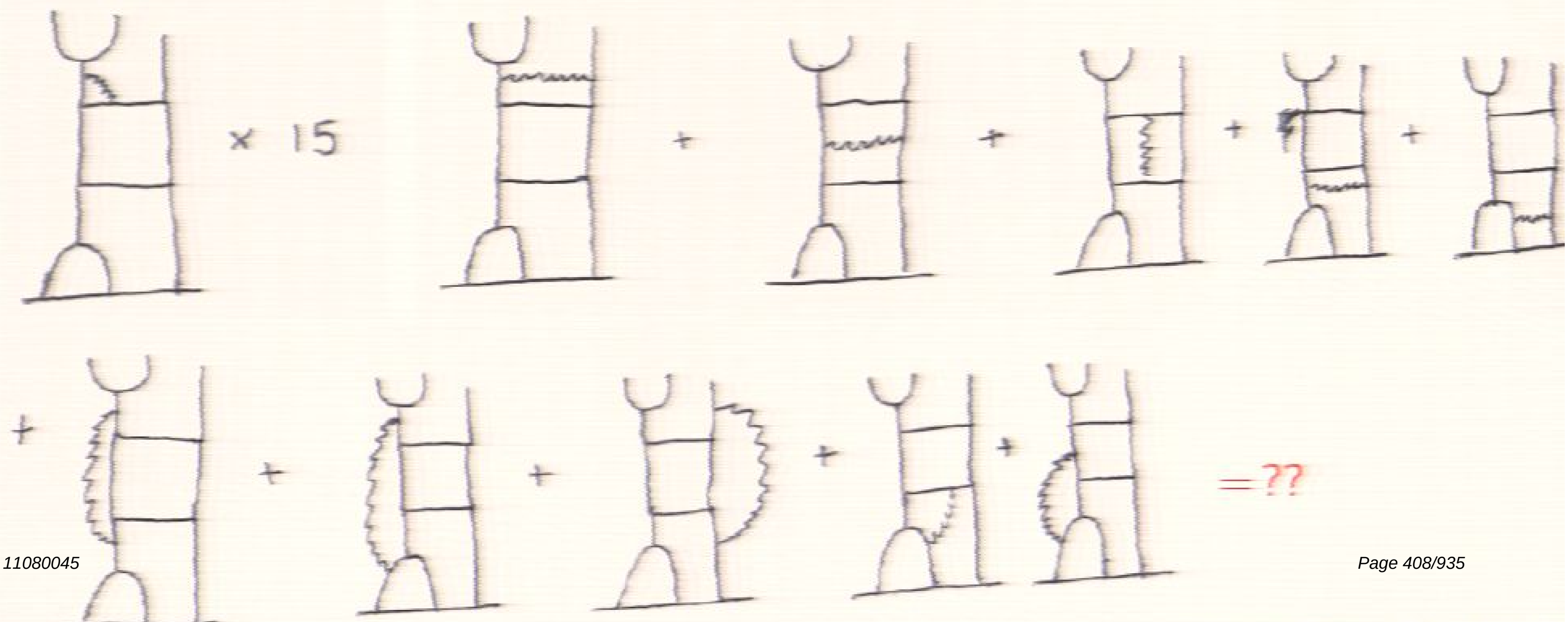

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$$W = \kappa\left(\mathrm{tr}(XYZ - q\,XZY) + \frac{h}{3}(X^3 + Y^3 + Z^3)\right) \qquad q \;\&\; h \text{ complex.}$$

Conformal condition : $\gamma_i = 0$

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Graphs where neighboring legs are only connected by vectors are finite (after removing subdivergences)

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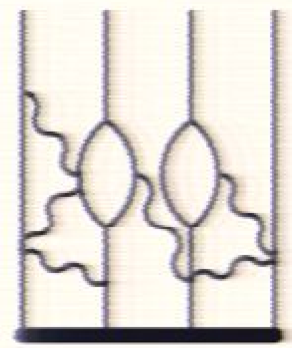

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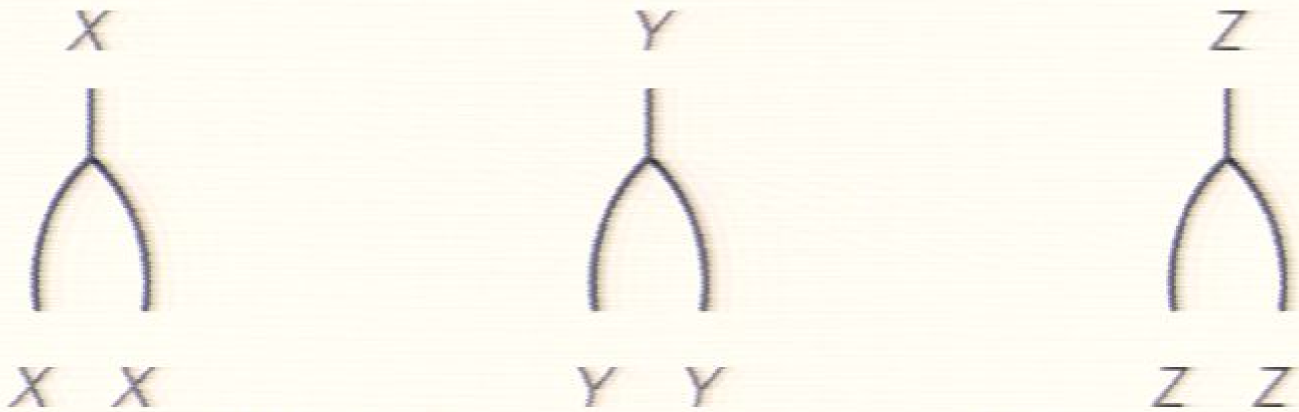

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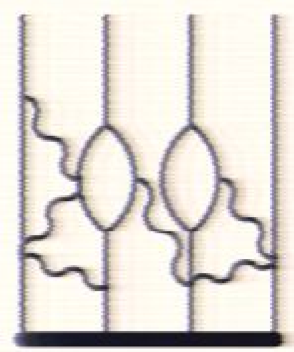

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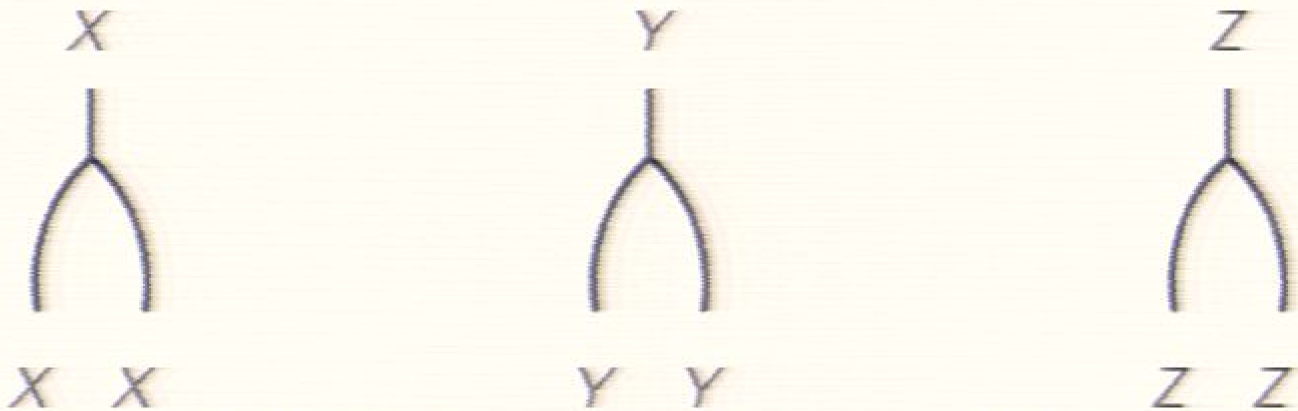

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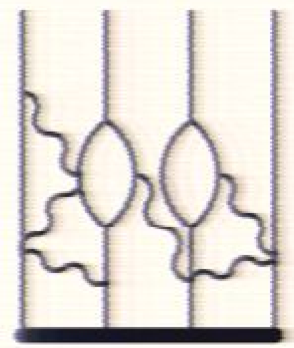

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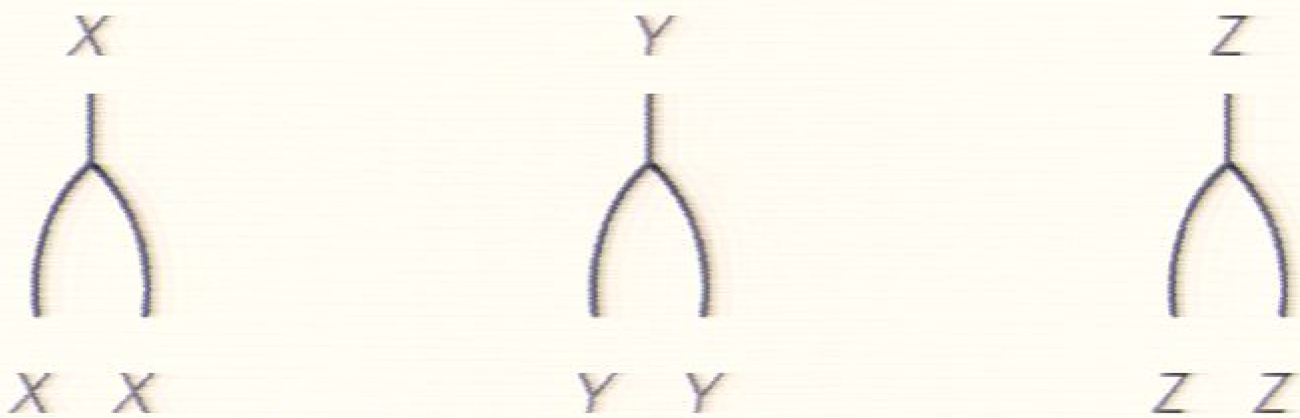

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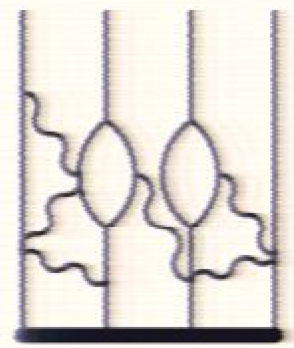

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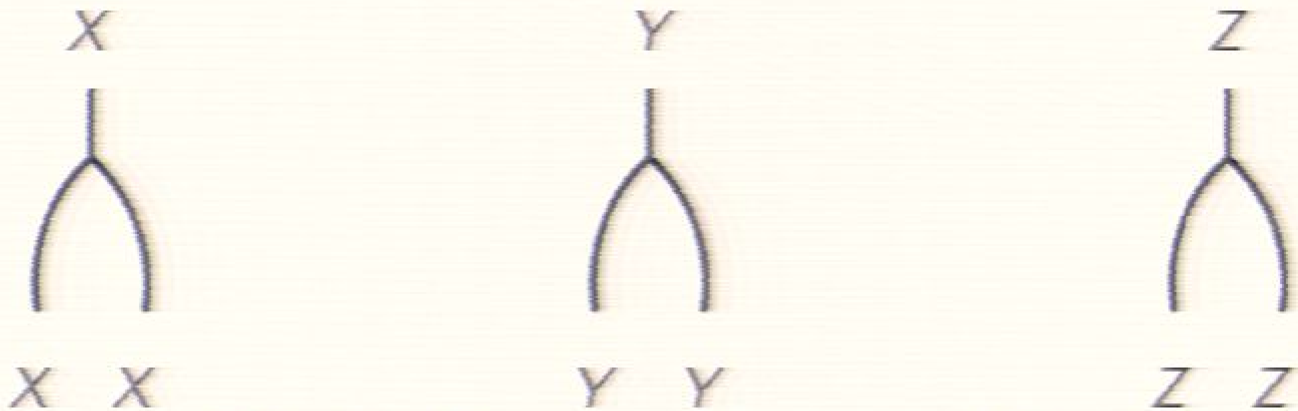

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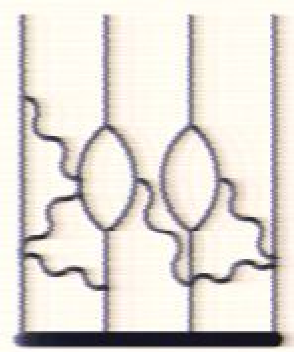

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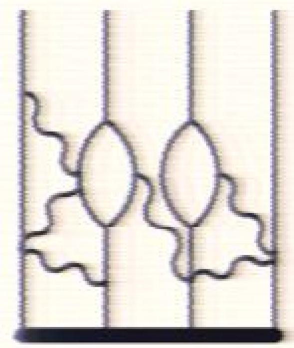

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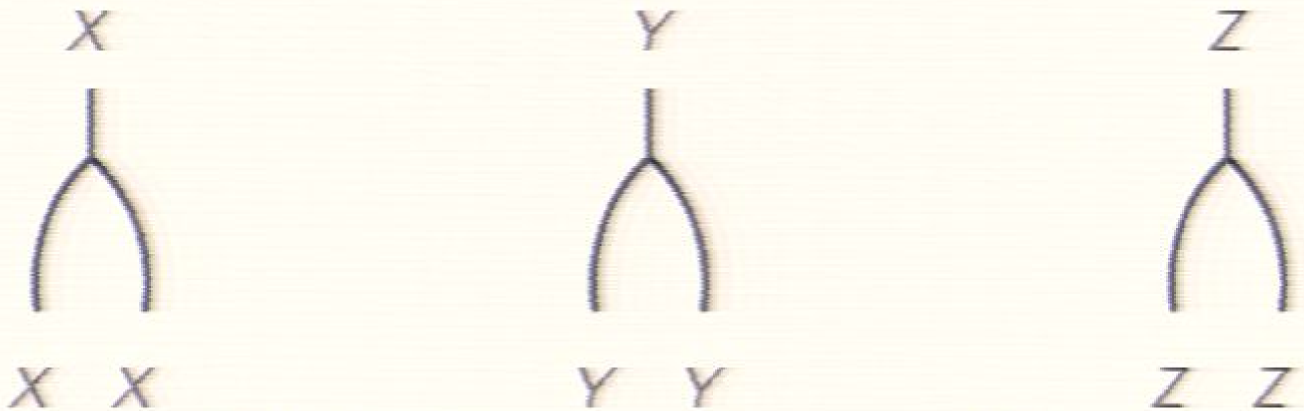

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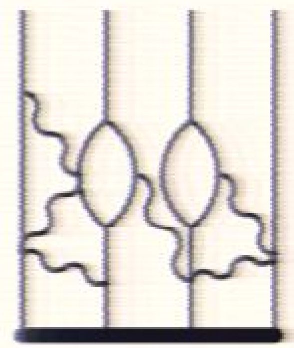

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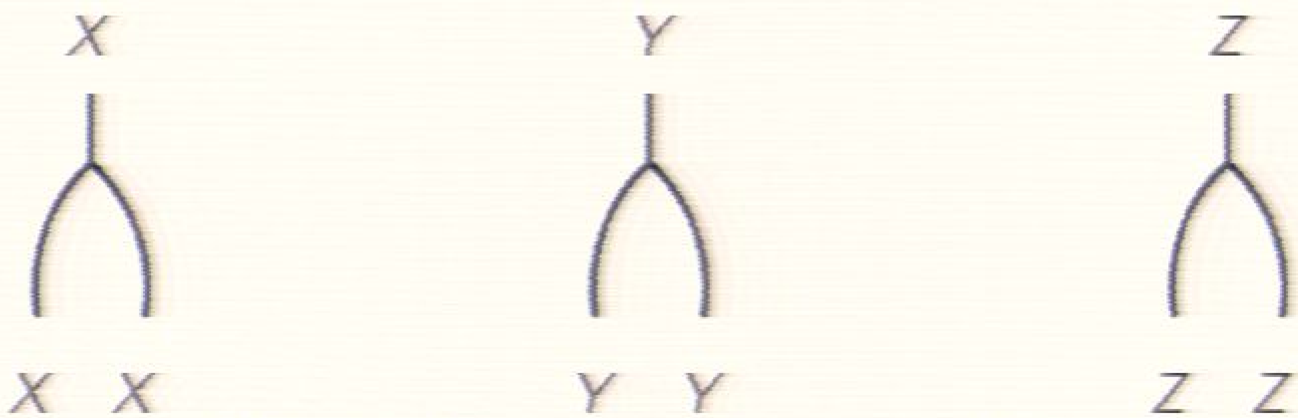

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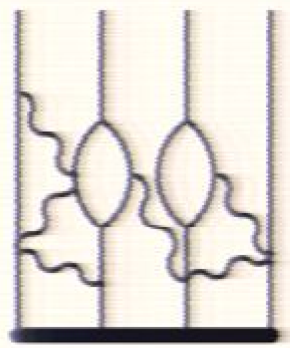

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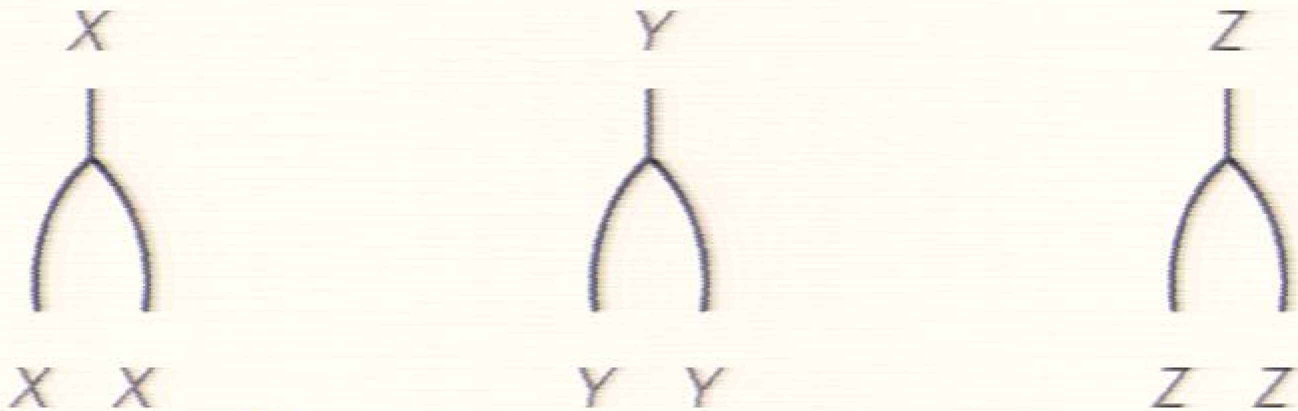

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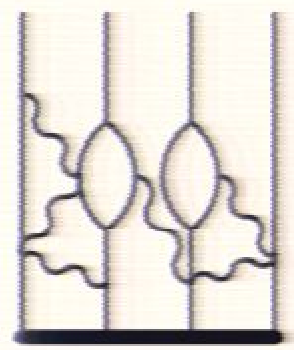

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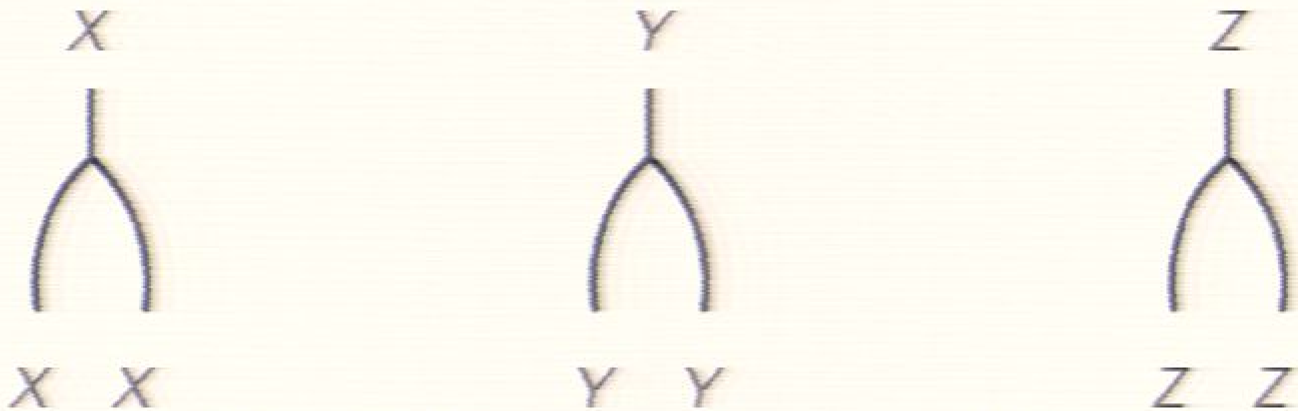

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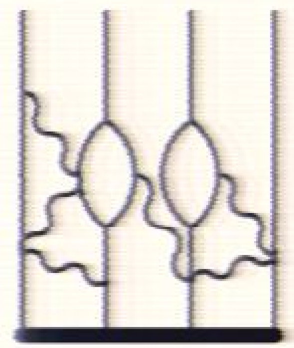
e.g. 

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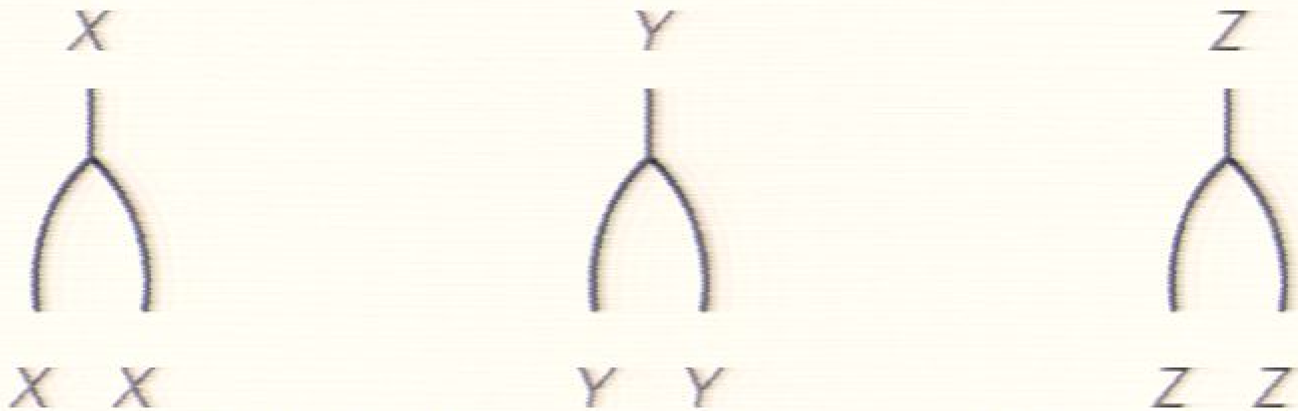

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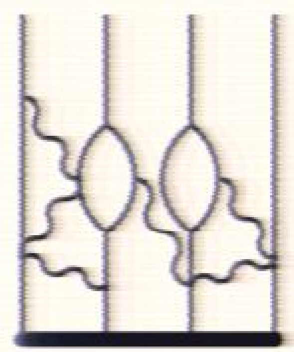

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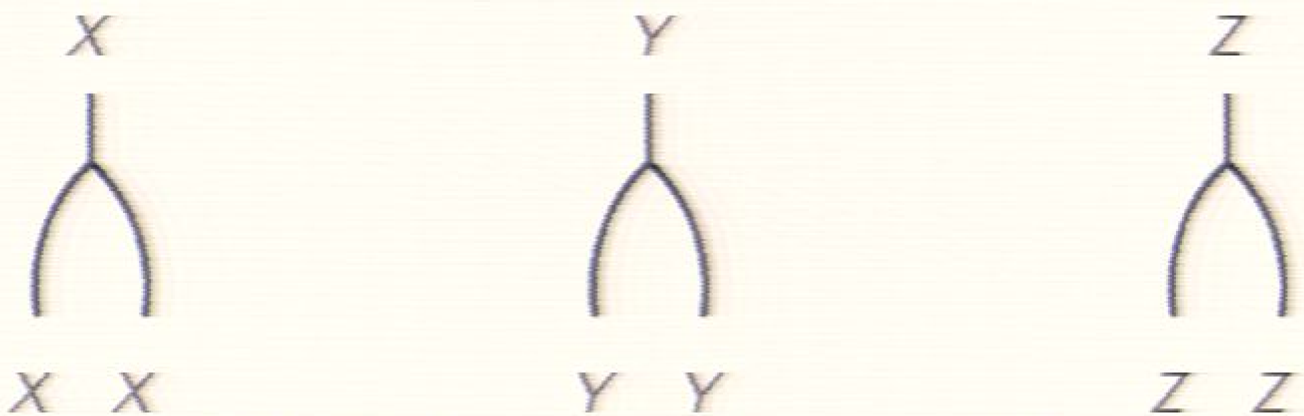

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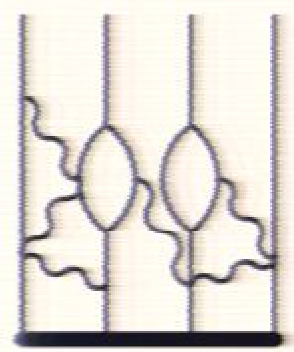

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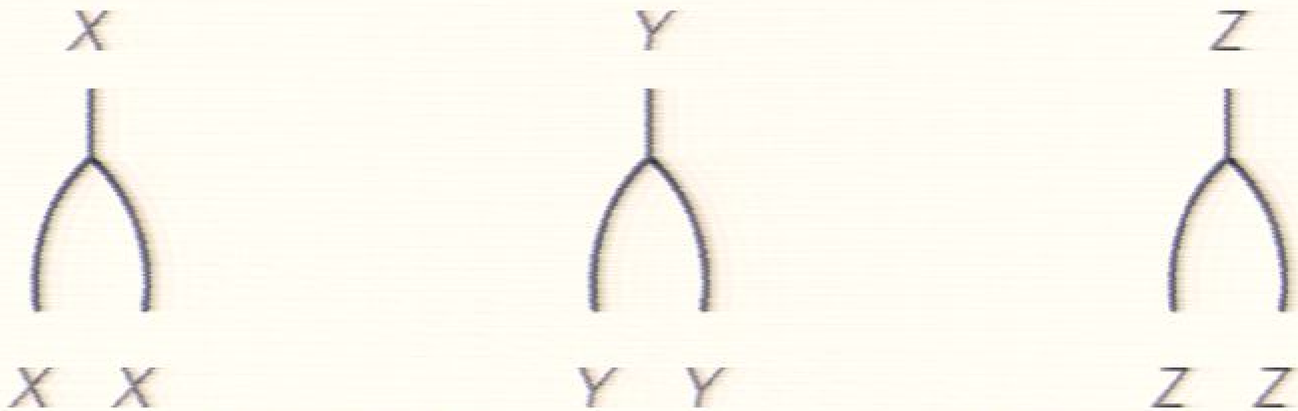

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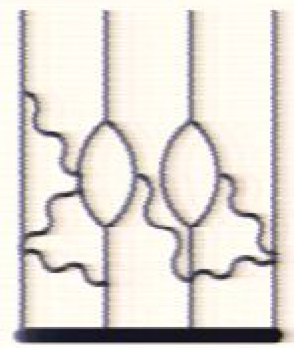

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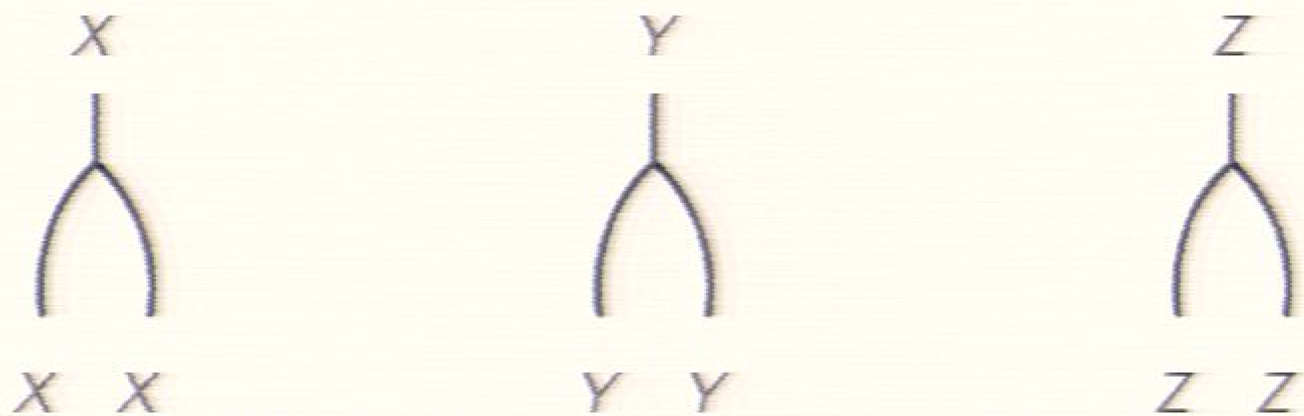

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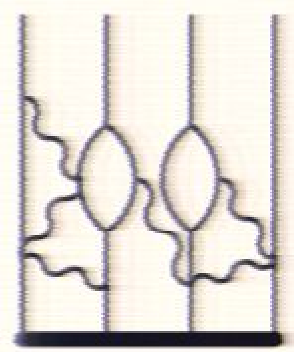

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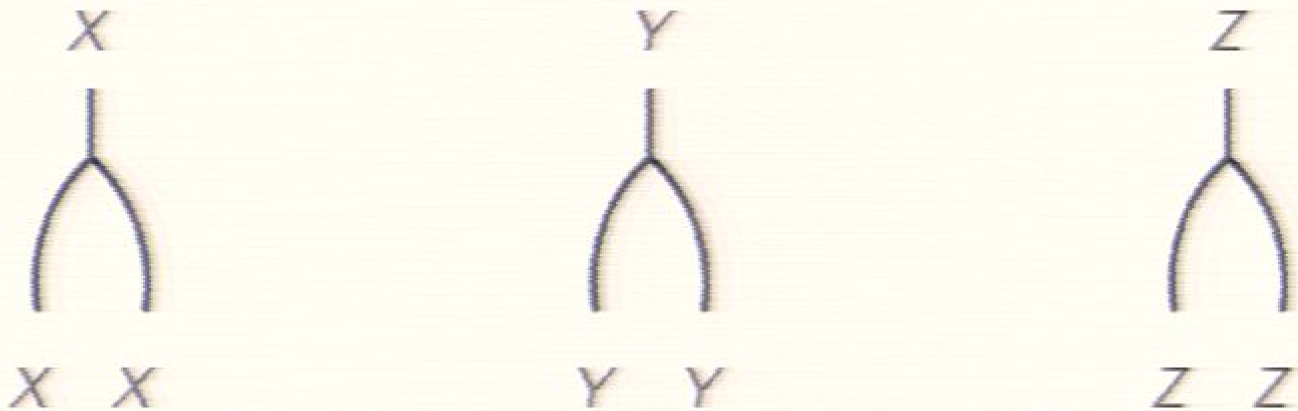

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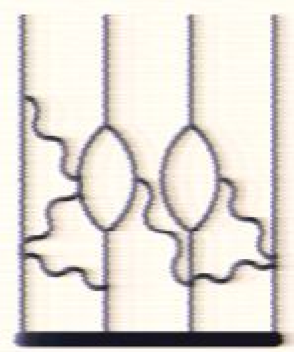

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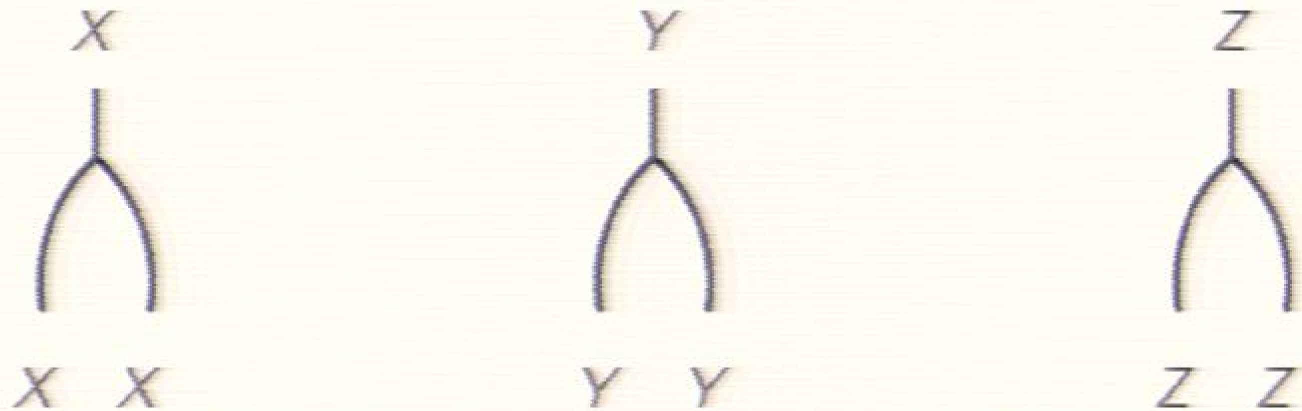

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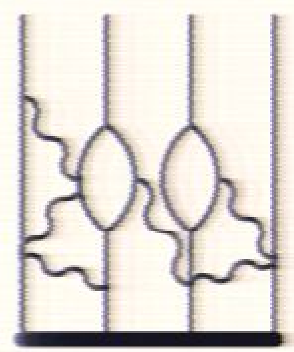

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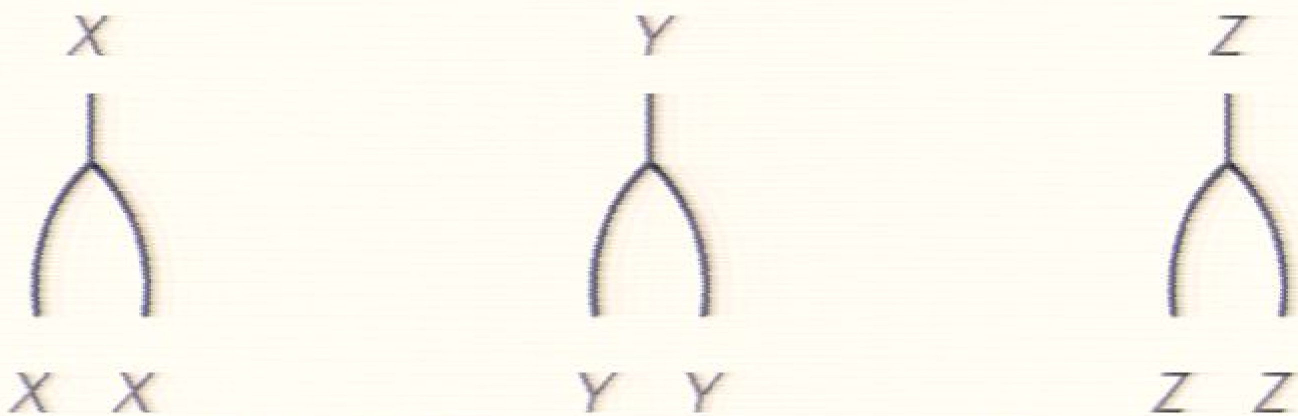

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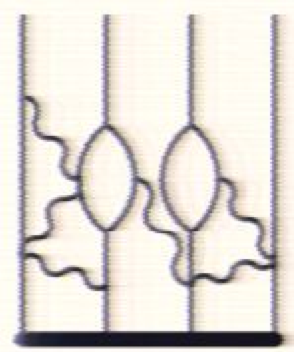

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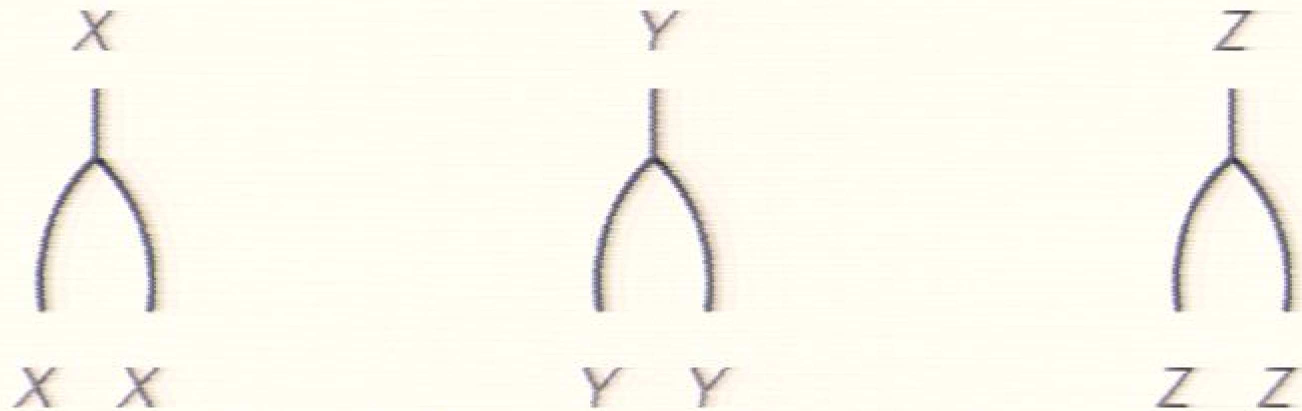

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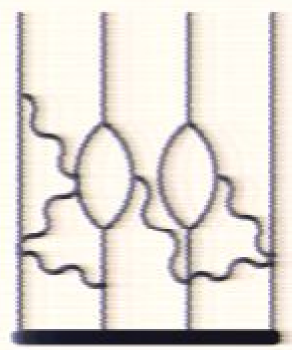

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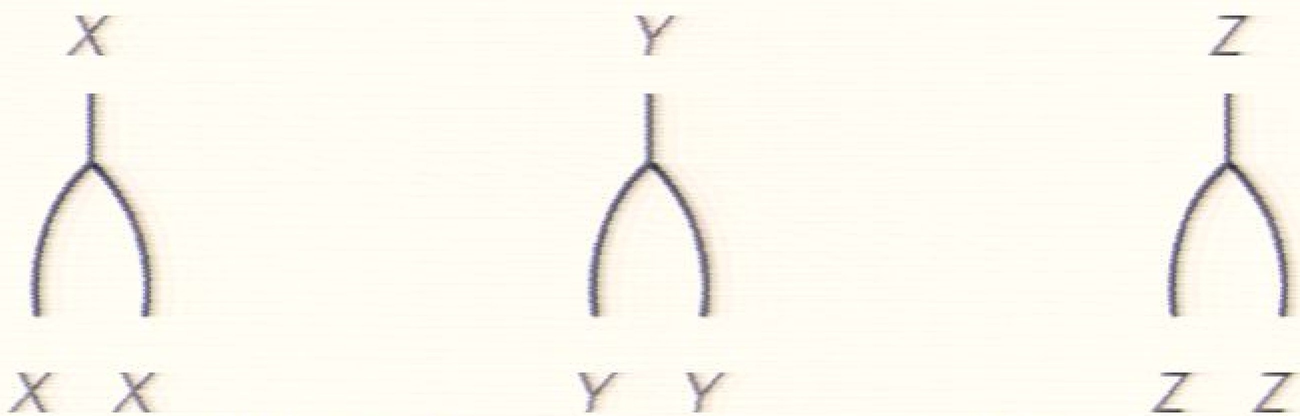

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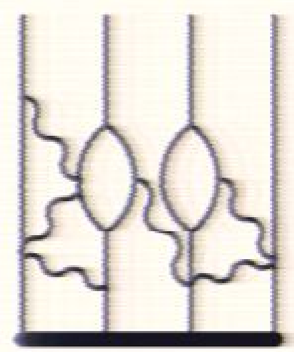

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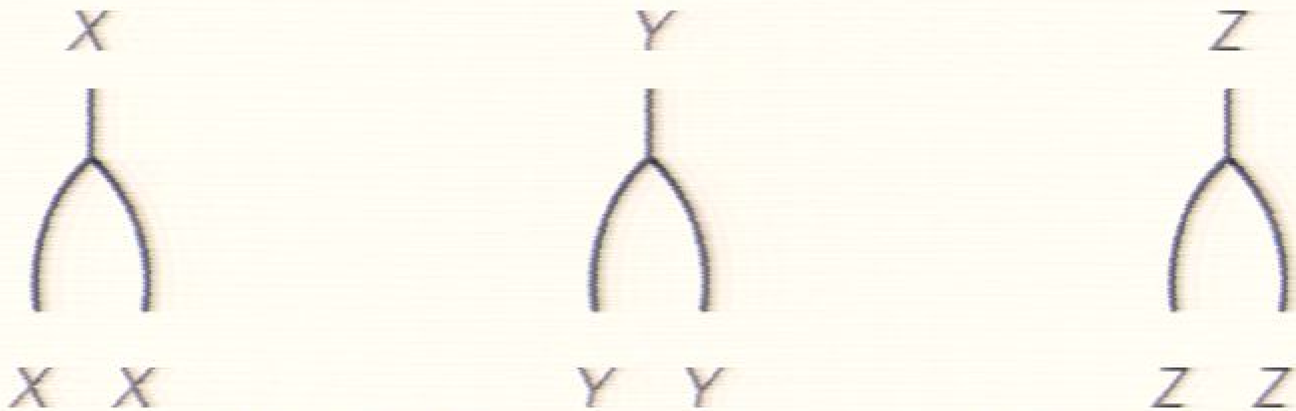

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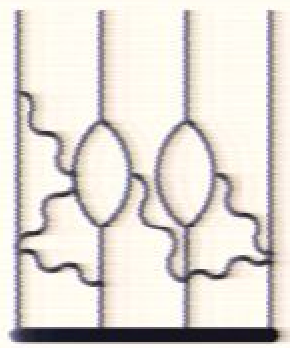

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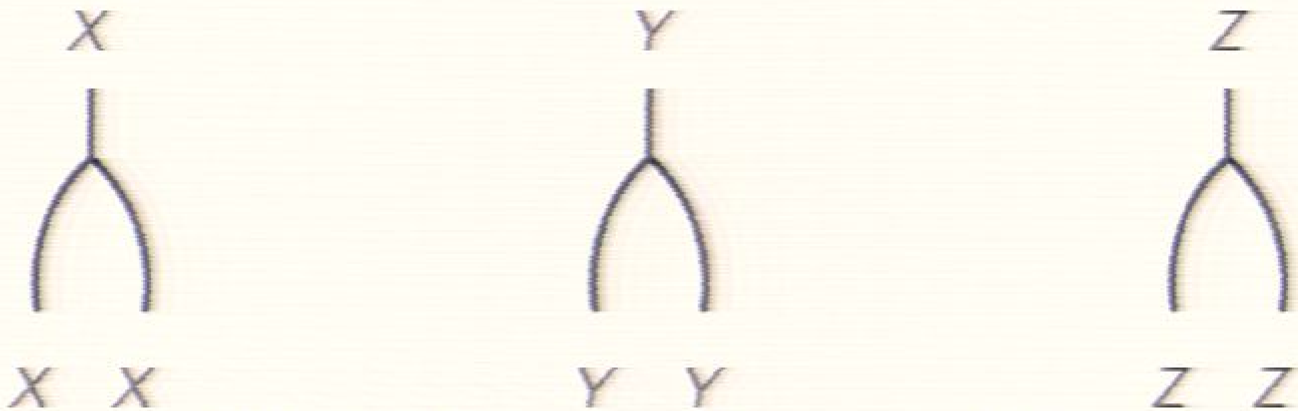

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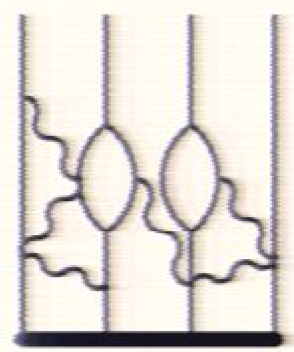

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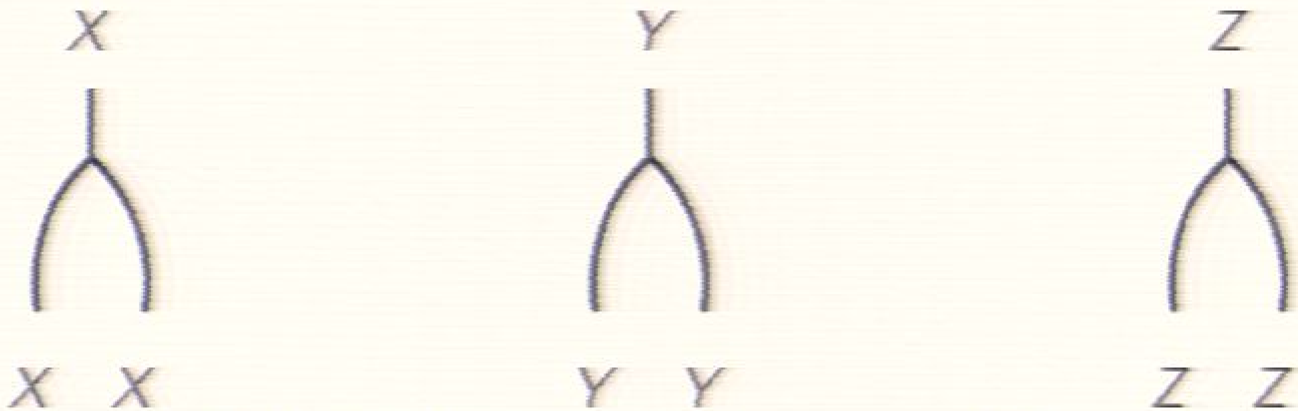

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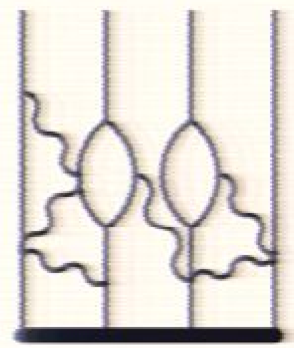

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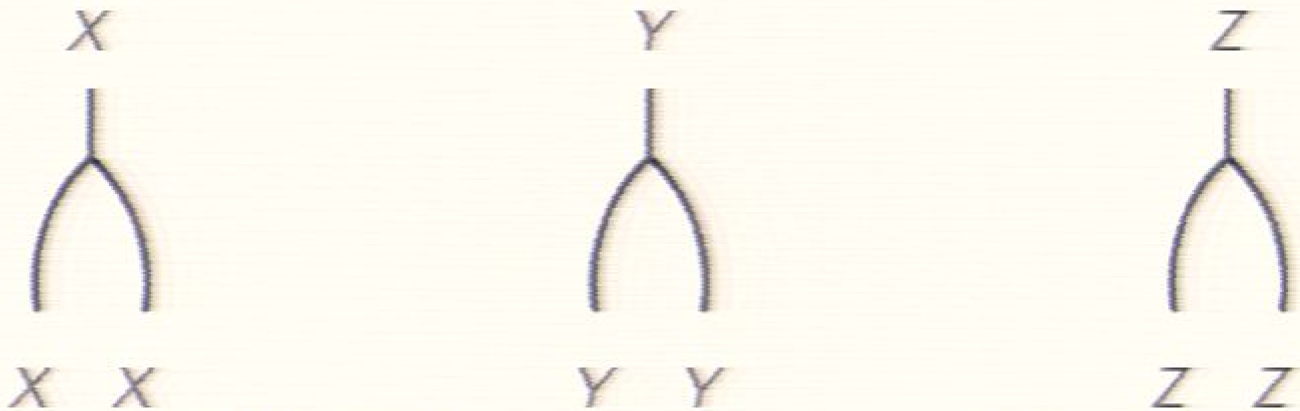

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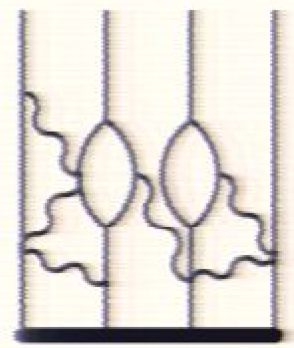

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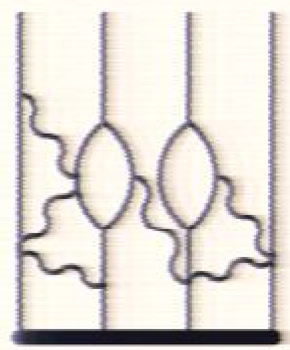

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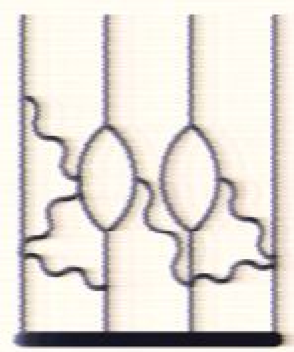

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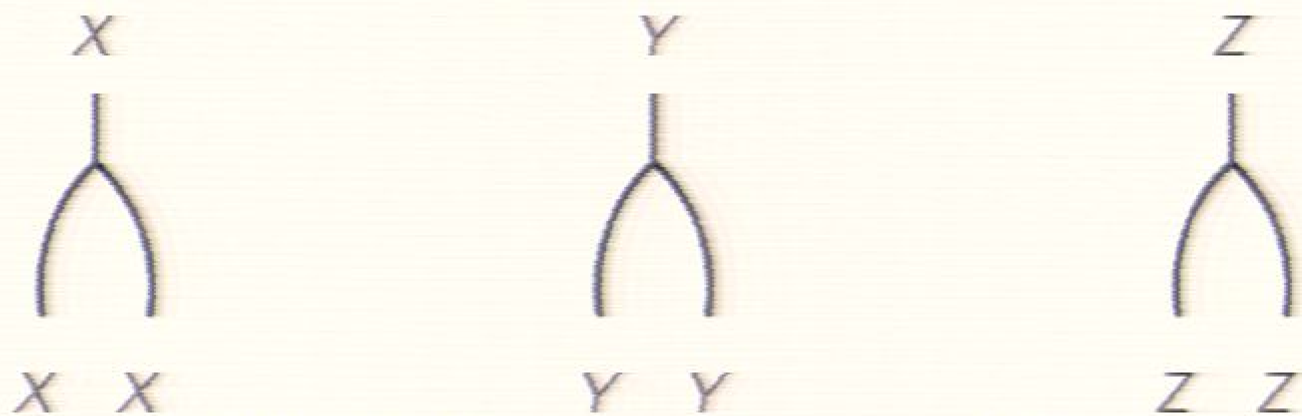

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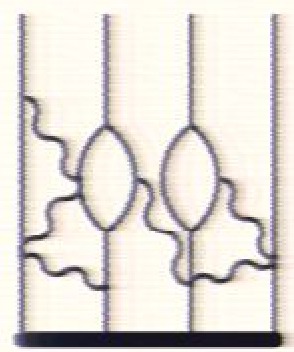

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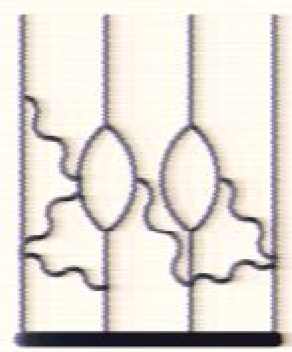

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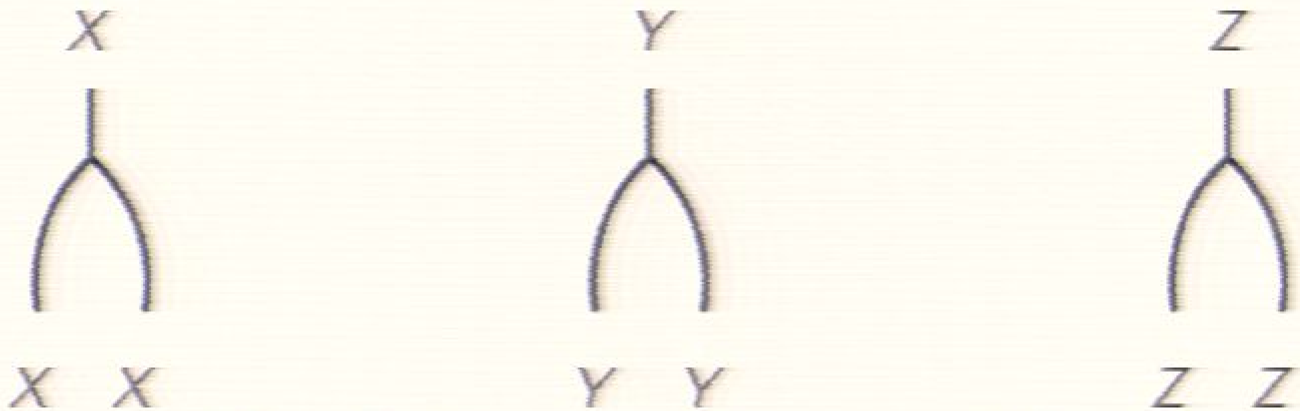

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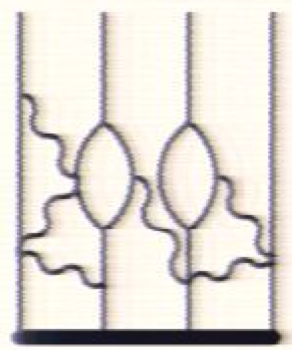

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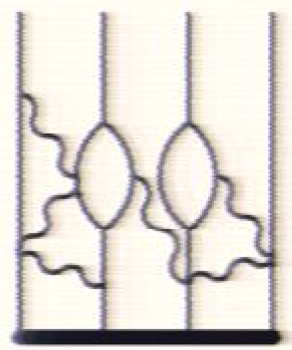

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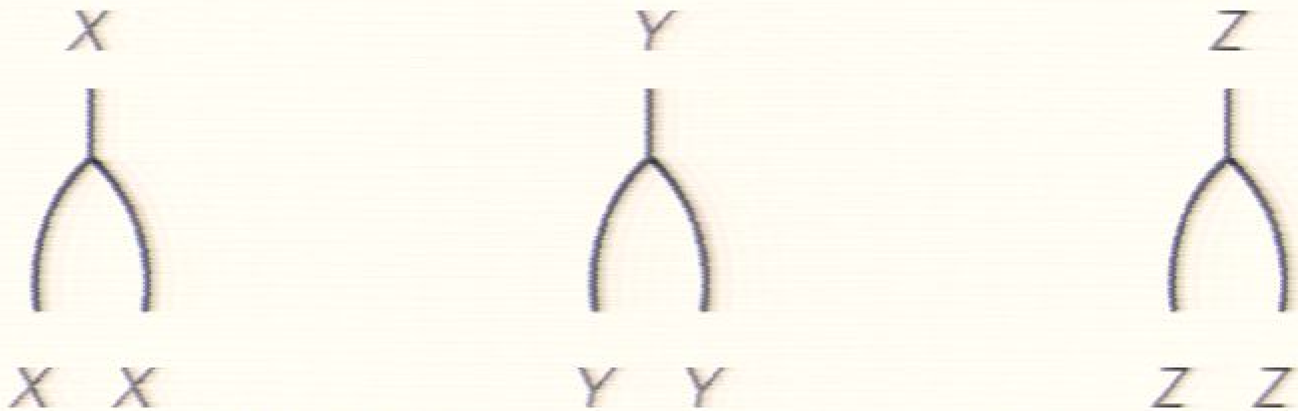

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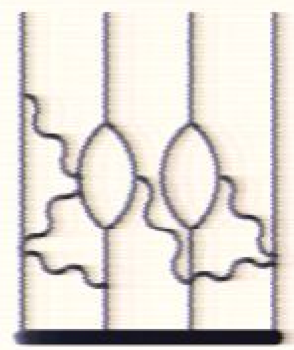

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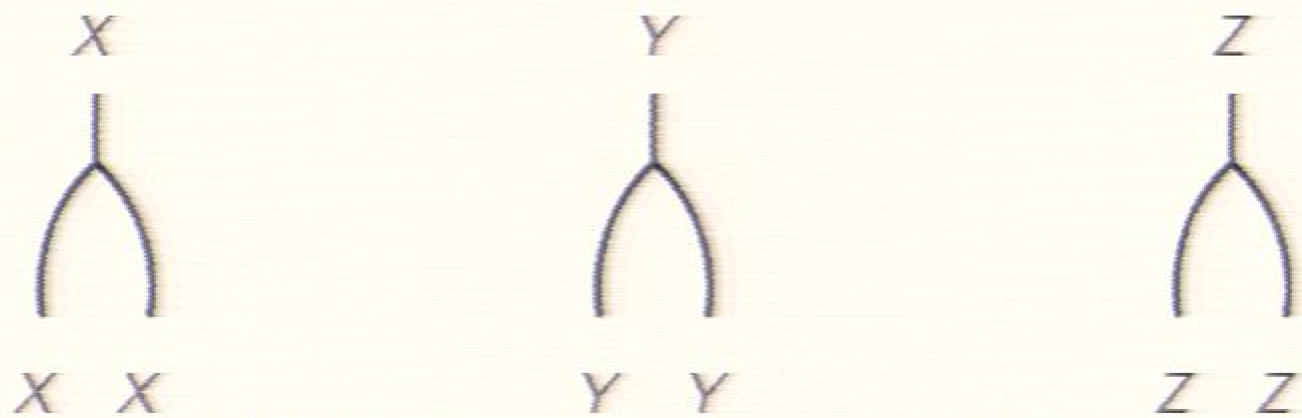

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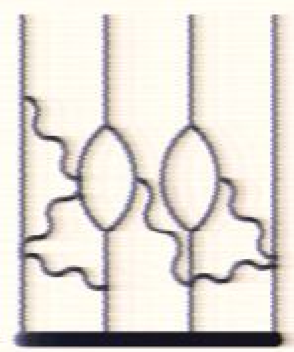

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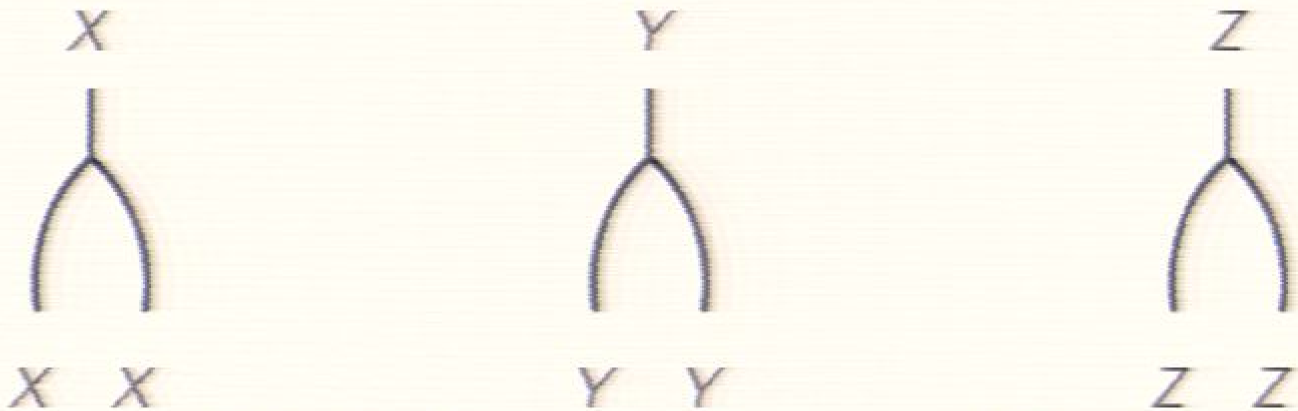

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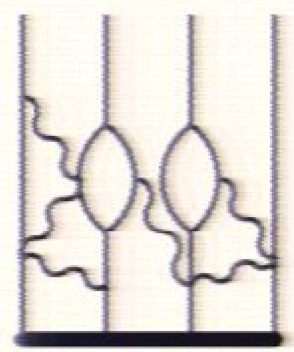

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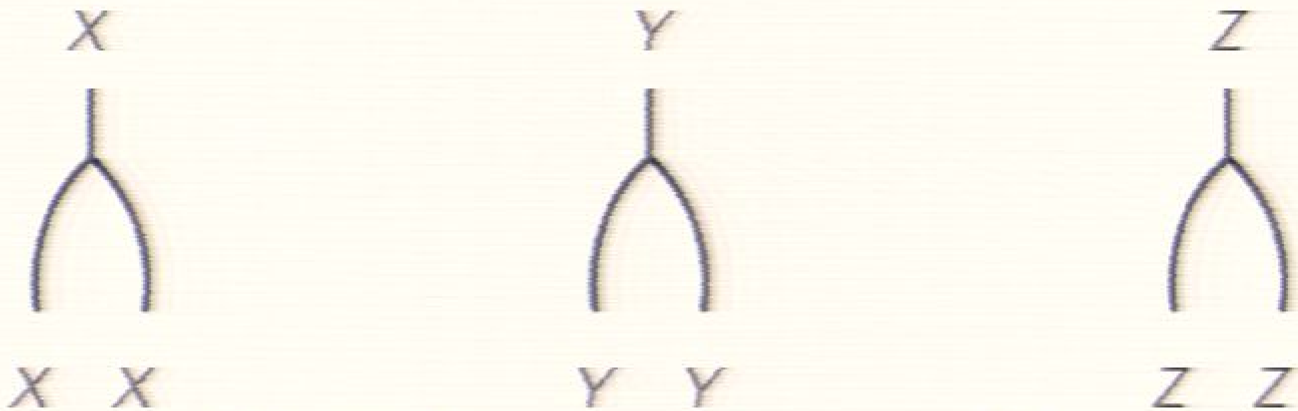

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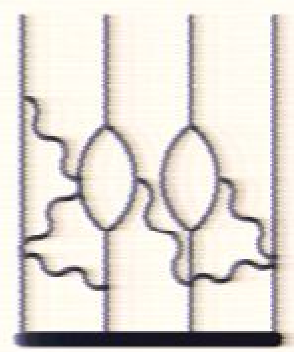

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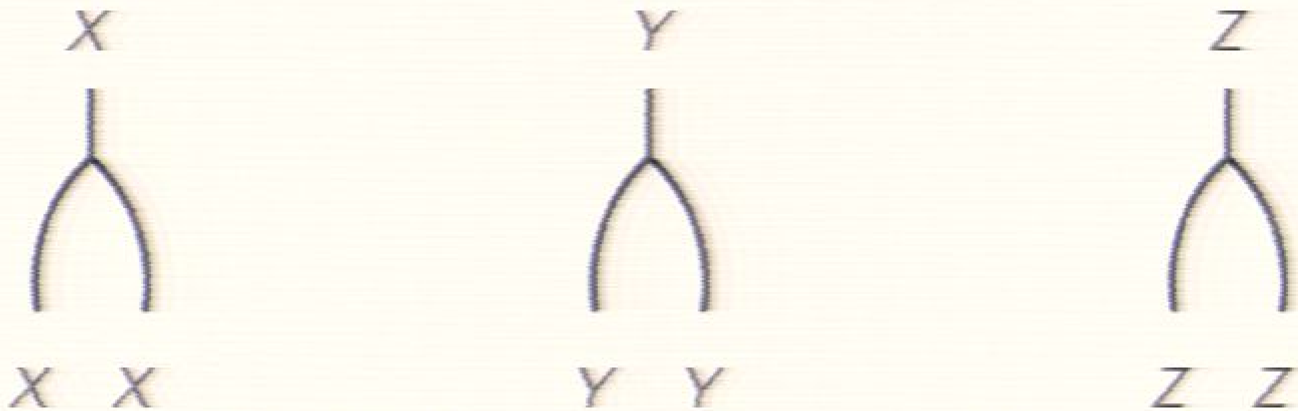

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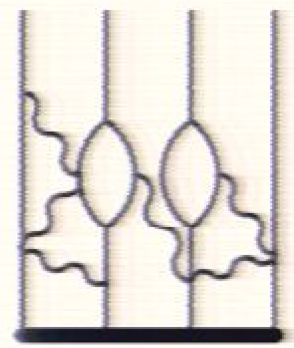

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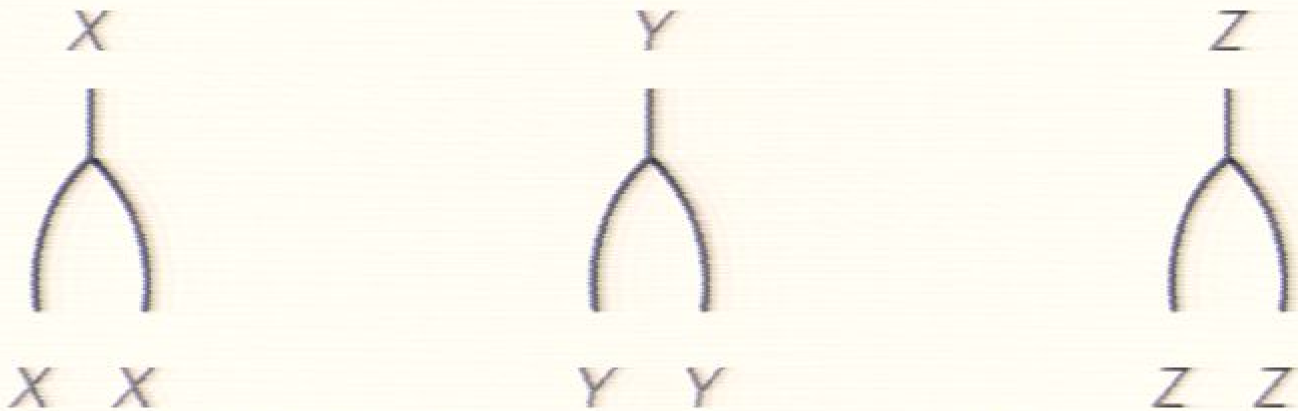

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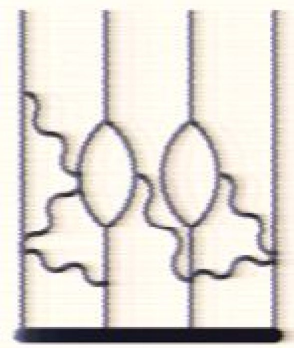

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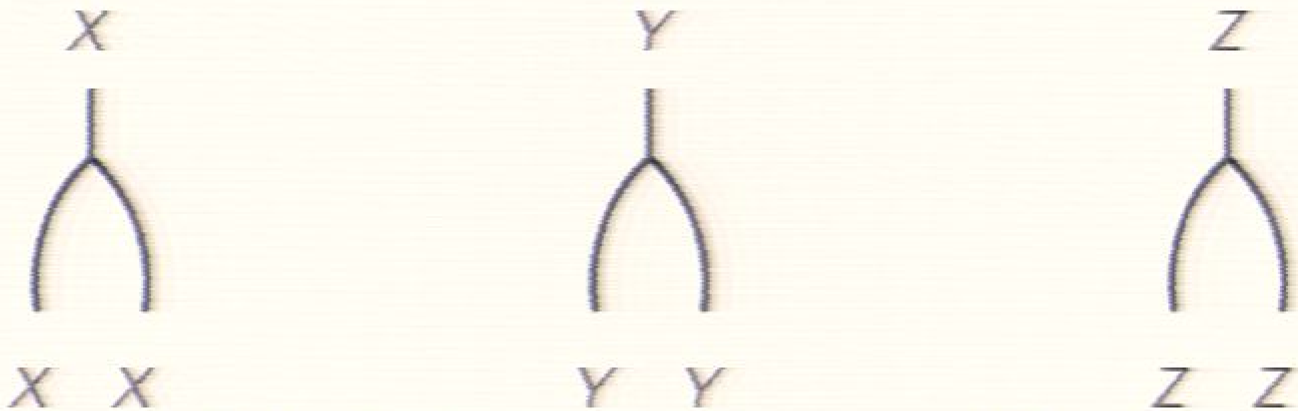

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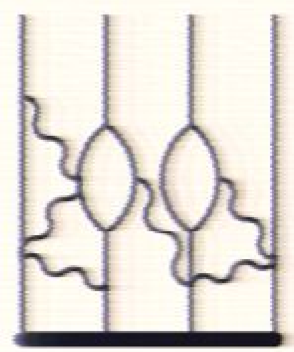

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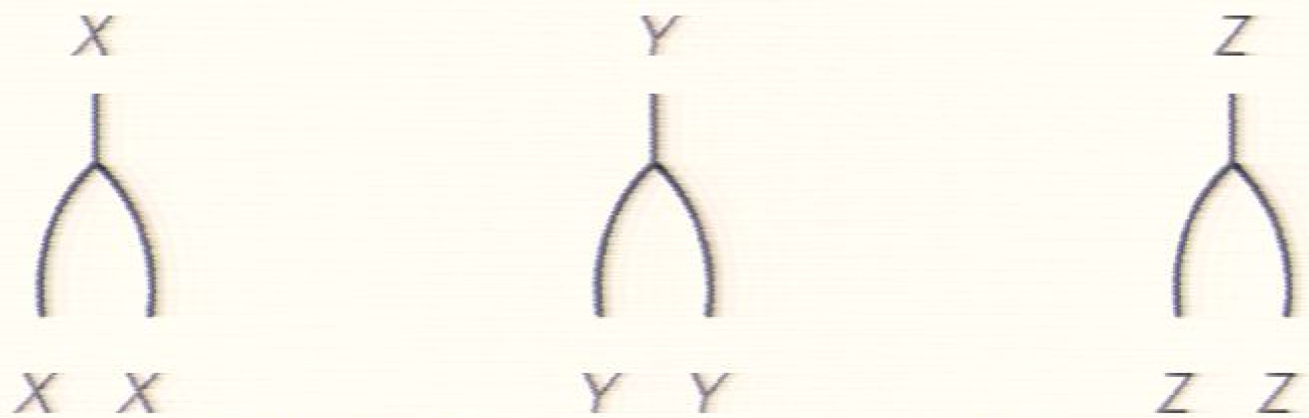

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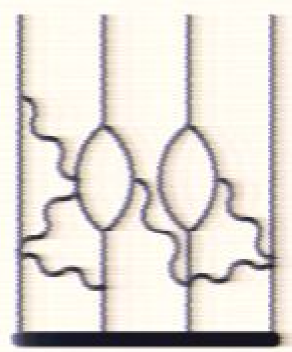

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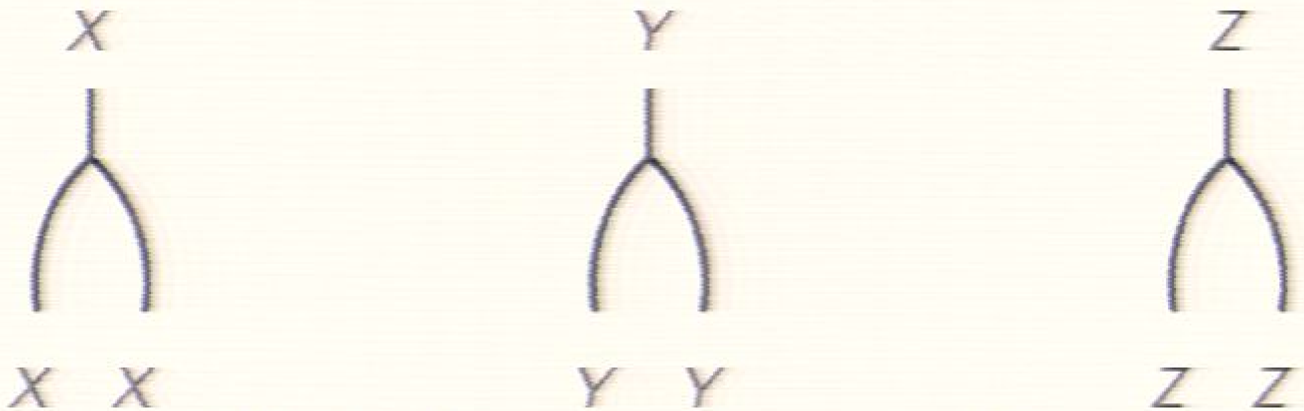

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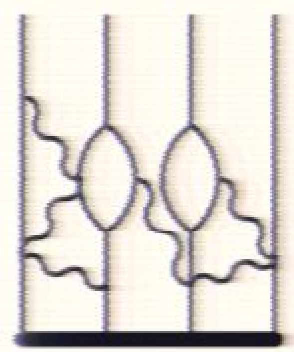

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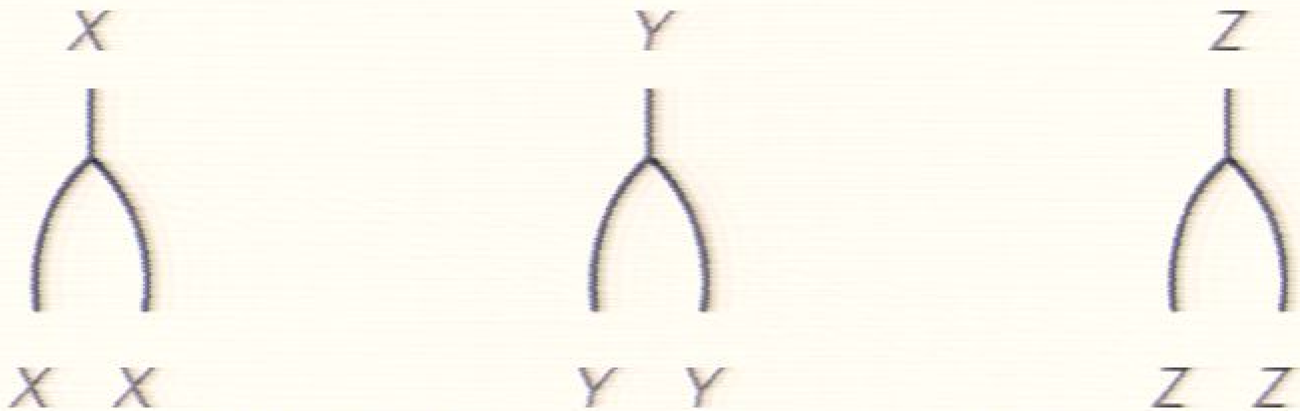

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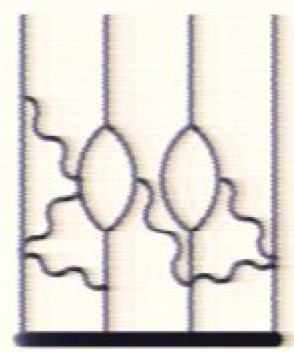

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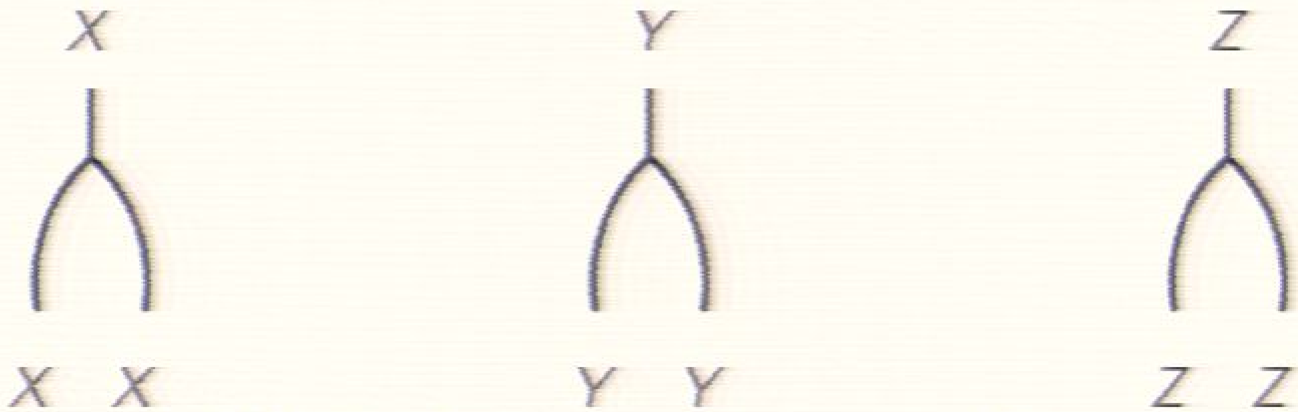

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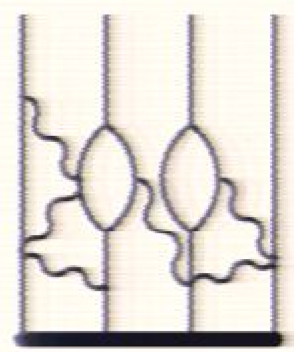

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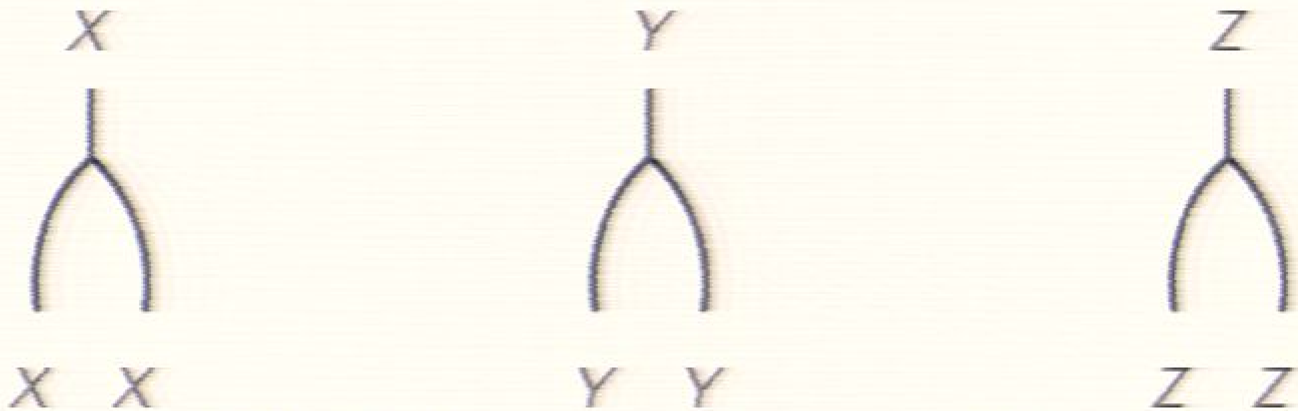

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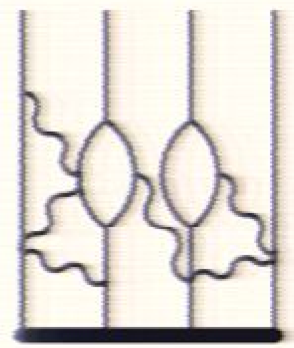

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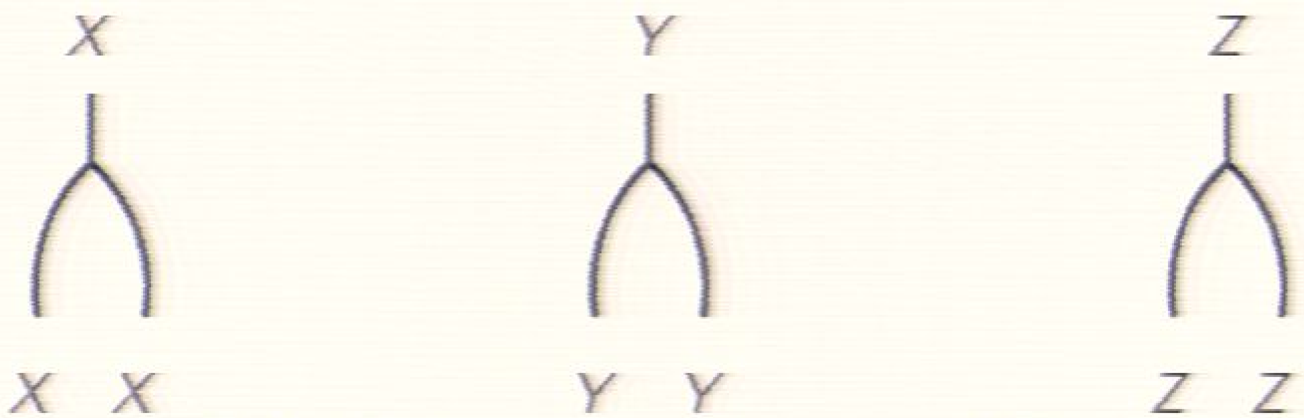

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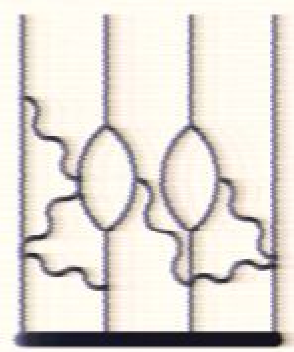

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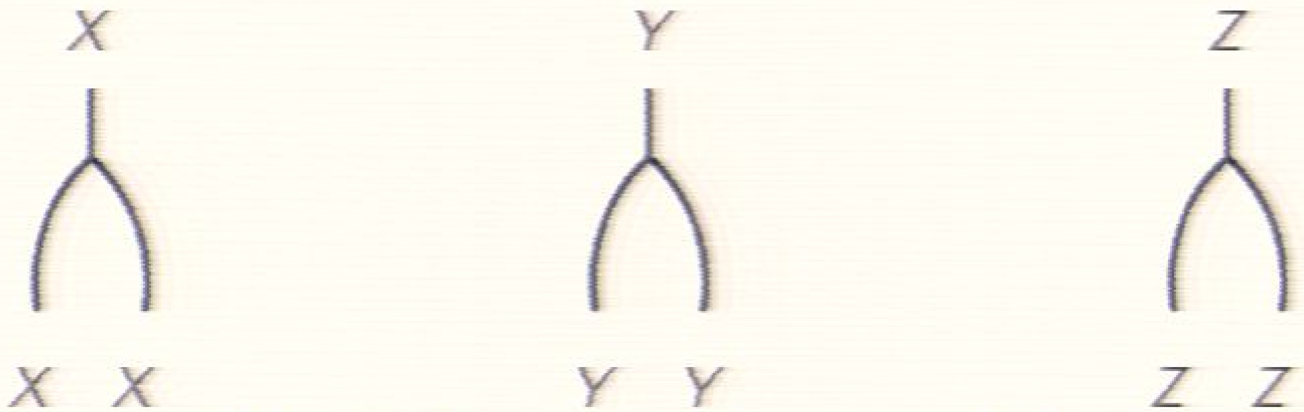

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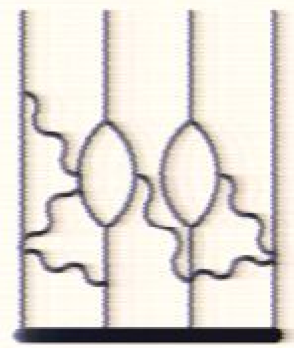

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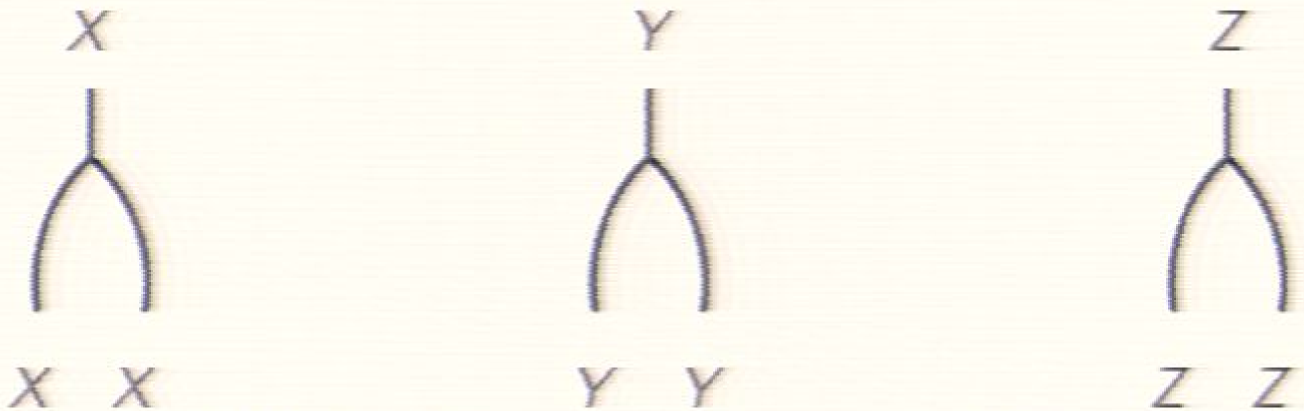

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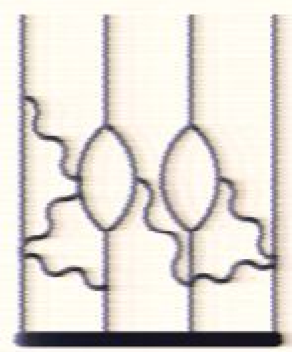

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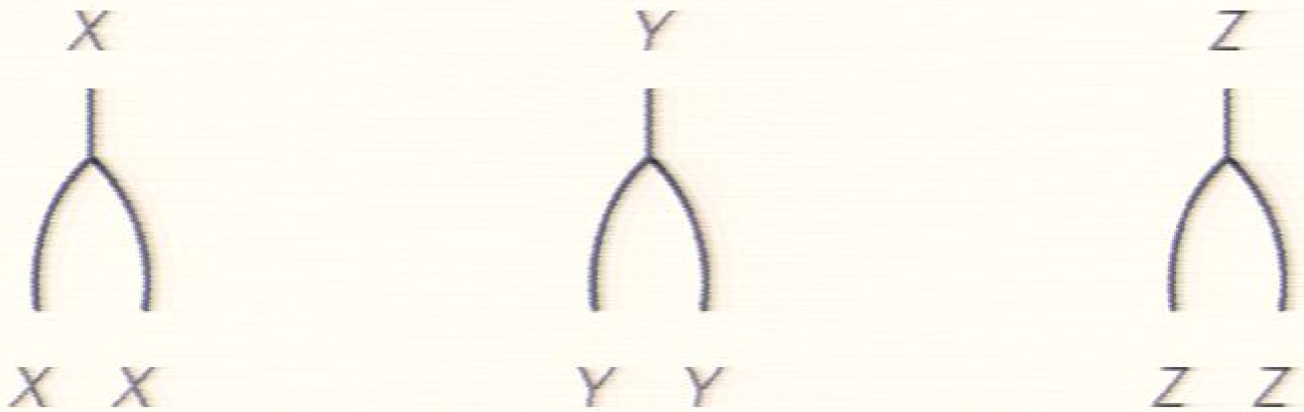

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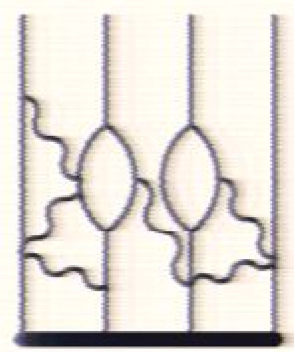

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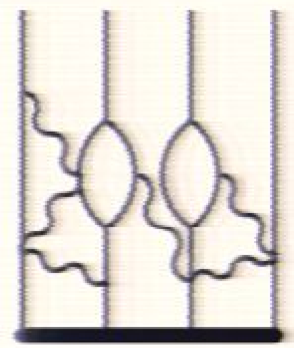

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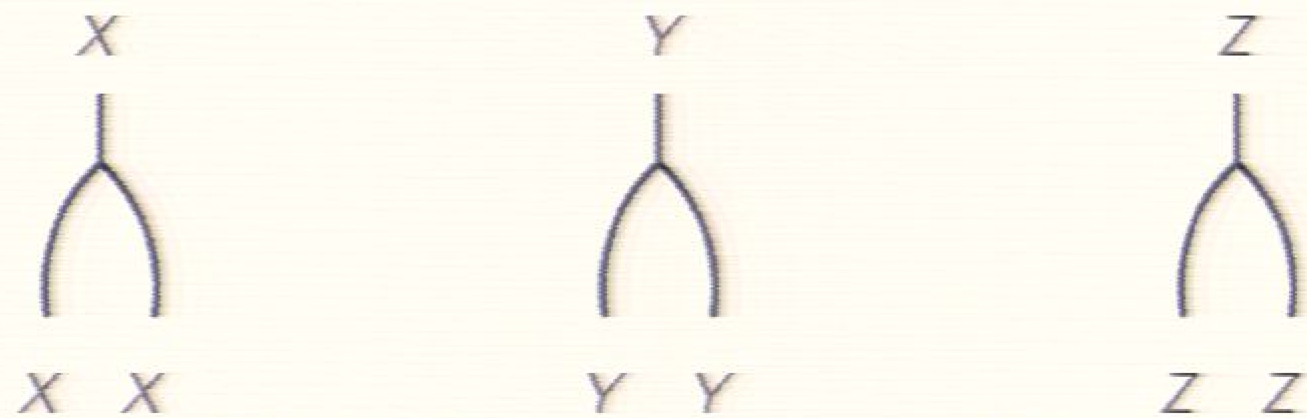

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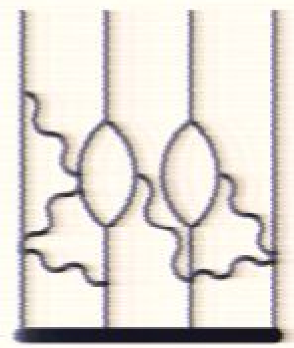
e.g. 

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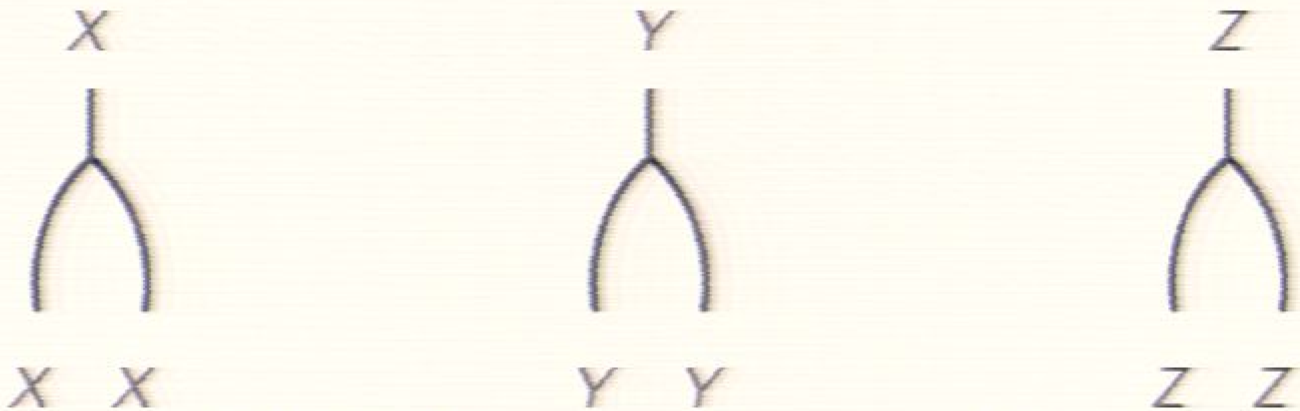

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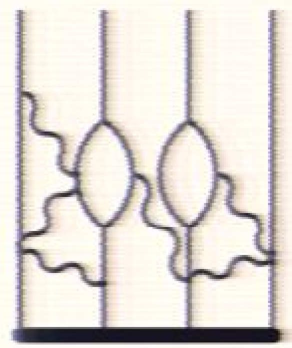

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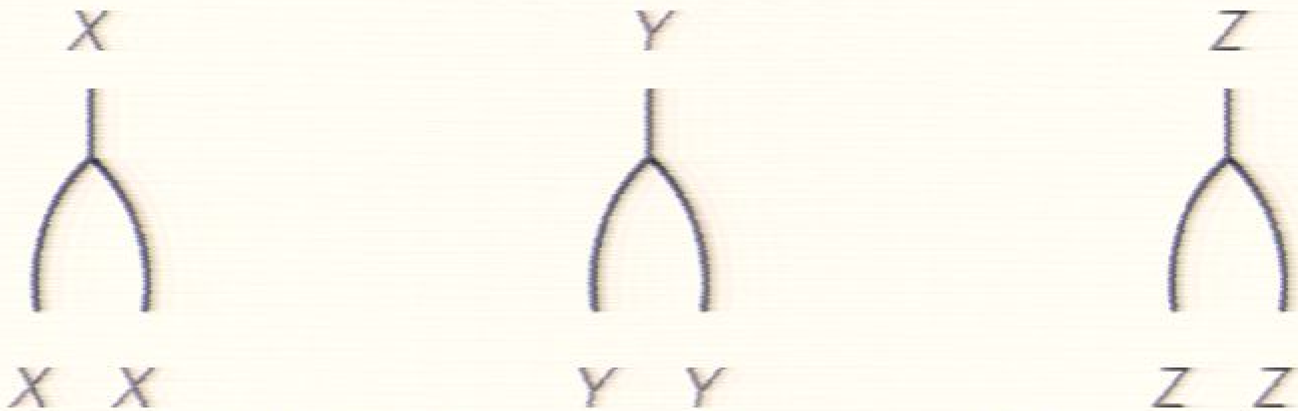

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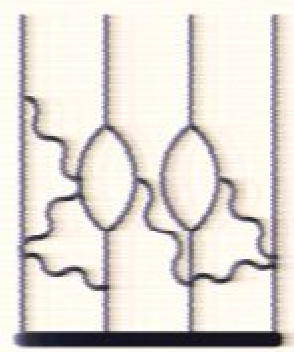

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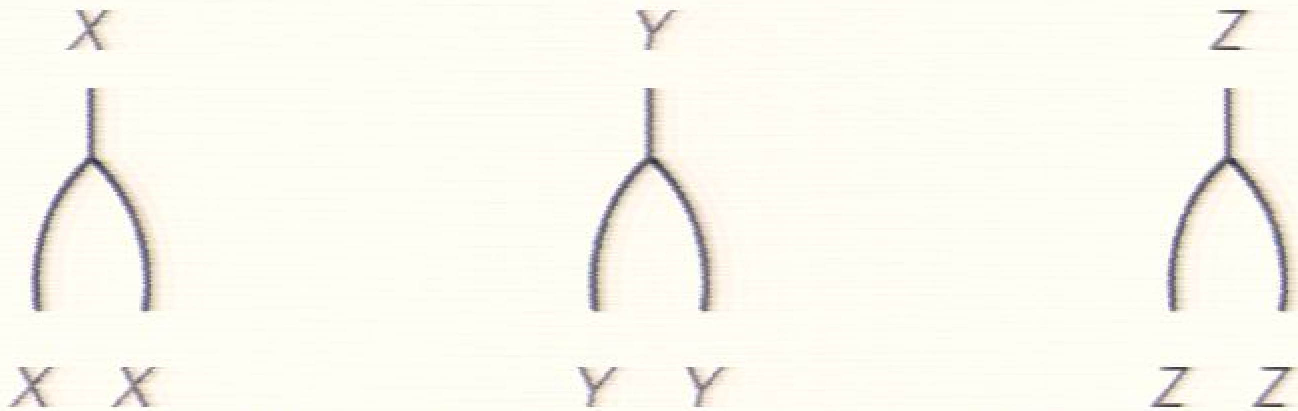

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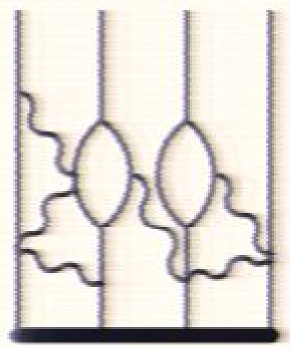

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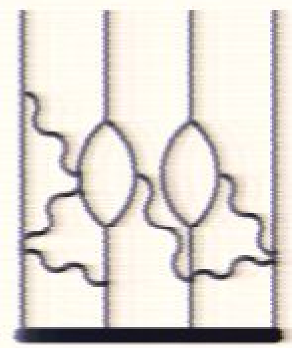

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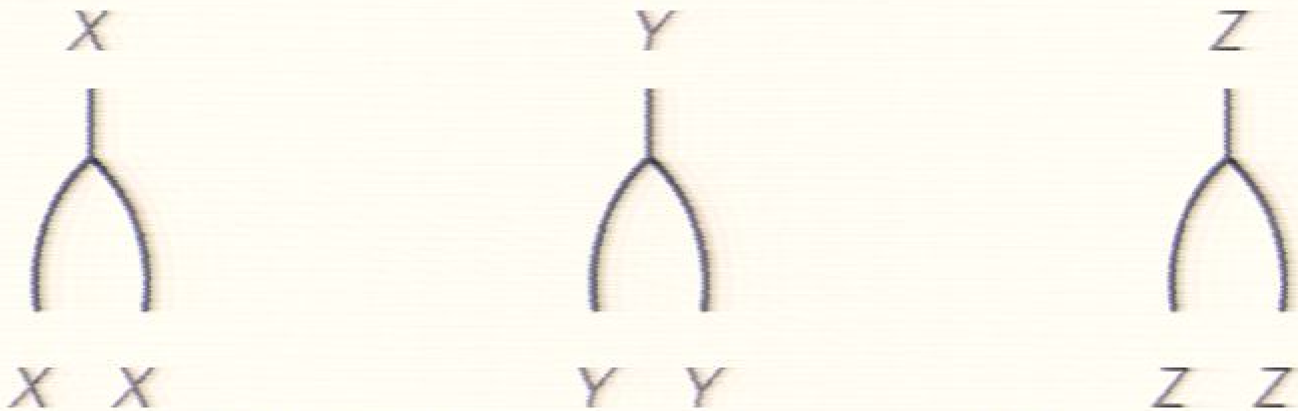

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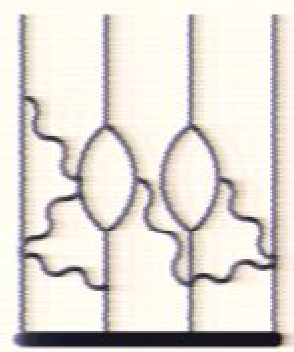
e.g. 

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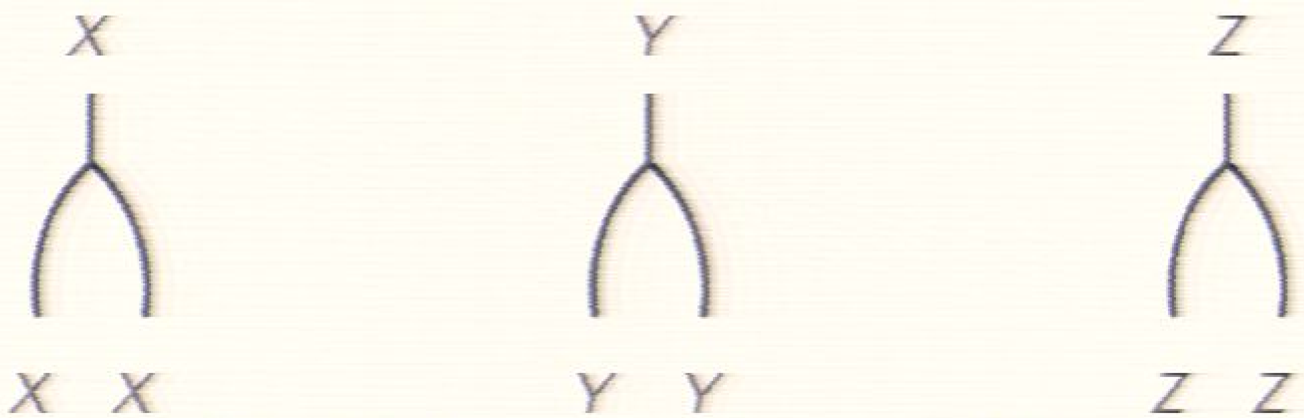
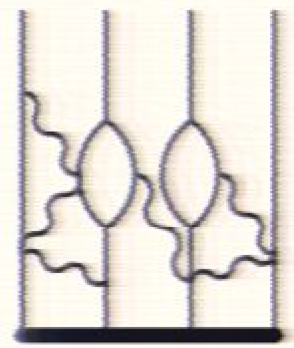


Graphs where neighboring legs are only connected by vectors are finite
(after removing subdivergences)

e.g.



Let $\mathcal{O} = \mathrm{tr}[XYXYZX\ldots XYZYZY]$ All neighbors different $\Rightarrow \delta = 0$
All graphs in the plane are finite since legs can't connect by chiral verts.

Leigh-Strassler deformations

$$W = \kappa\left(\mathrm{tr}(XYZ - q\,XZY) + \frac{h}{3}(X^3 + Y^3 + Z^3)\right) \qquad q \;\&\; h \text{ complex.}$$

Conformal condition : $\gamma_i = 0$

$$2g_{YM}^2 = \kappa\bar{\kappa}(1 + q\bar{q} + h\bar{h}) \qquad (\textit{planar})$$

All loop exact if $h = 0$, $q = e^{-2\pi i\beta}$, β real. 4-loop corrections otherwise.

"Cubic Model" : $\kappa \to 0$, $h \to \infty$, $\hat{h} = \kappa h$ finite.

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Conjecture

The all-loop sum of supergraphs with the connected chiral function $\chi(a_1, a_2 \dots a_j, \dots a_n)$ is given by

$$F_n(g^2)\chi(a_1, a_2 \dots a_j, \dots a_n)$$
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- This is a statement about supergraphs and can be applied outside the $SU(2)$ sector where

$$\chi(a_1 \dots a_j, a_j \pm 1, a_j \dots a_n) \neq \chi(a_1 \dots a_j \dots a_n)$$

- Does not directly require $\mathcal{N} = 4$ susy.
- Can be applied it to $\mathcal{N} = 1$ superconformal theories with different chiral functions.

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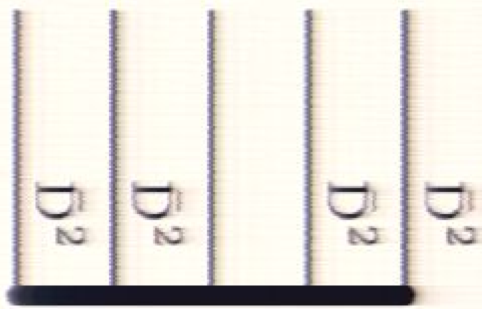
Computing supergraphs: Chiral Operators

Single trace operators made with ϕ^i or W_α

Scalar operators: $\mathcal{O} = \mathrm{tr}[XYYXZZZYXXXX]$

Scalar operators as chiral vertices:

$\mathcal{O} = \ldots$  $\cdots$ One leg missing $\bar{D}^2$.

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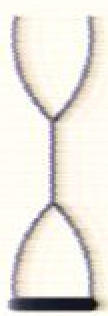
$$\mathcal{D} = \sum_{\ell=0}^{\infty} g^{2\ell} \mathcal{D}_\ell$$

$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1), \quad \mathcal{D}_2 = -2\left[\chi(1,2) + \chi(2,1)\right] - 4\chi(1)$

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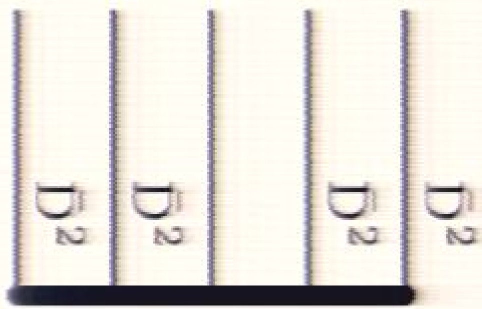
$\mathcal{O} = \ldots$ 

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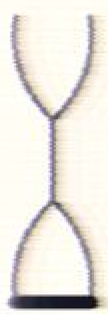
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1)\,, \quad \mathcal{D}_2 = -2\left[\chi(1,2) + \chi(2,1)\right] - 4\chi(1)$

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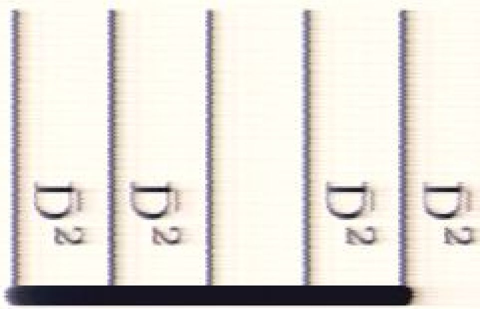

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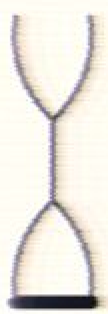

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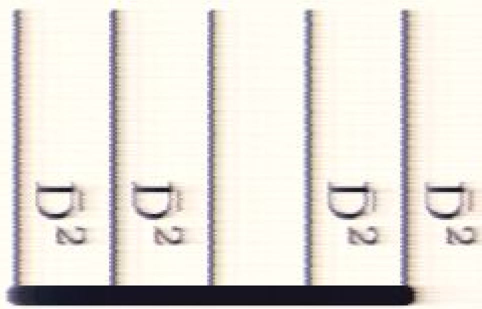

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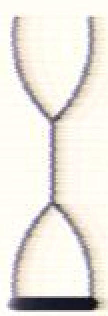

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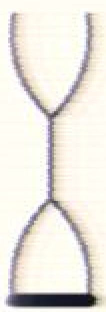
$\mathcal{D}_0 = L,$  $\mathcal{D}_1 = 2\chi(1)\,,\quad \mathcal{D}_2 = -2\,[\chi(1,2) + \chi(2,1)] - 4\chi(1)$

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n.b. No matter what the outcome of the conjecture, it is still true that the connected chiral components sum to the dispersion relation.

e.g. If $\chi(1, 2, 1)$ is known at four loops, then so is $\chi(1)$.

Leigh-Strassler deformations

$$W = \kappa\left(\mathrm{tr}(XYZ - qXZY) + \frac{h}{3}(X^3 + Y^3 + Z^3)\right) \qquad q \,\&\, h \text{ complex.}$$

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Planar protected states in the cubic model:

- For scalar ops. of length L there are $\sim 2^L/L$ planar protected ops.

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One pair: $\mathcal{O} = \mathrm{tr}[XYXZ \ldots YXXZ \ldots]$
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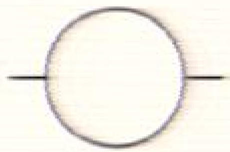
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\mathrm{YM}}^2$

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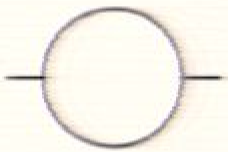
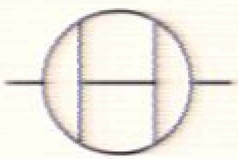
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g^2_{YM}$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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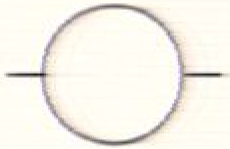
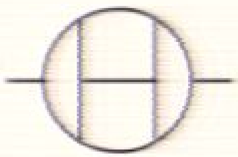
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g^2_{YM}$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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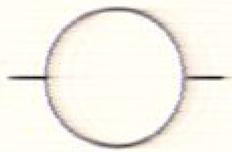
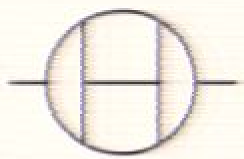
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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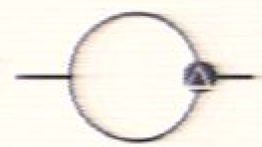
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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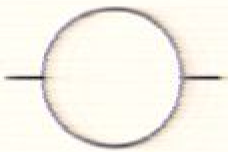
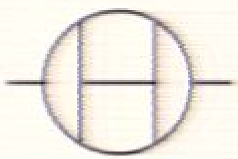
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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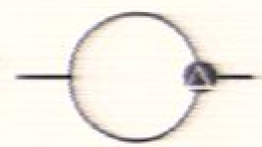
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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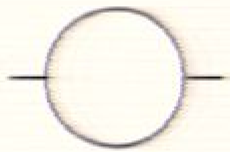
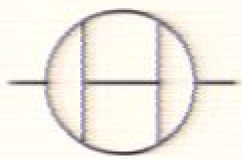
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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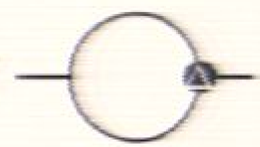
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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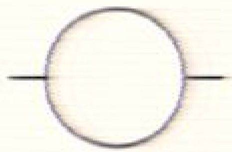
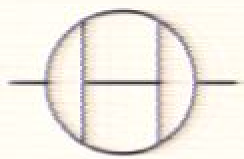
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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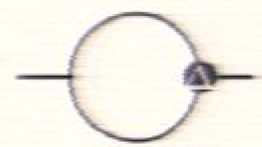
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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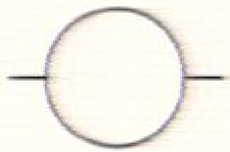
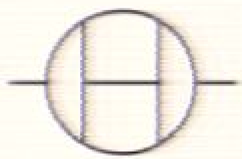
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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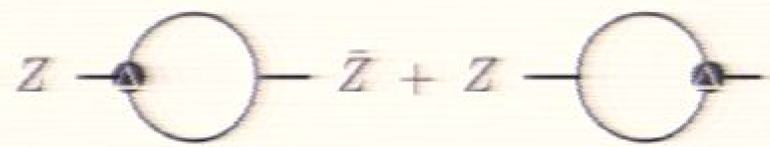
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h} \Rightarrow$ 

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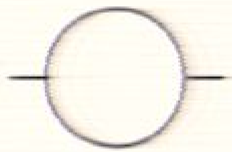
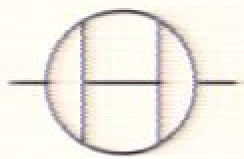
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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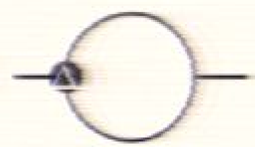
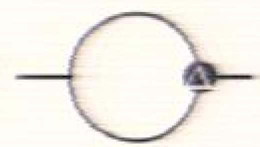
Compensate: $\hat{h} \to \sqrt{2}g_{\mathrm{YM}} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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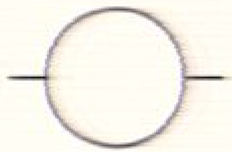
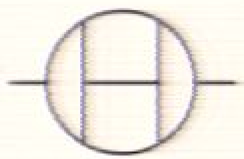
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX); Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8; Cubic: 1

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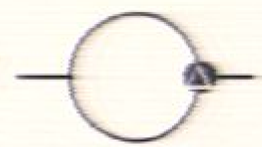
Compensate: $\hat{h} \rightarrow \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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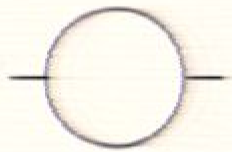
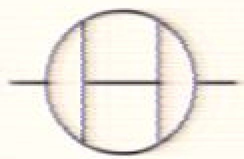
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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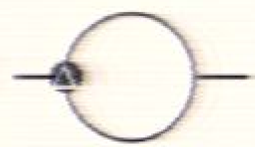
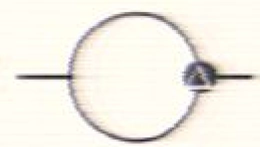
Compensate: $\hat{h} \to \sqrt{2} g_{\mathrm{YM}} + \Delta \hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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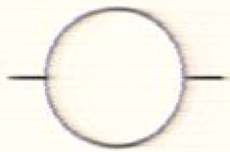
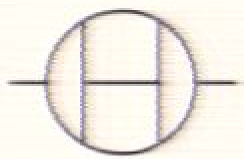
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX), Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8, Cubic: 1

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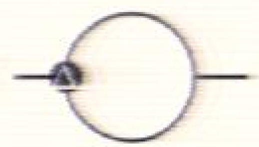
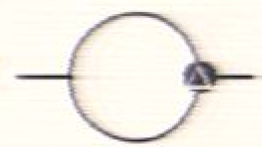
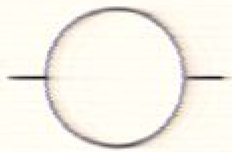
Compensate: $\hat{h} \to \sqrt{2}g_{\rm YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

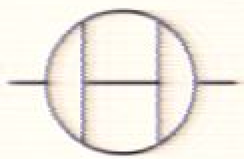
Cancel anom. dim.
(Dim. Red)
$$\mu\frac{d}{d\mu}\left[\frac{A\,g^2\,\delta\hat{h}}{g_{\rm YM}\,\epsilon}\left(\frac{\mu^2}{p^2}\right)^{\epsilon} + \frac{B\,g^8}{\epsilon}\left(\frac{\mu^2}{p^2}\right)^{4\epsilon}\right] = 0 \Rightarrow \delta\hat{h} = -4\,g_{\rm YM}\,g^6\,\frac{B}{A}$$

Counterterm to cancel the divergence: $\frac{3B\,g^8}{\epsilon}$

Higher loops:

Why a 4-loop correction?

One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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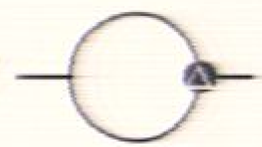
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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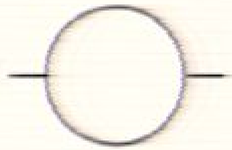
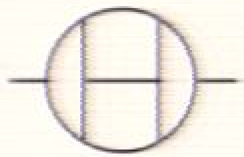
One-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } (XY, YX) \\ \text{Cubic: } (ZZ)\end{matrix}$ $\therefore \quad \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } 8 \\ \text{Cubic: } 1\end{matrix}$

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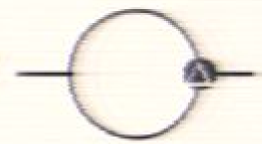
Compensate: $\hat{h} \to \sqrt{2}g_{\rm YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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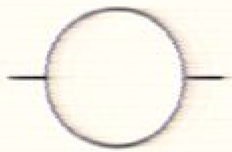
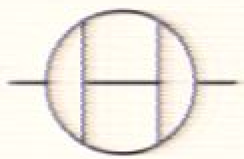
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g^2_{\text{YM}}$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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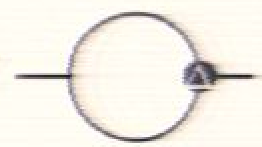
Compensate: $\hat{h} \to \sqrt{2} g_{\text{YM}} + \Delta \hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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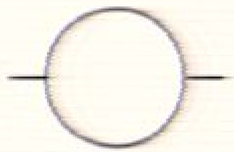
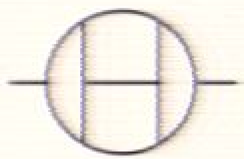
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX), Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8, Cubic: 1

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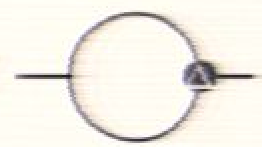
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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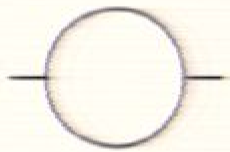
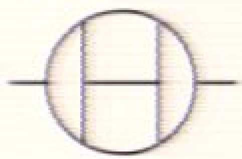
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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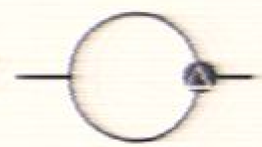
Compensate: $\hat{h} \to \sqrt{2}g_{\mathrm{YM}} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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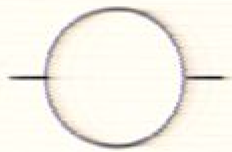
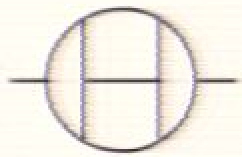
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX), Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\text{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8, Cubic: 1

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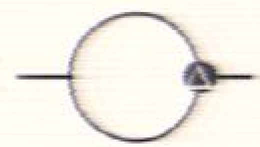
Compensate: $\hat{h} \to \sqrt{2} g_{\text{YM}} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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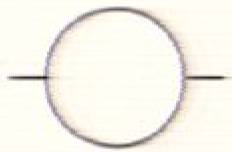
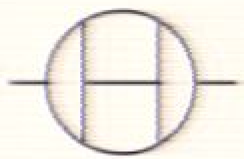
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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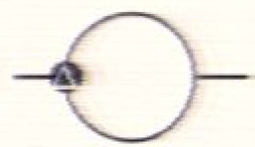
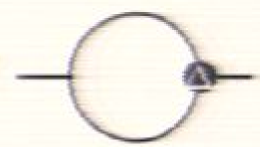
Compensate: $\hat{h} \to \sqrt{2}g_{\mathrm{YM}} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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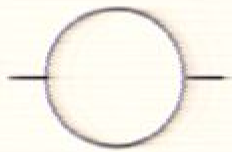
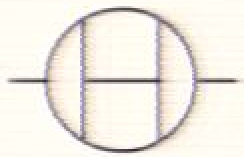
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\text{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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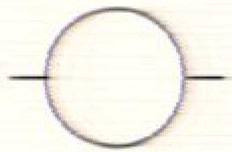
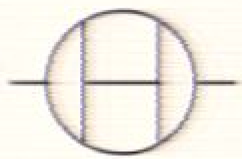
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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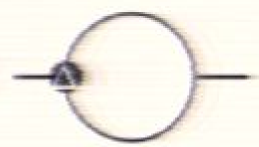
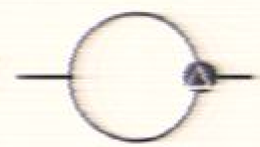
Compensate: $\hat{h} \to \sqrt{2} g_{\mathrm{YM}} + \Delta \hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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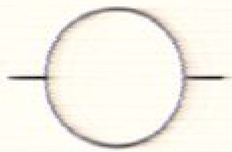
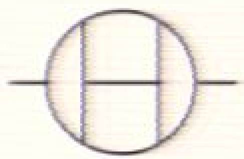
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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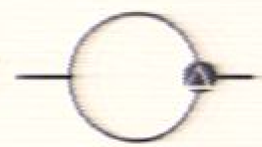
Compensate: $\hat{h} \rightarrow \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow$ Z  $\bar{Z}$ + Z 

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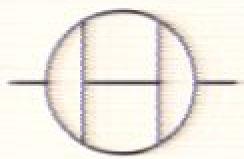
Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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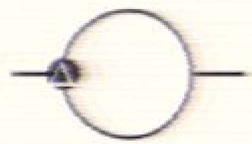
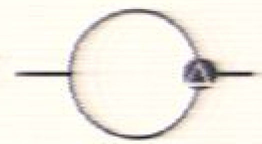
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta \hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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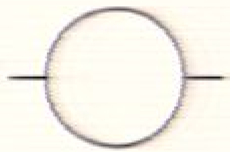
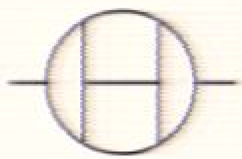
One-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } (XY, YX) \\ \text{Cubic: } (ZZ)\end{matrix}$ $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } 8 \\ \text{Cubic: } 1\end{matrix}$

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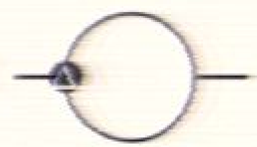
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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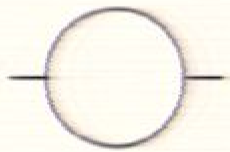
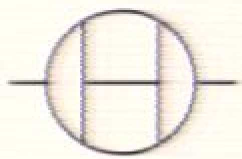
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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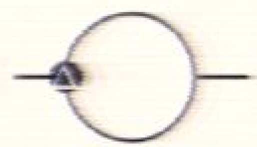
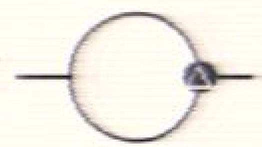
Compensate: $\hat{h} \to \sqrt{2} g_{\rm YM} + \Delta \hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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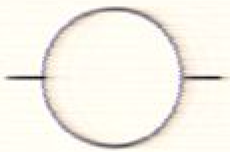
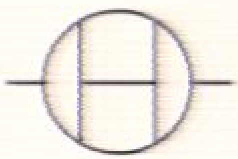
One-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix} \mathcal{N}=4\text{: } (XY, YX) \\ \text{Cubic: } (ZZ) \end{matrix}$ $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix} \mathcal{N}=4\text{: } 8 \\ \text{Cubic: } 1 \end{matrix}$

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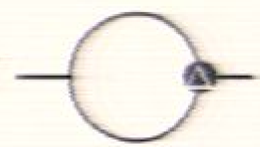
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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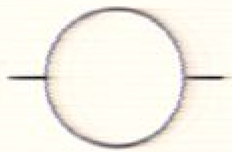
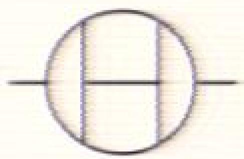
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\text{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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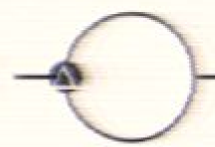
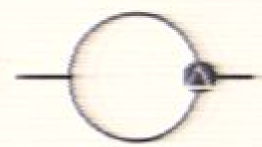
Compensate: $\hat{h} \to \sqrt{2} g_{\text{YM}} + \Delta \hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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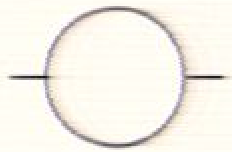
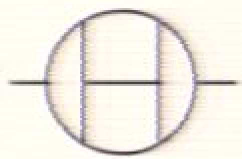
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\text{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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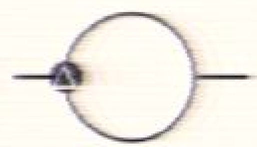
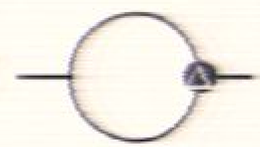
Compensate: $\hat{h} \to \sqrt{2}g_{\text{YM}} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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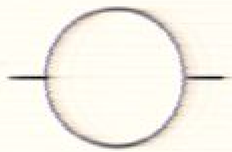
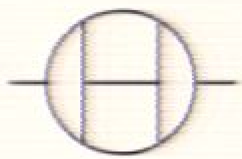
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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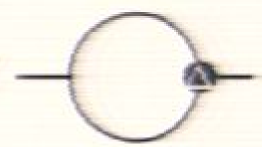
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

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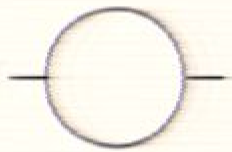
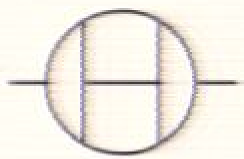
One-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } (XY, YX) \\ \text{Cubic: } (ZZ)\end{matrix}$ $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } 8 \\ \text{Cubic: } 1\end{matrix}$

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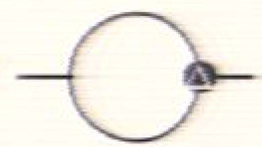
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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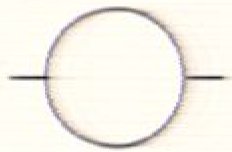
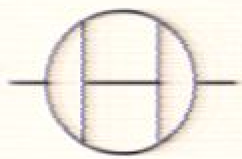
One-loop: Z  $\bar Z$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore \quad \hat h^2 = 2 g_{YM}^2$

Four-loop: Z  $\bar Z$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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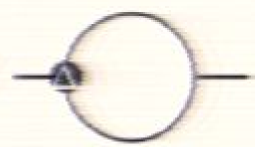
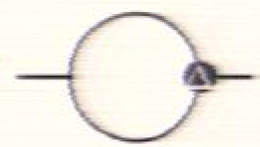
Compensate: $\hat h \to \sqrt{2} g_{YM} + \Delta \hat h \Rightarrow Z$  $\bar Z + Z$ 

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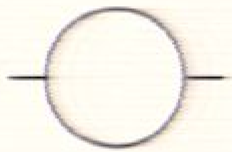
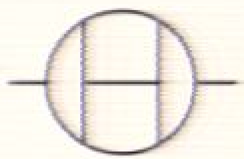
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) / Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 / Cubic: 1

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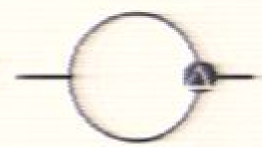
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta \hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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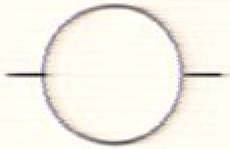
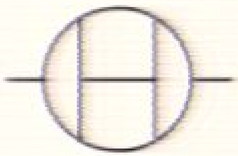
One-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } (XY, YX) \\ \text{Cubic: } (ZZ)\end{matrix}$ $\therefore \quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\begin{matrix}\mathcal{N}=4\text{: } 8 \\ \text{Cubic: } 1\end{matrix}$

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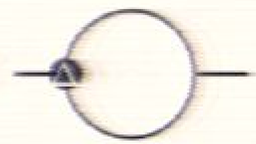
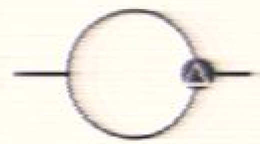
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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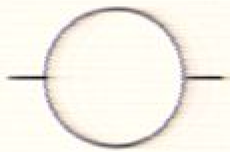
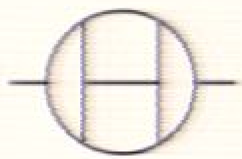
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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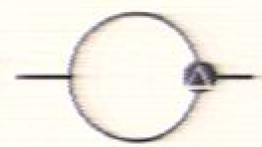
Compensate: $\hat{h} \to \sqrt{2} g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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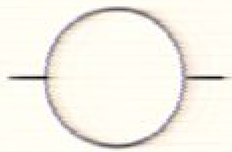
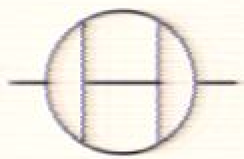
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\quad \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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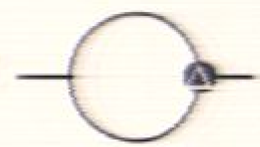
Compensate: $\hat{h} \to \sqrt{2}g_{\mathrm{YM}} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z}$ $+$ Z 

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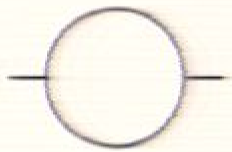
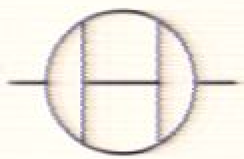
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\mathrm{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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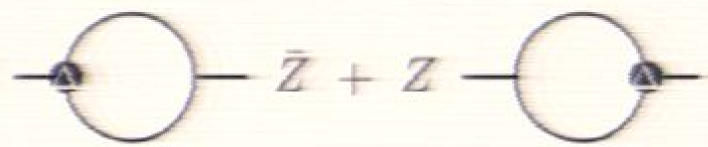
Compensate: $\hat{h} \to \sqrt{2} g_{\mathrm{YM}} + \Delta \hat{h} \Rightarrow$ Z  $\bar{Z}$

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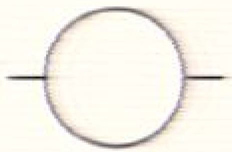
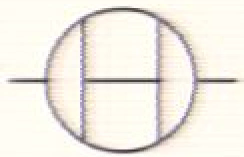
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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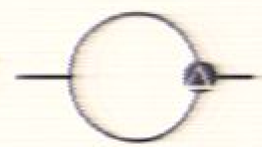
Compensate: $\hat{h} \to \sqrt{2}g_{\rm YM} + \Delta\hat{h}$ $\Rightarrow$ Z  $\bar{Z}$ + Z 

Cancel anom. dim.
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$$\mu\frac{d}{d\mu}\left[\frac{A\,g^2\,\delta\hat{h}}{g_{\rm YM}\,\epsilon}\left(\frac{\mu^2}{p^2}\right)^{\epsilon} + \frac{B\,g^8}{\epsilon}\left(\frac{\mu^2}{p^2}\right)^{4\epsilon}\right] = 0 \Rightarrow \delta\hat{h} = -4\,g_{\rm YM}\,g^6\,\frac{B}{A}$$

Counterterm to cancel the divergence: $\frac{3B\,g^8}{\epsilon}$

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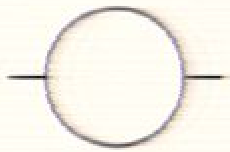
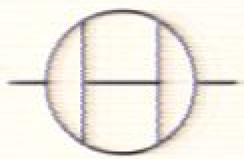
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\quad \hat{h}^2 = 2g_{YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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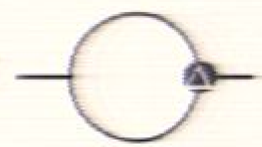
Compensate: $\hat{h} \to \sqrt{2}g_{YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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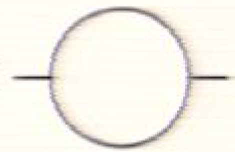
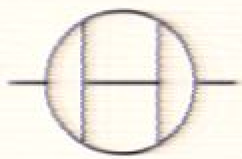
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX), Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8, Cubic: 1

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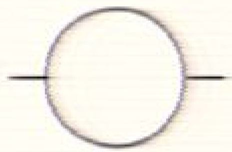
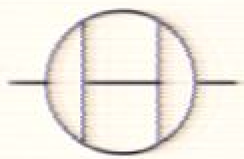
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore \quad \hat{h}^2 = 2g_{\text{YM}}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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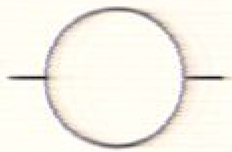
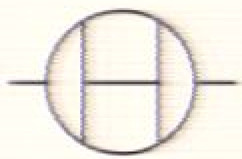
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \ \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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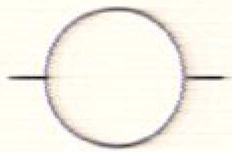
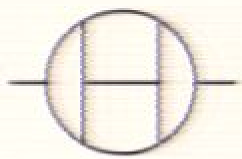
One-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: (XY, YX) Cubic: (ZZ) $\therefore\ \hat{h}^2 = 2g_{\rm YM}^2$

Four-loop: Z  $\bar{Z}$ Flavor choices $\mathcal{N}=4$: 8 Cubic: 1

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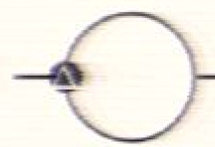
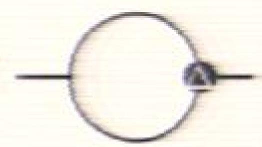
Compensate: $\hat{h} \to \sqrt{2} g_{\rm YM} + \Delta\hat{h} \Rightarrow Z$  $\bar{Z} + Z$ 

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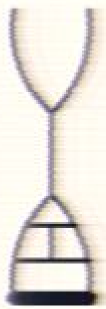

Flavor choices

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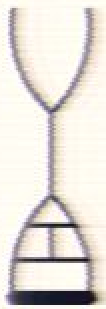

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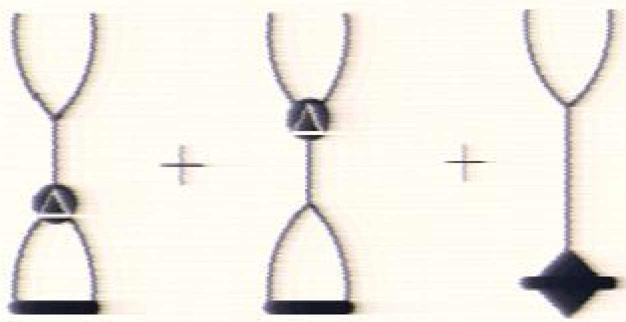

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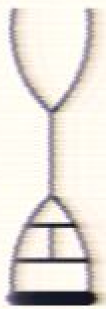

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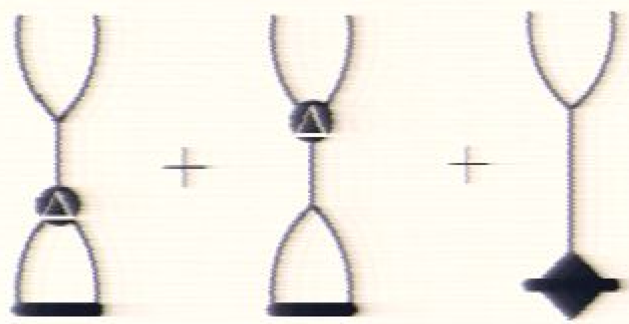
Corrections: 

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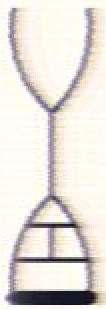

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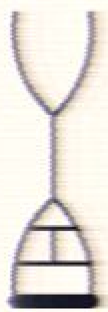

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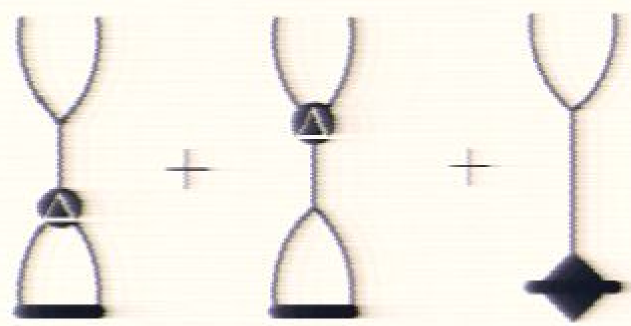

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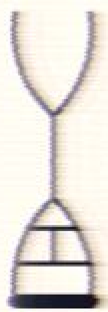

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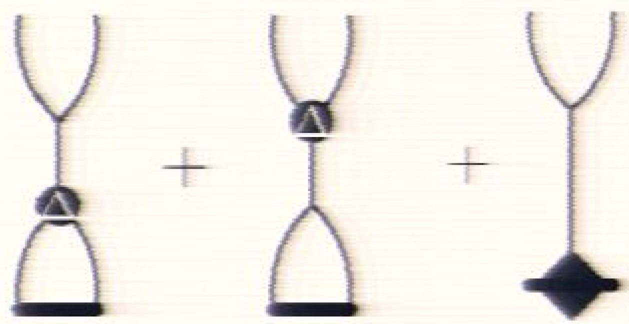

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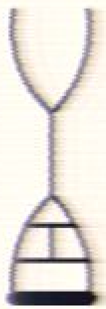

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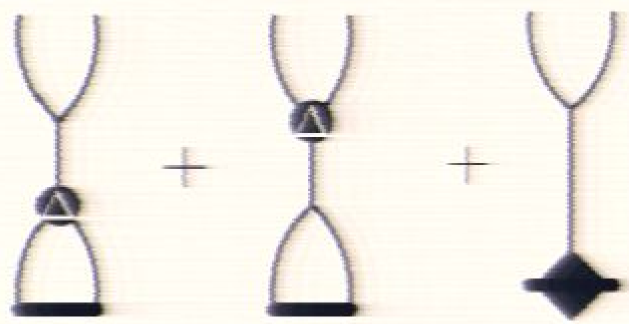

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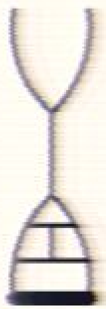

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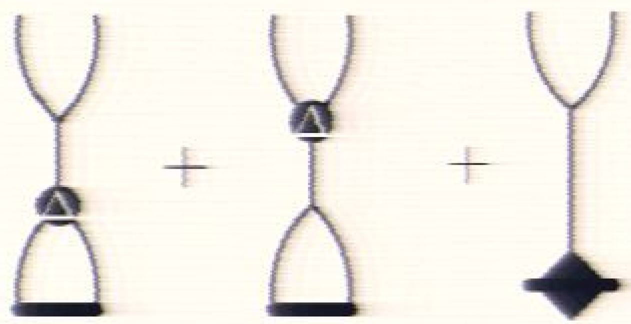
Corrections: 

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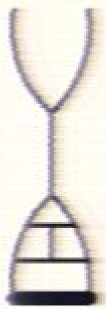

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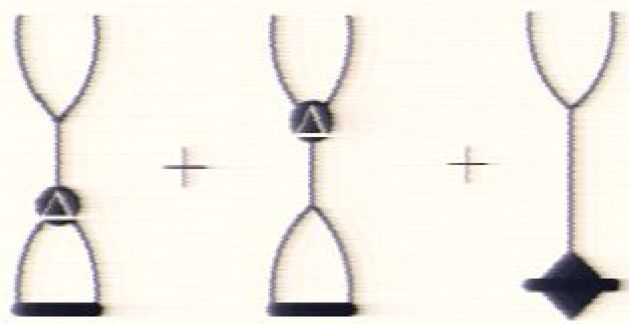
Corrections: 

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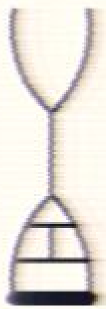

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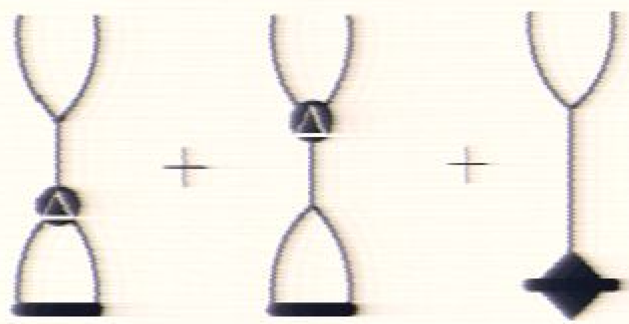

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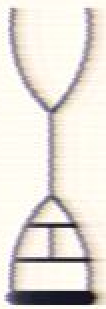

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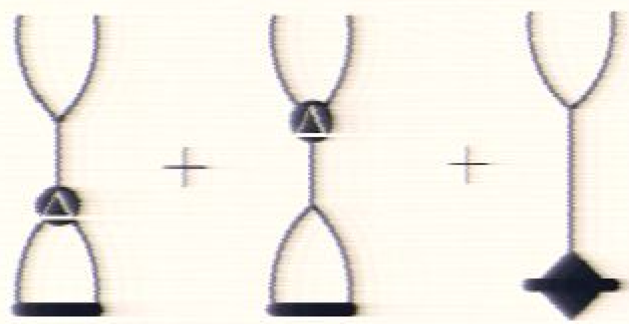

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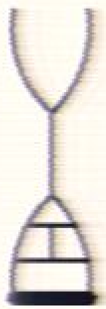

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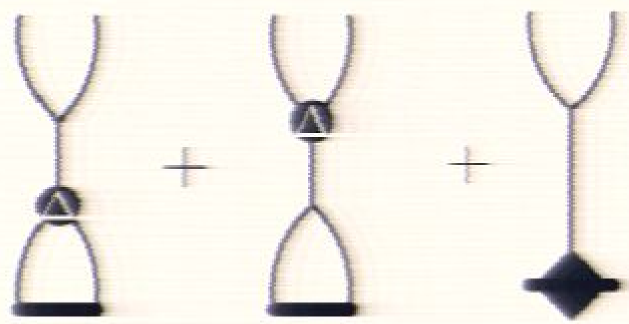
Corrections: 

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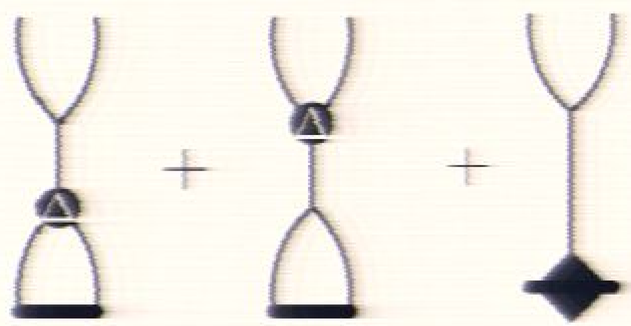
Corrections:  Same as 4-loop prop

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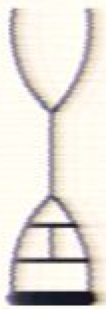

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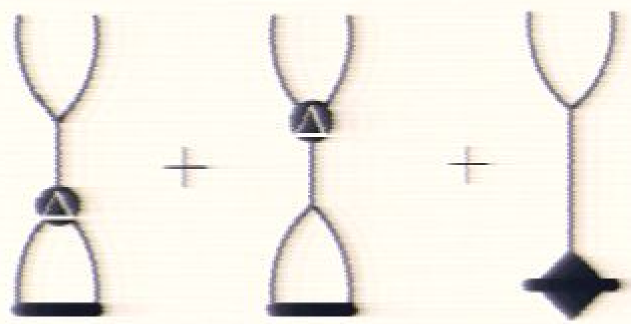

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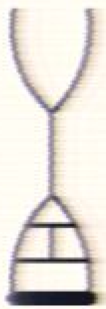

Flavor choices

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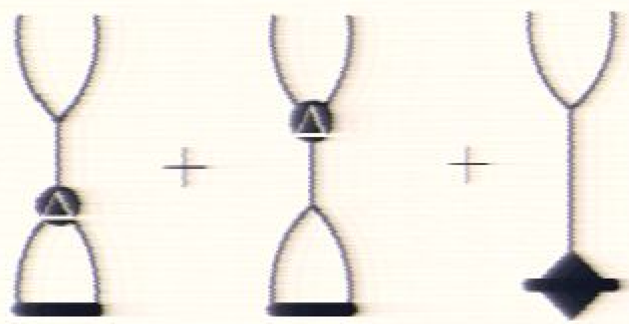
Cubic: 1

Same as 4-loop prop

Corrections:



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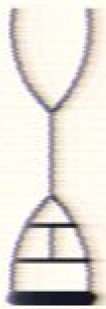

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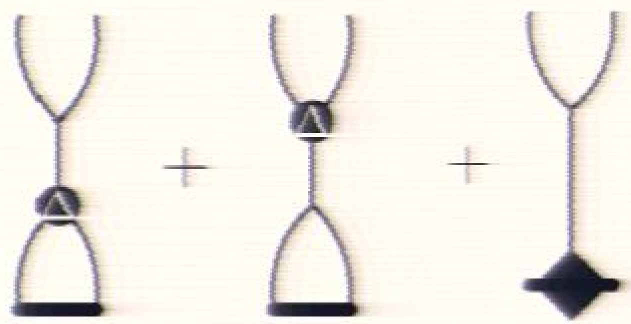
Corrections: 

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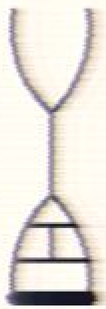

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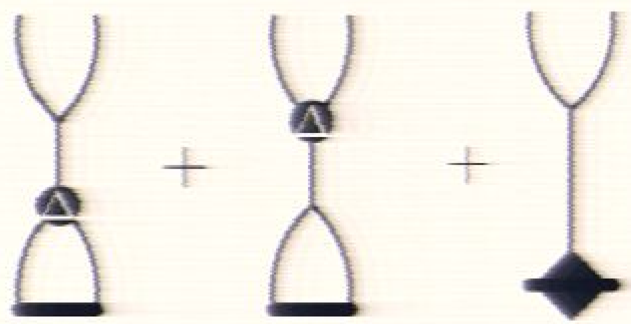
Corrections:  Same as 4-loop prop

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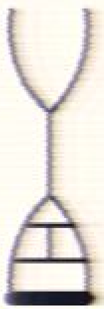

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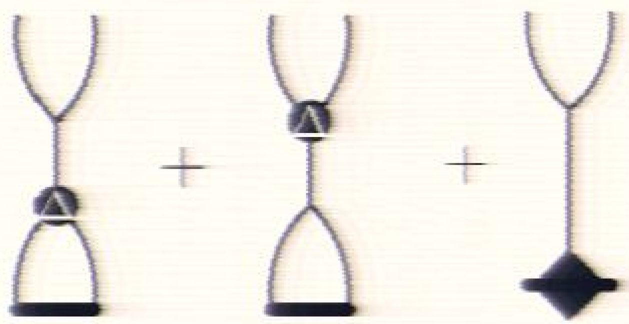

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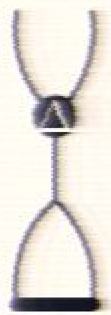
Corrections:  +  +  Same as 4-loop prop

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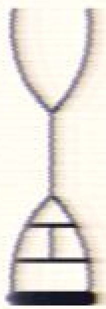

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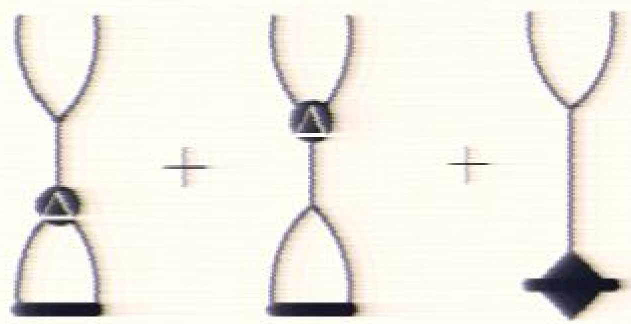
Corrections: 

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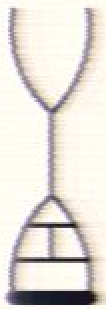

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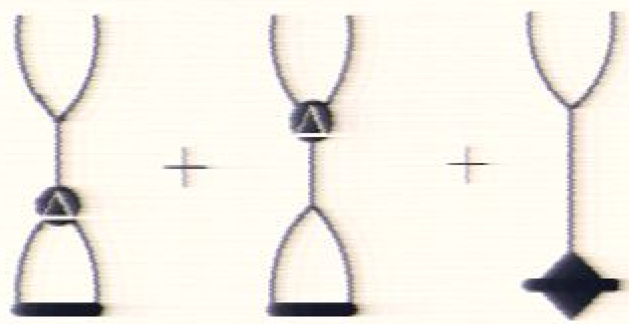

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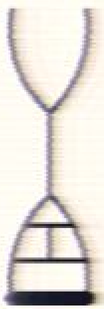

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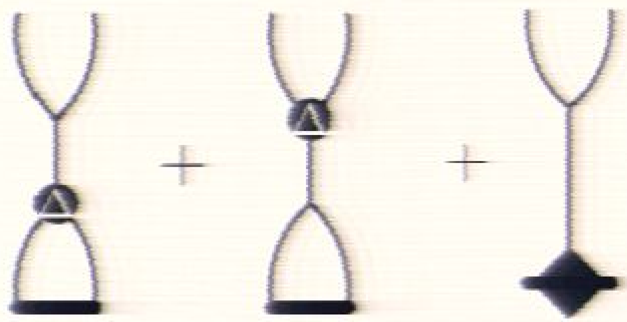

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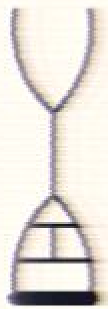

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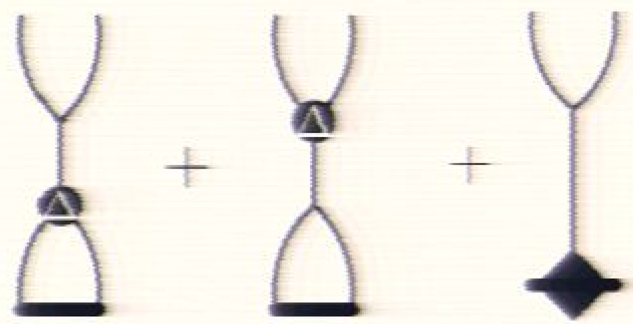
Corrections:  Same as 4-loop prop

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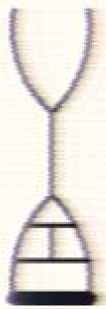

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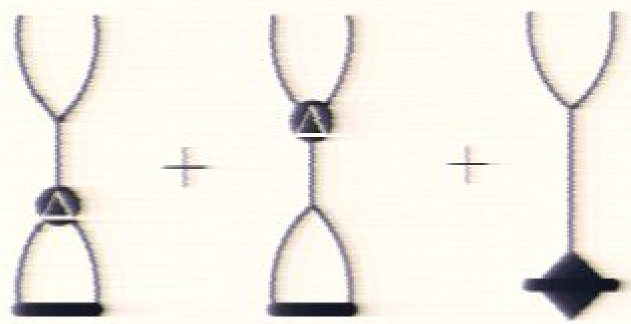

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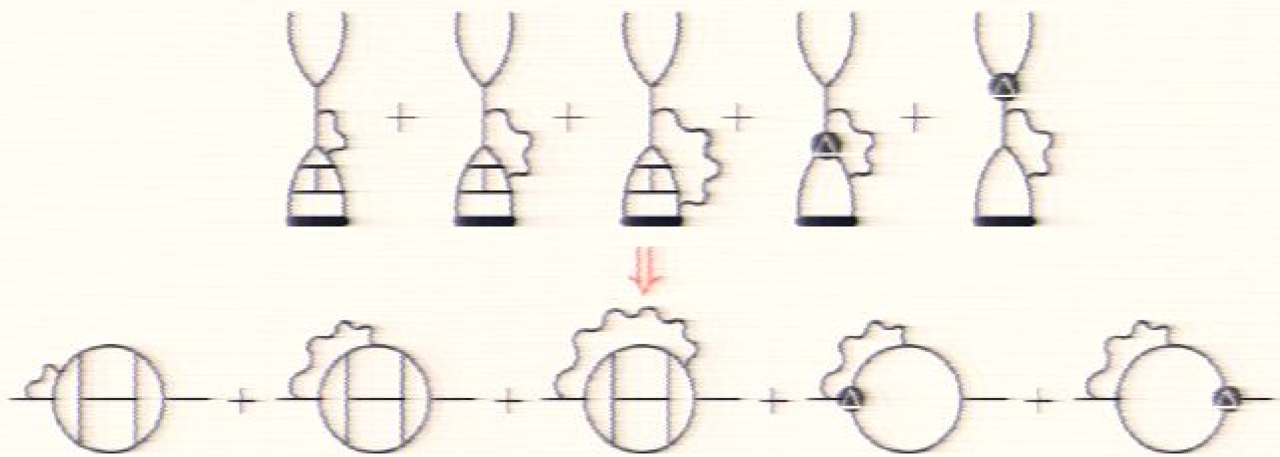

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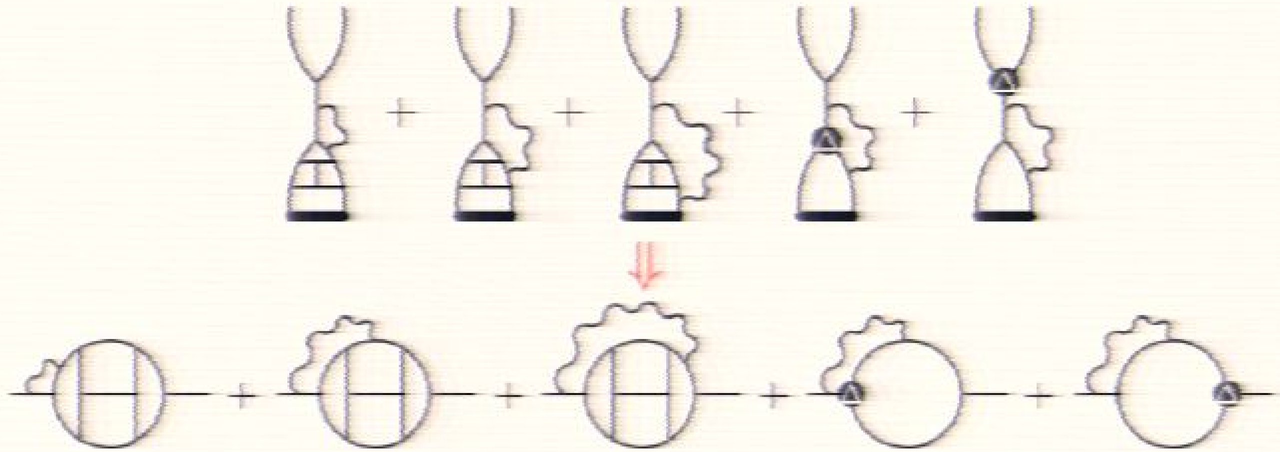

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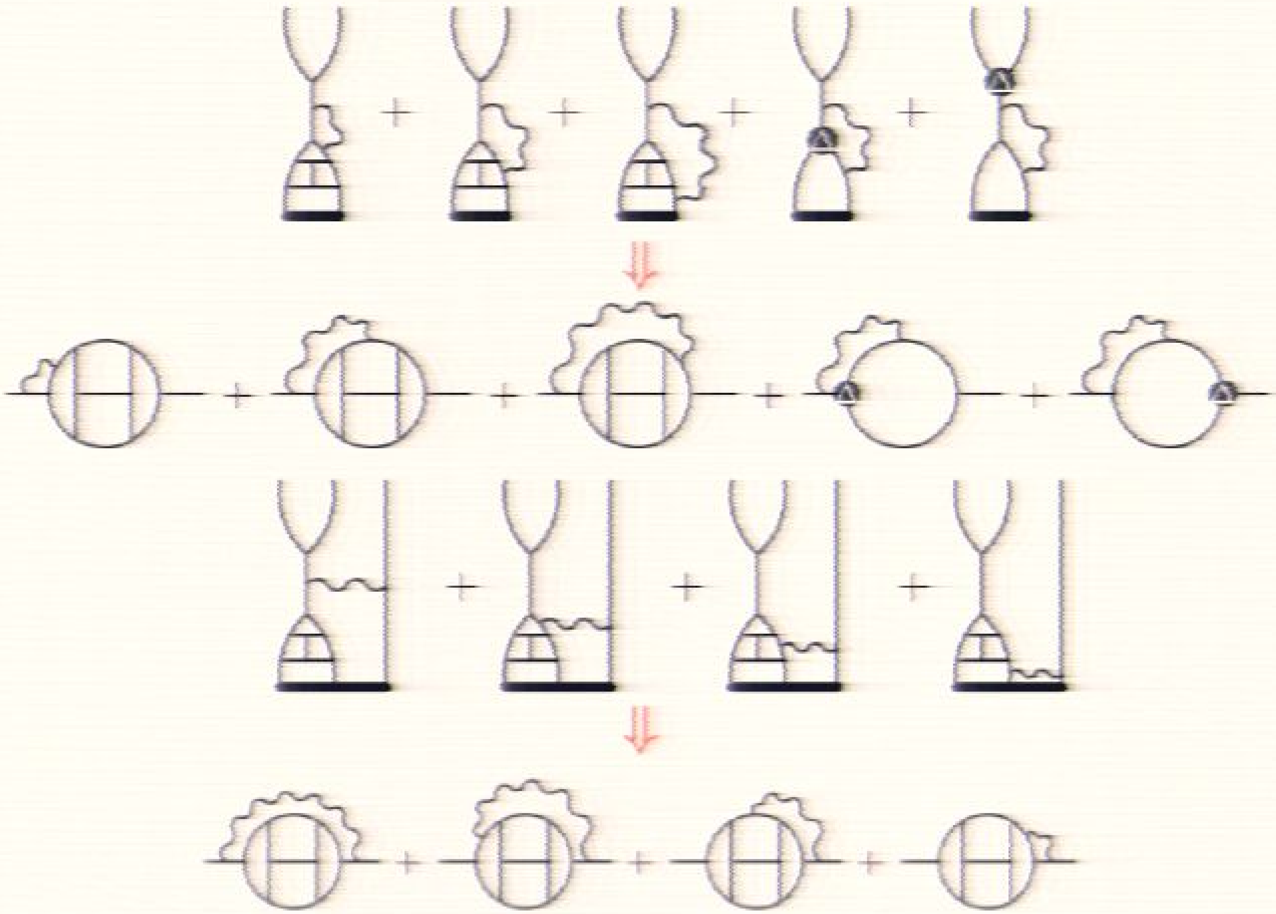

Canceling 5-loop divs. in props ⇒ Cancels 5-loop div. in ops.

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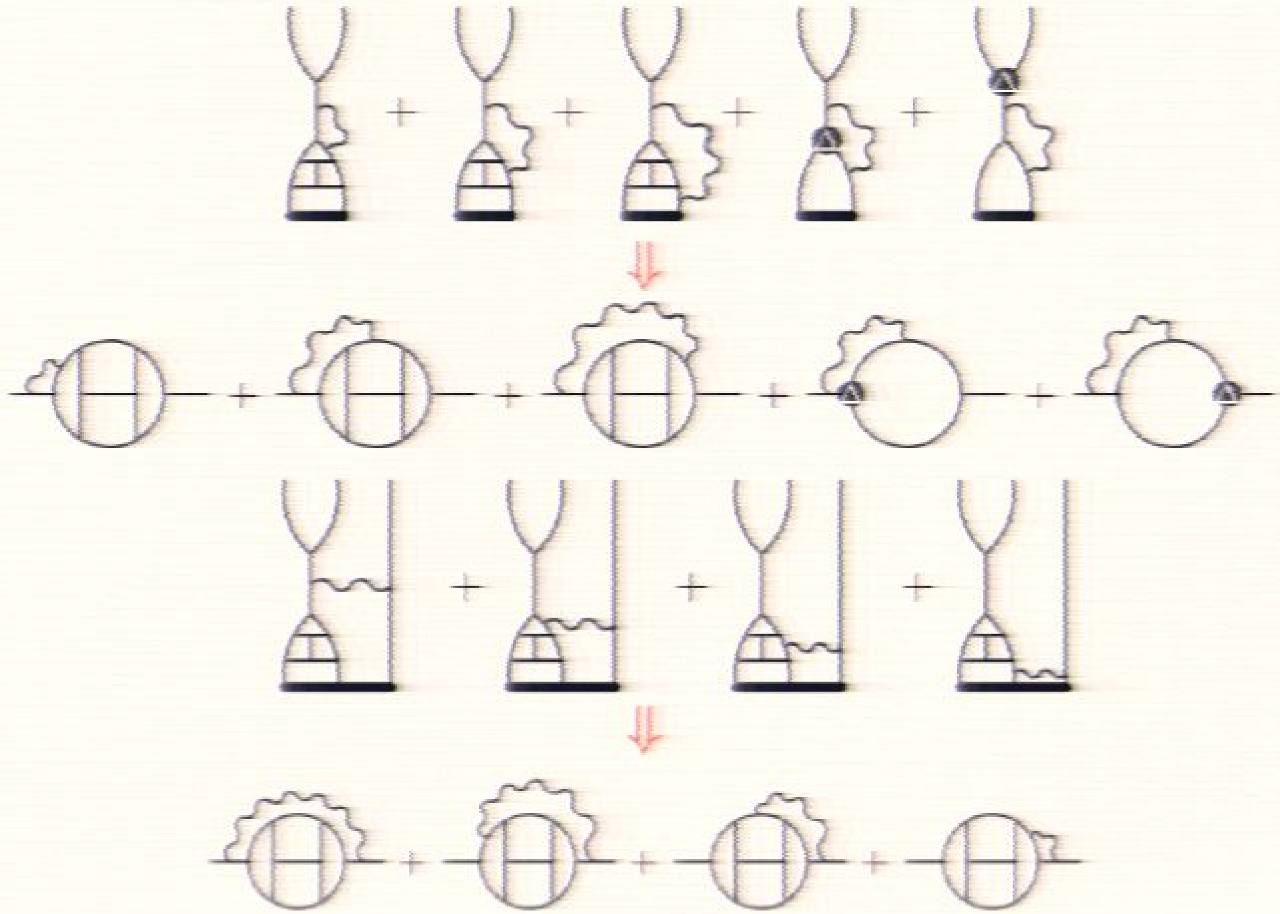

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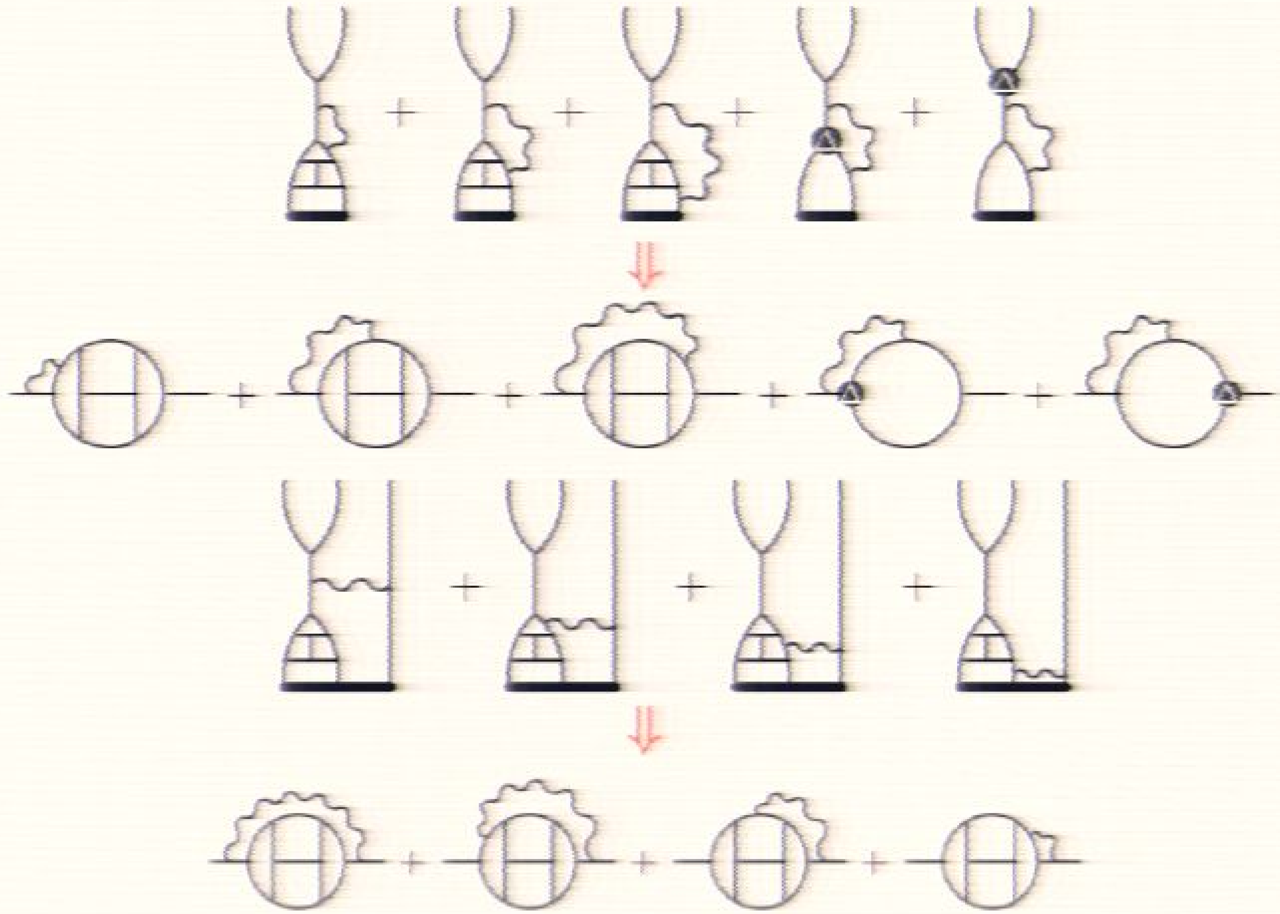

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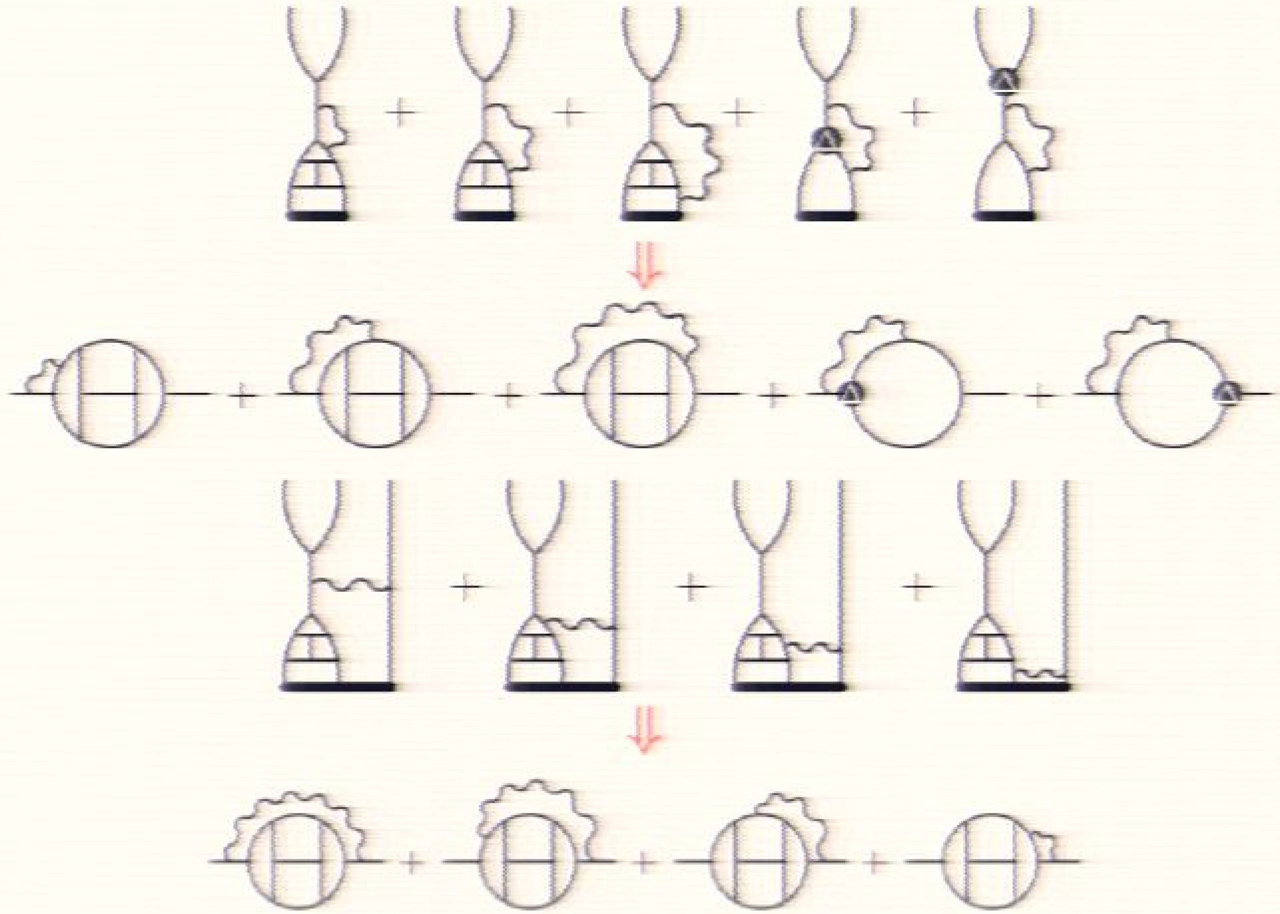

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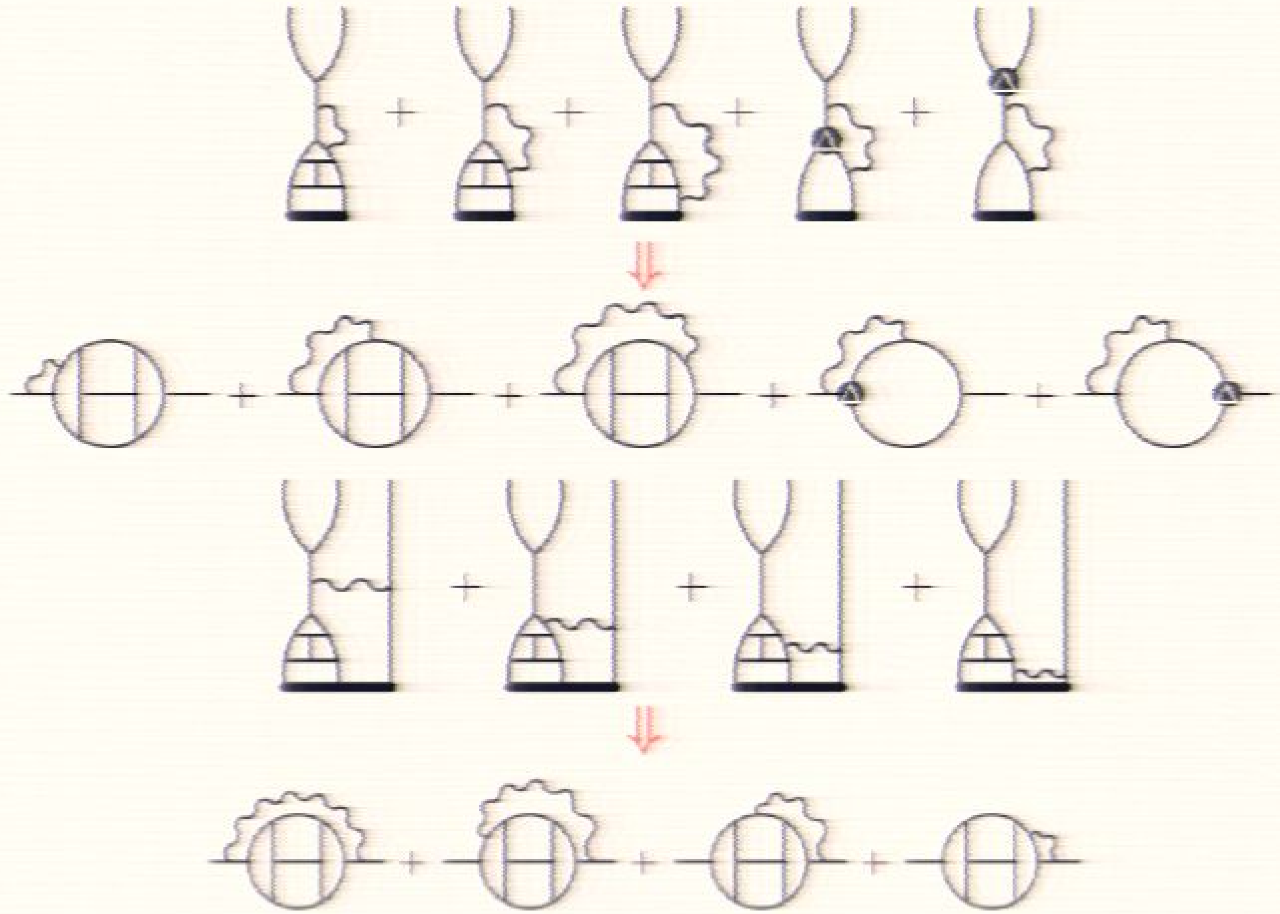

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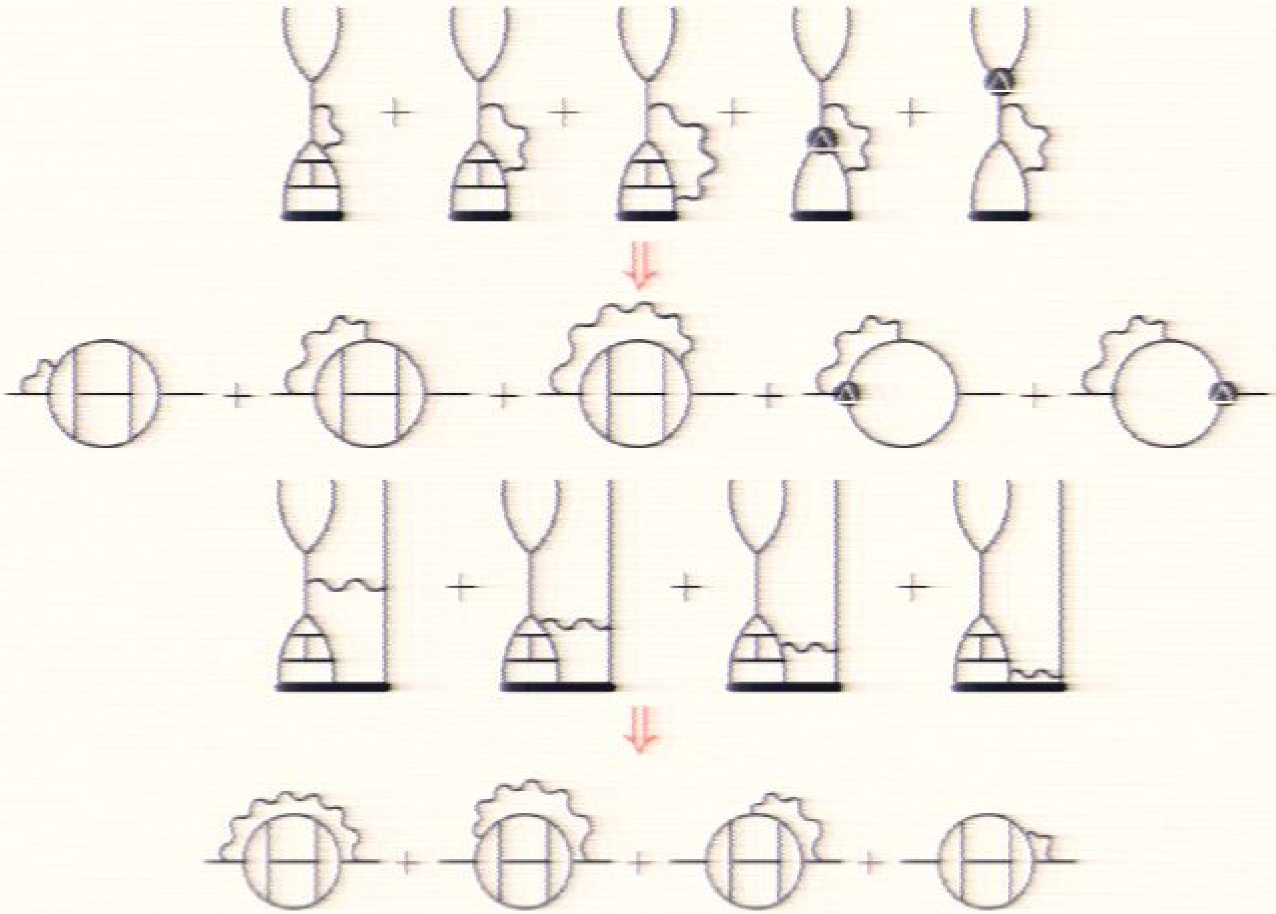

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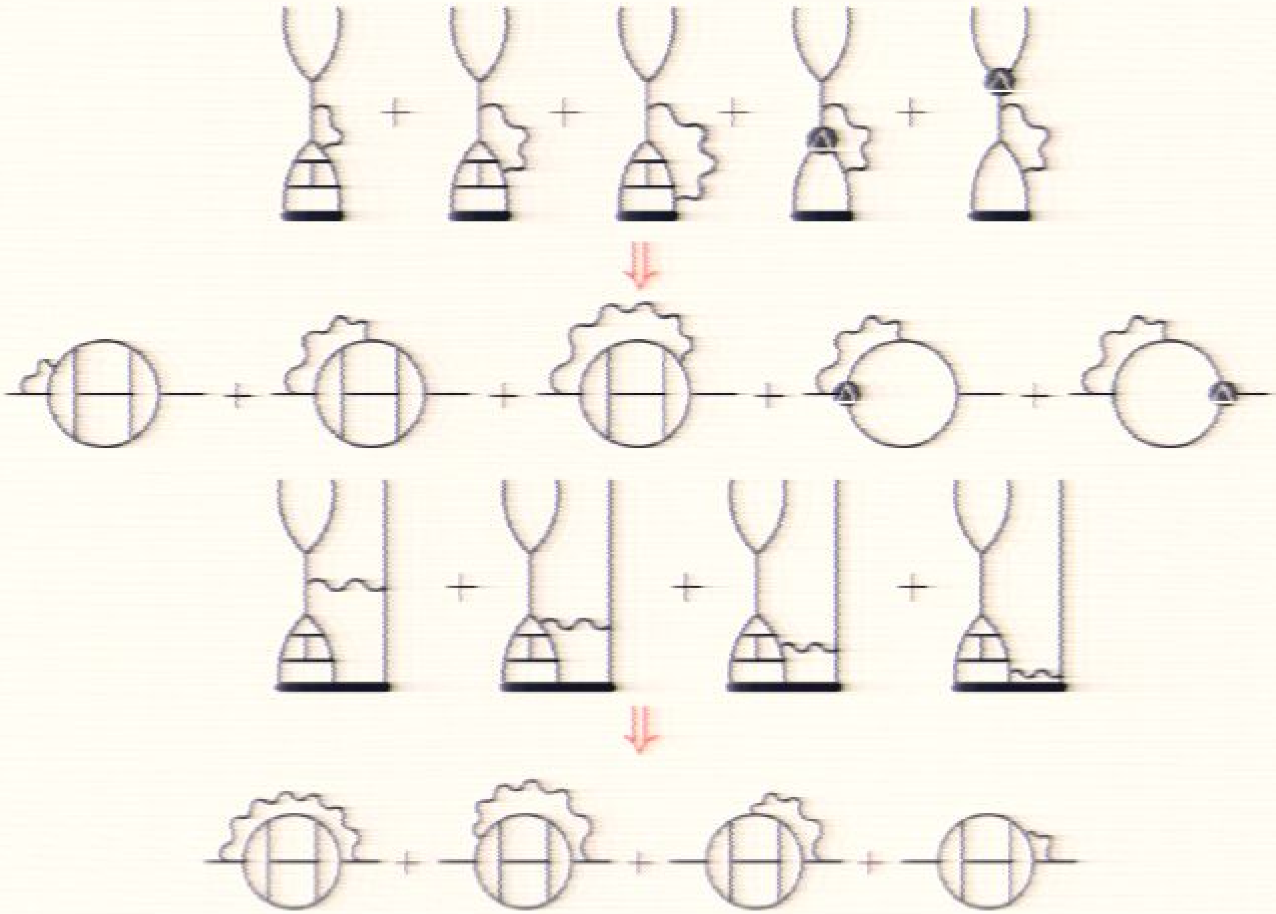

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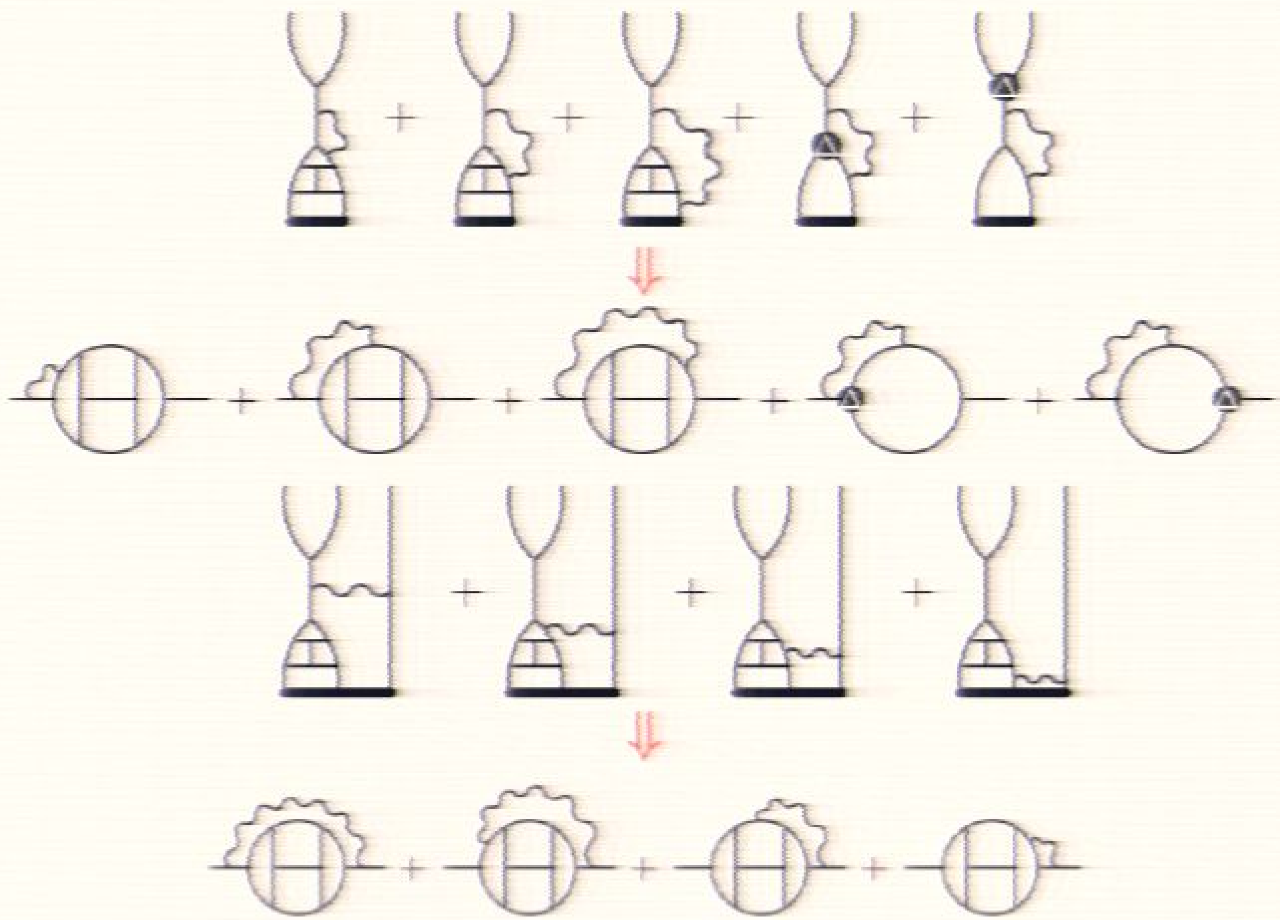

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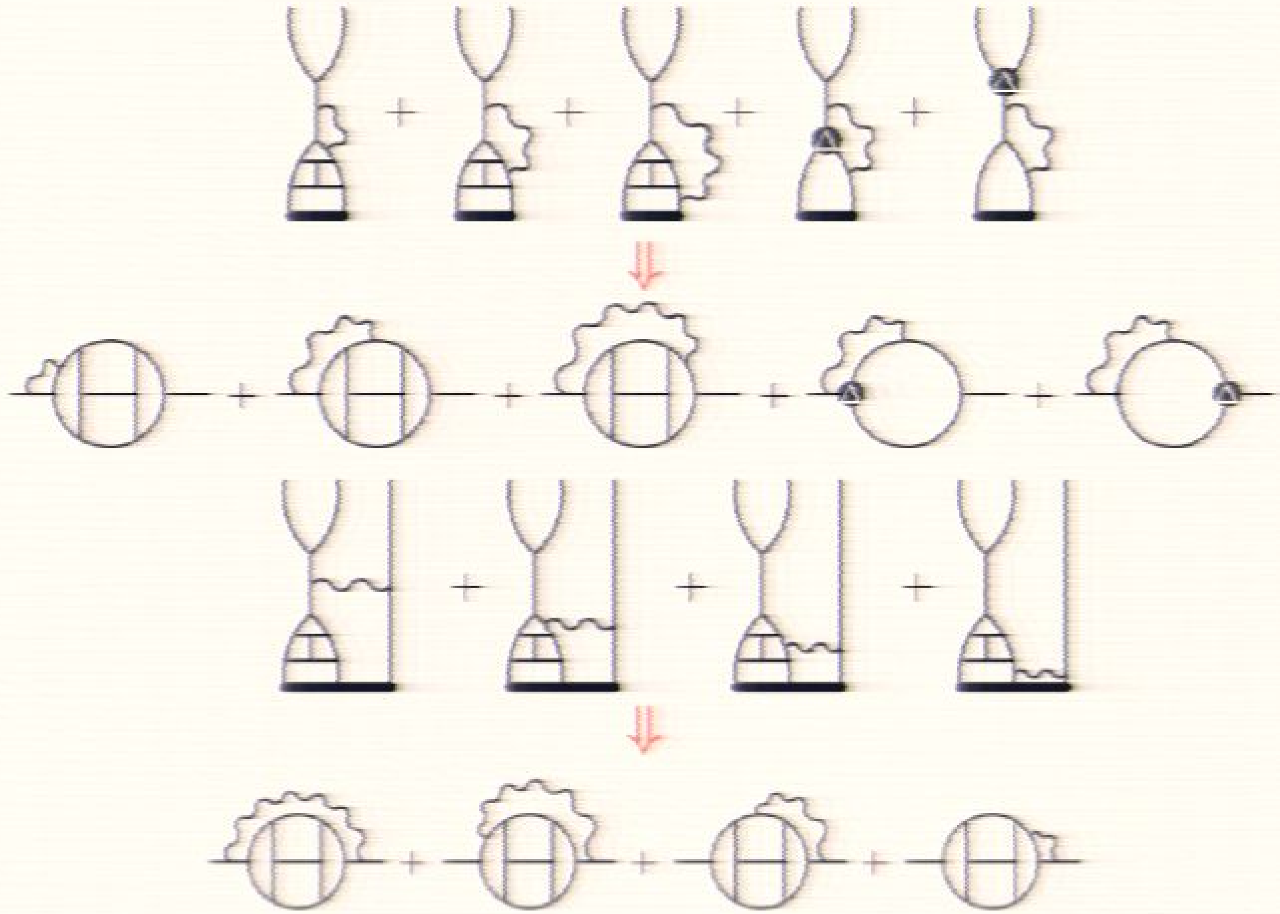

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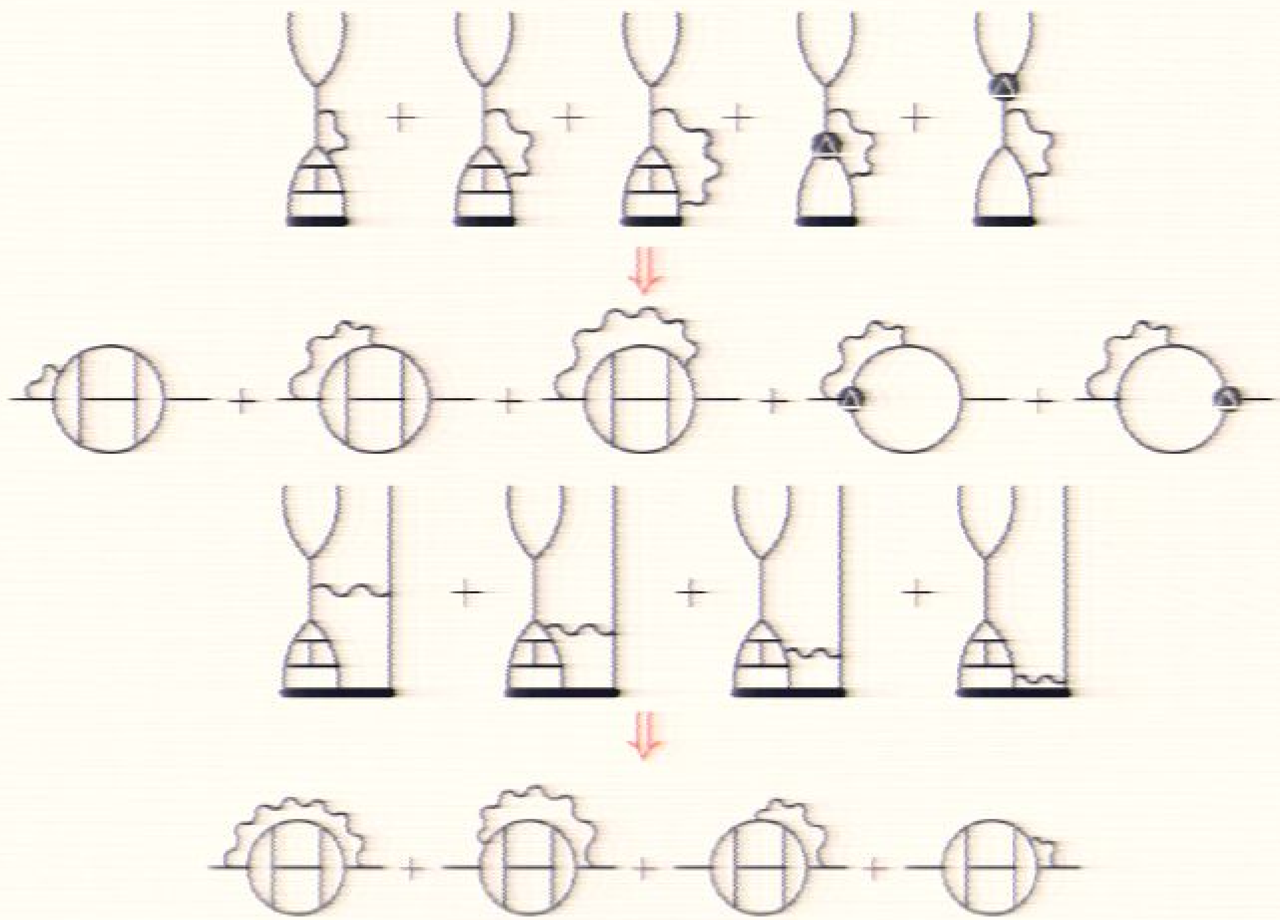

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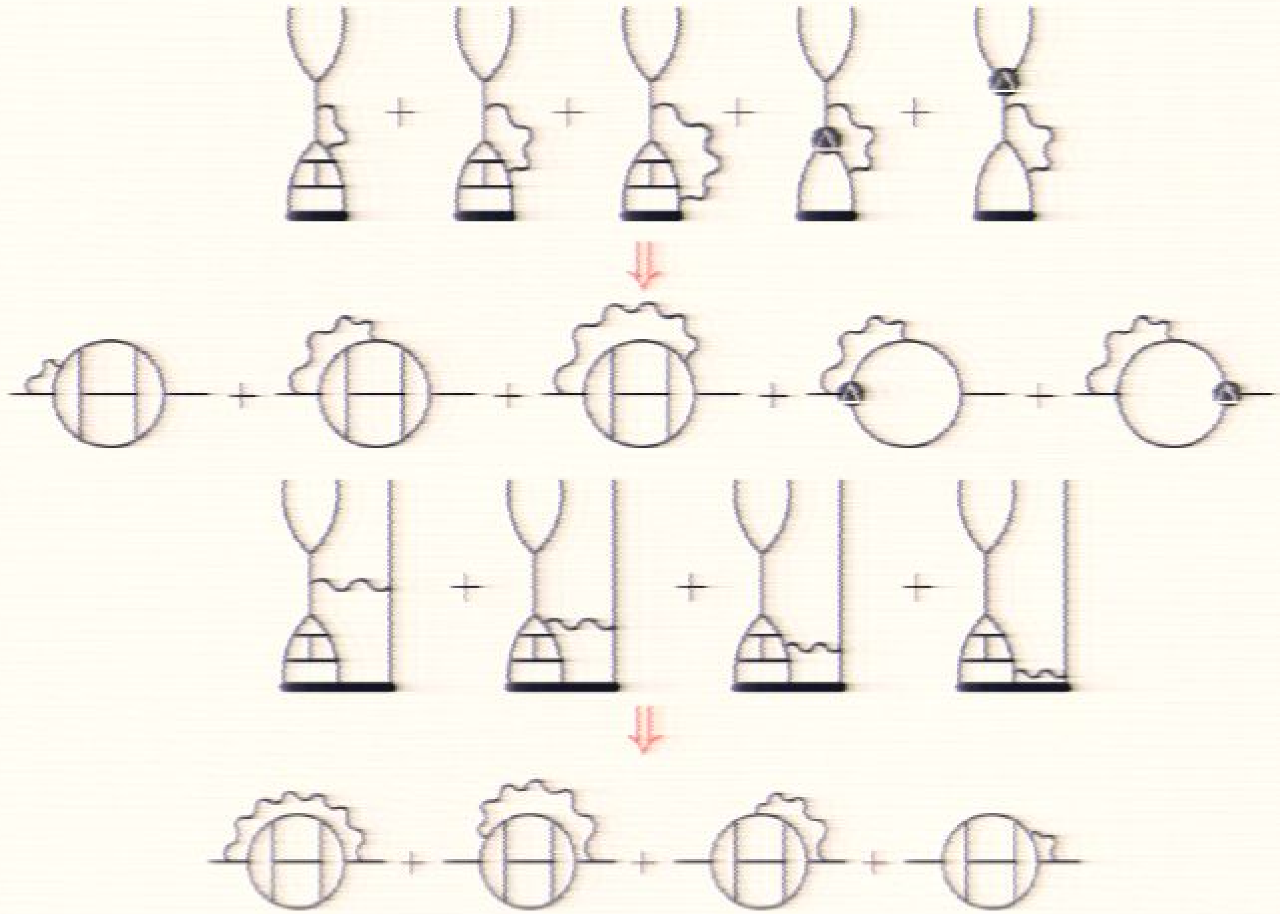

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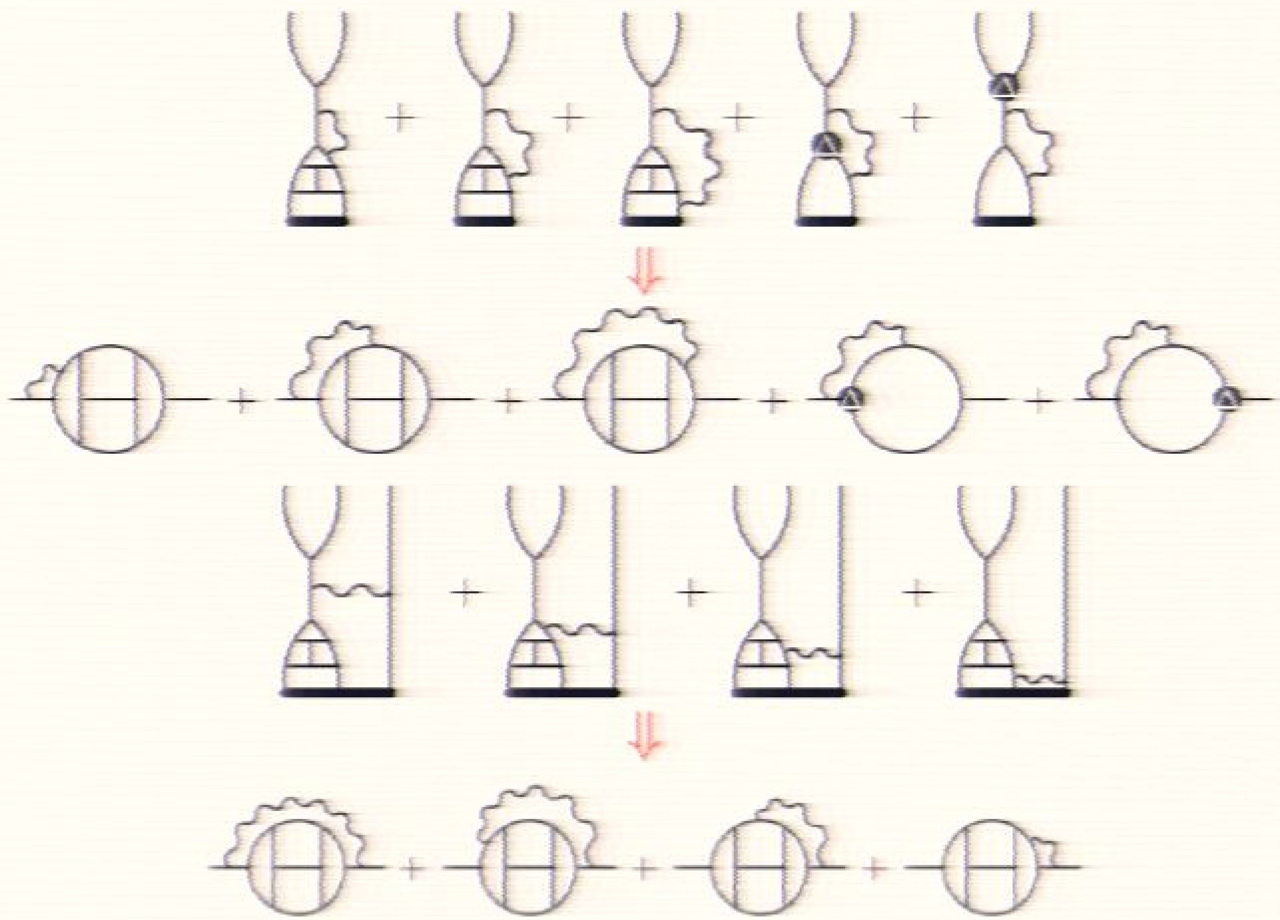

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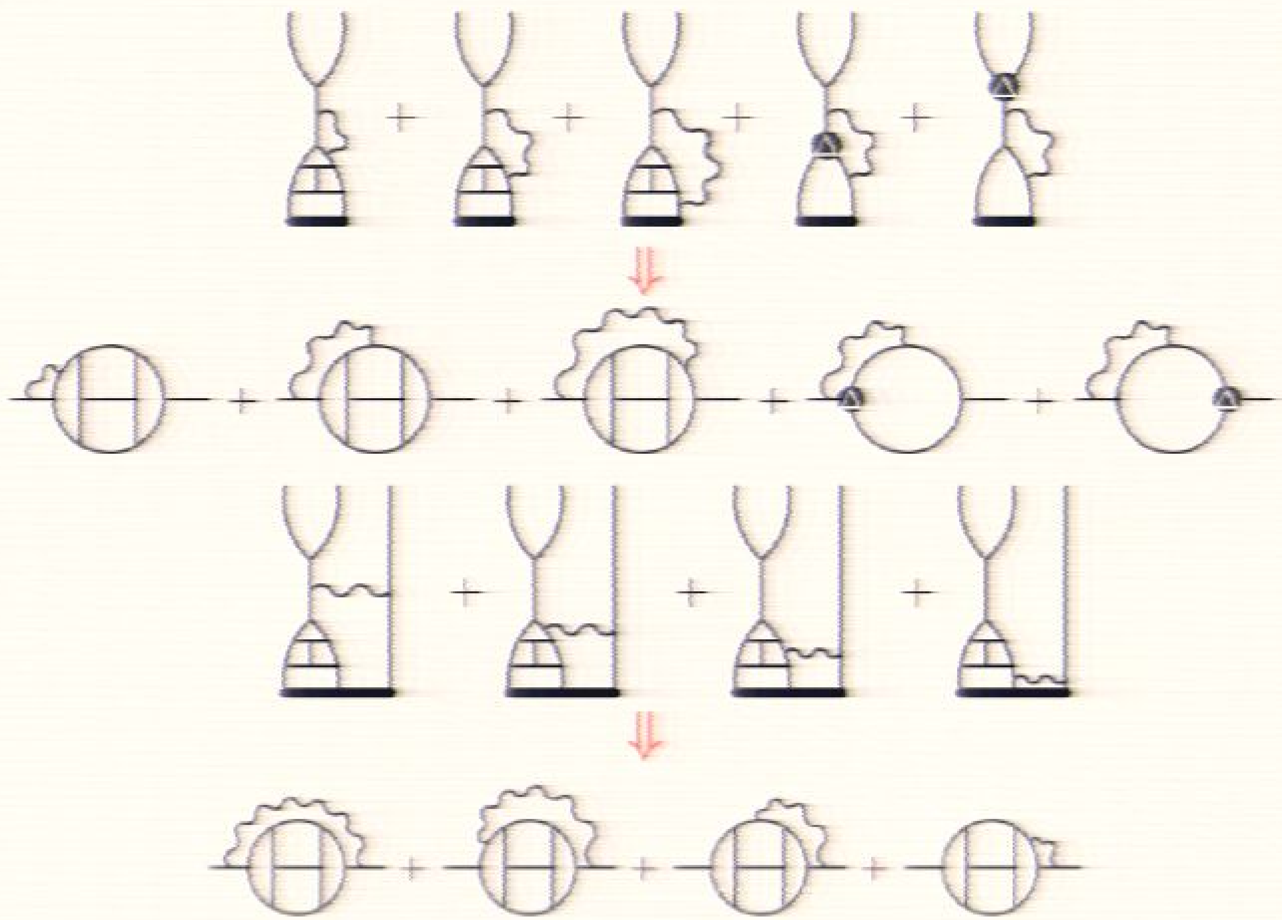

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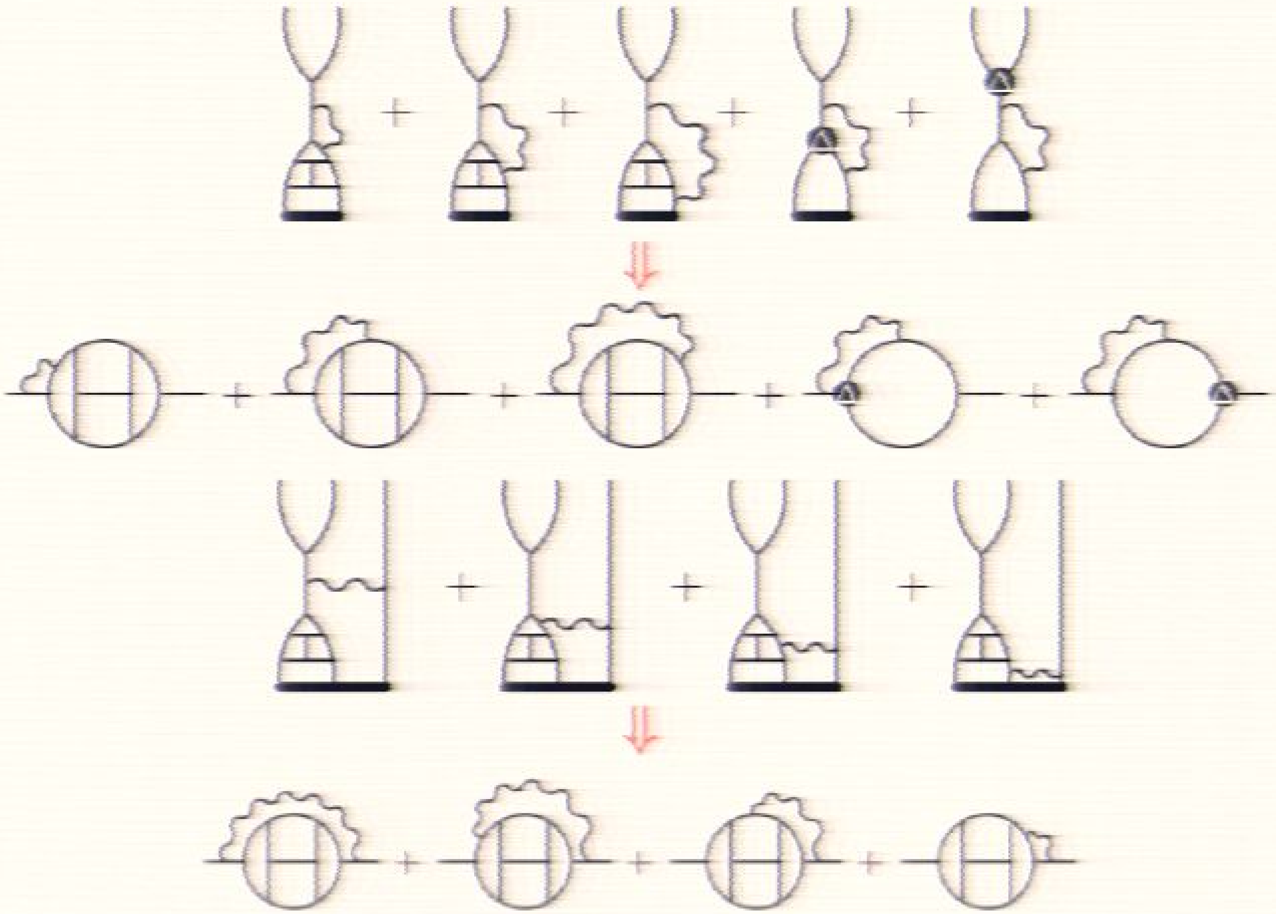

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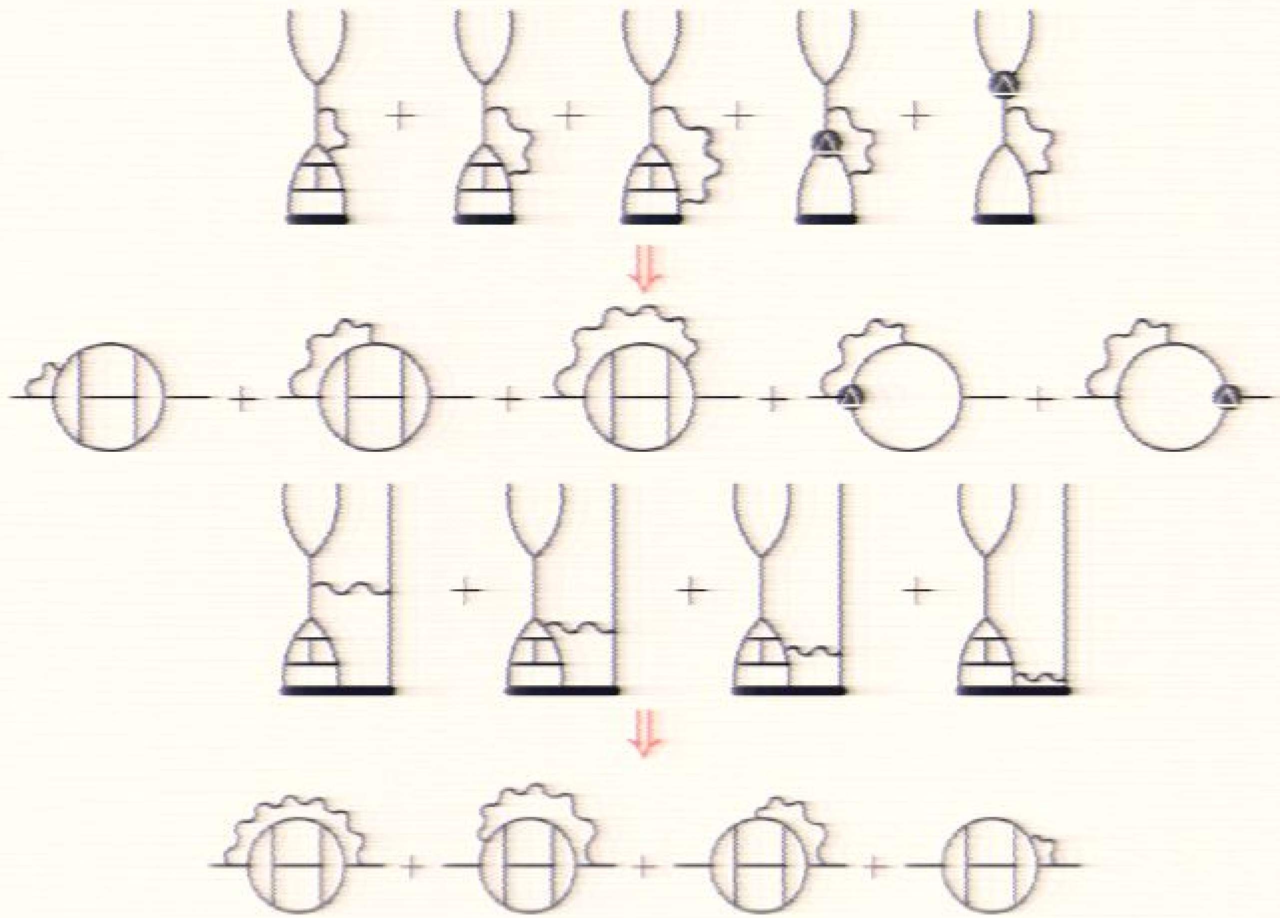

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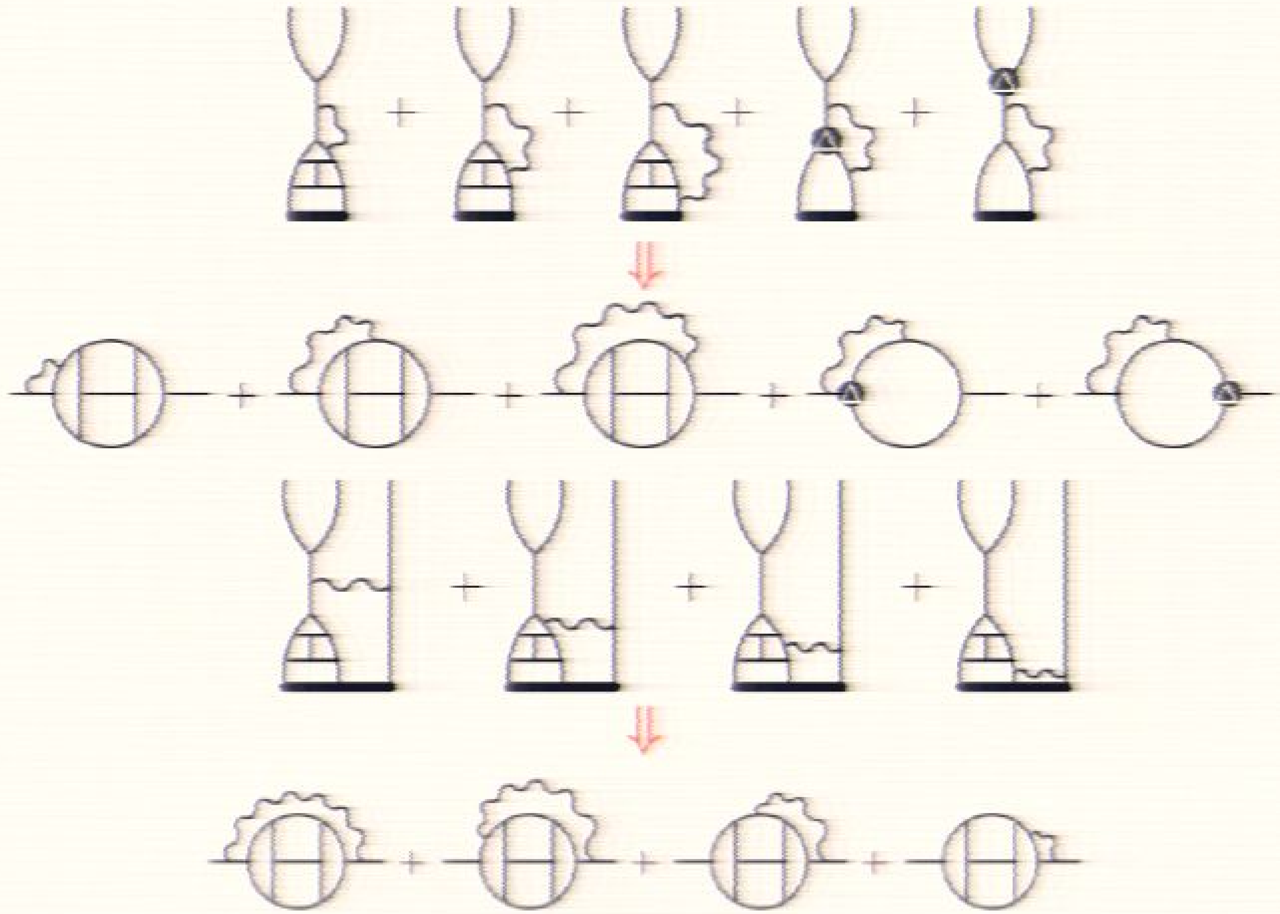

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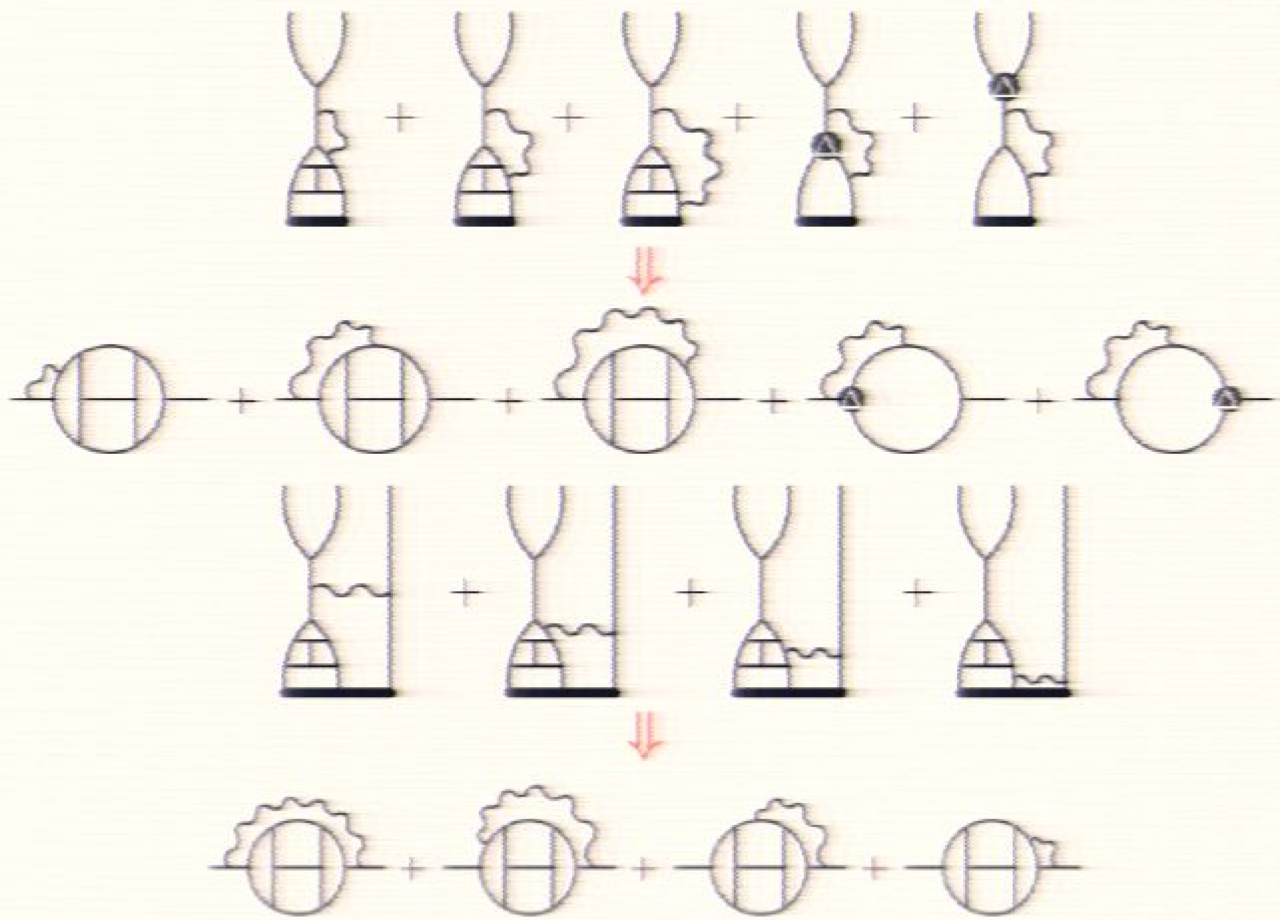

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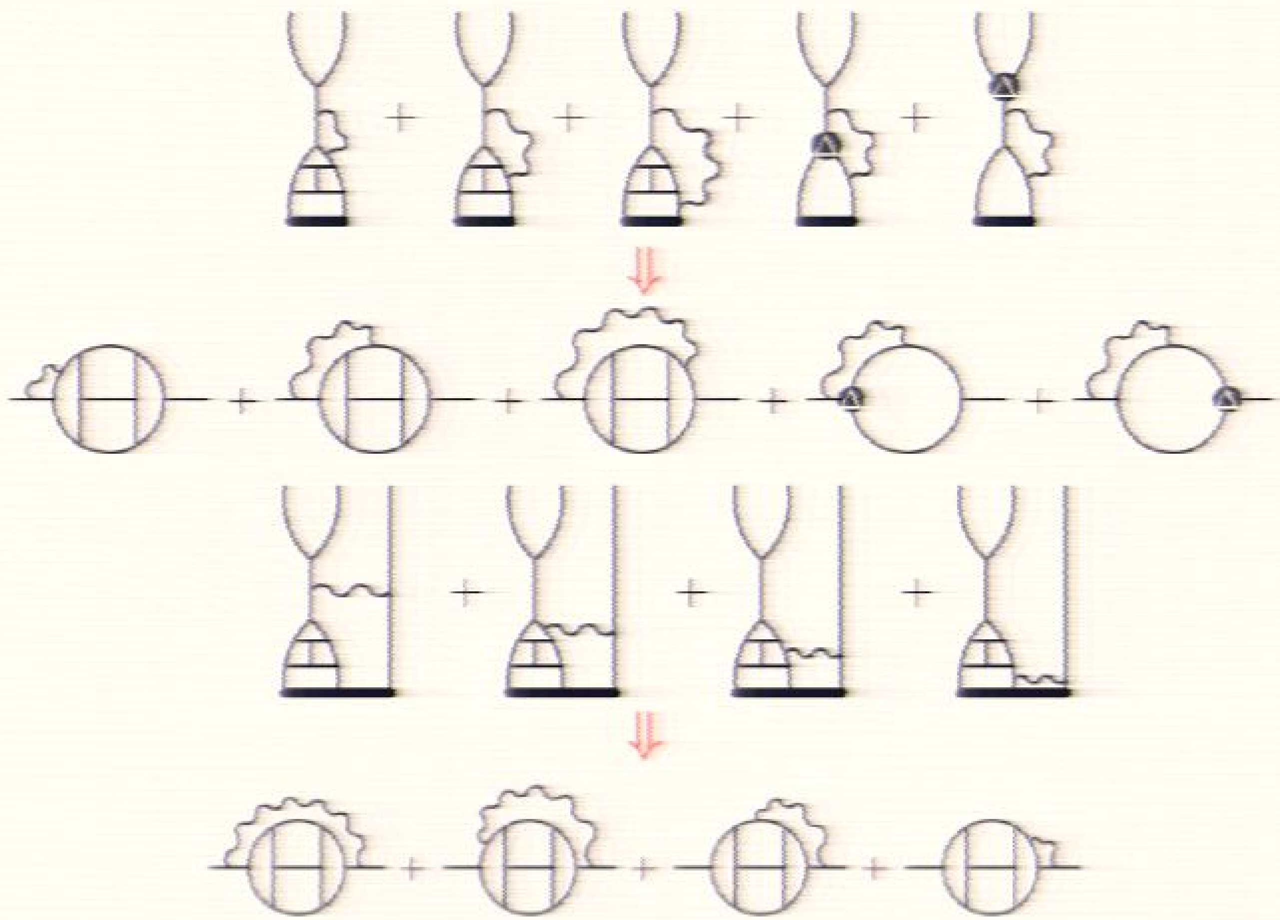

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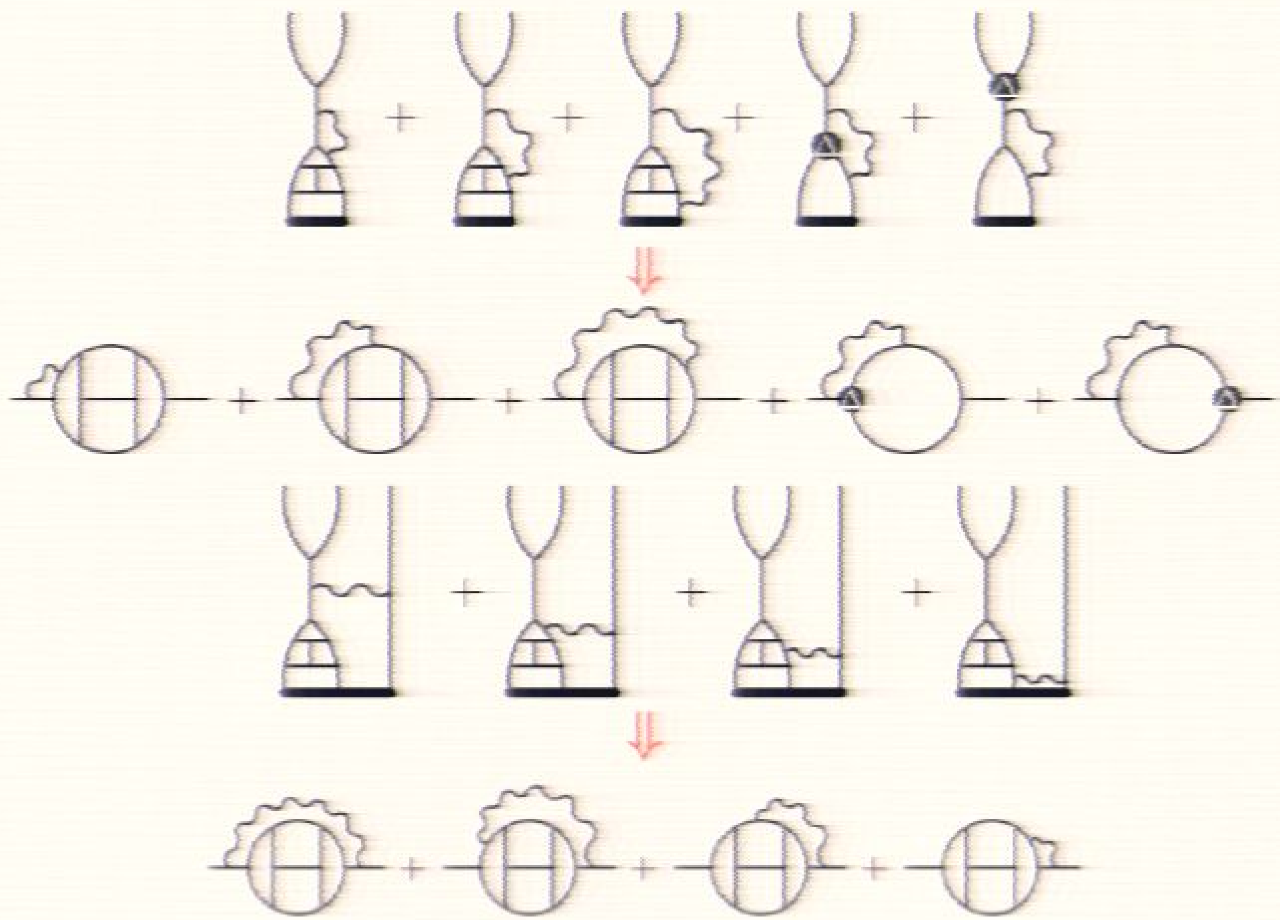

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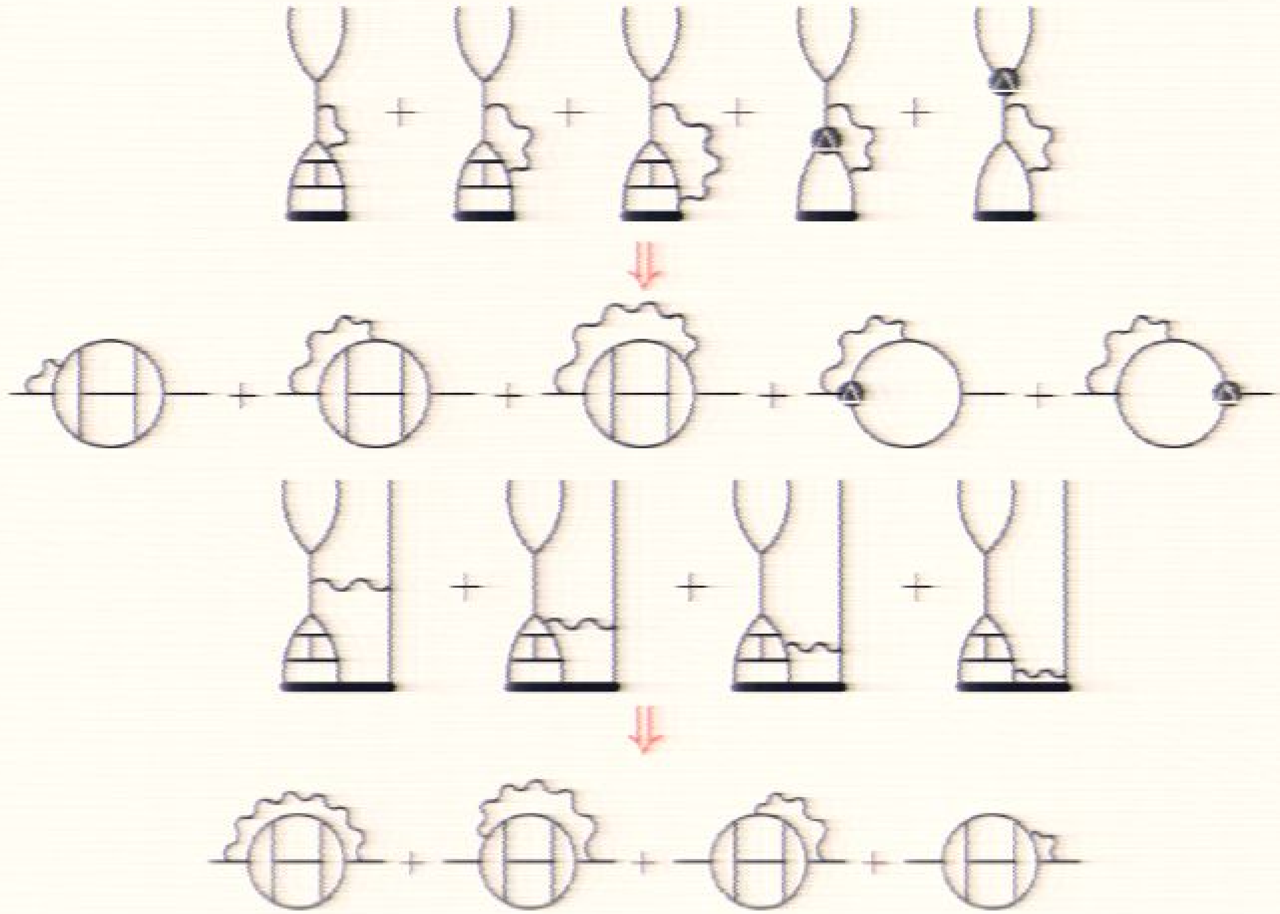

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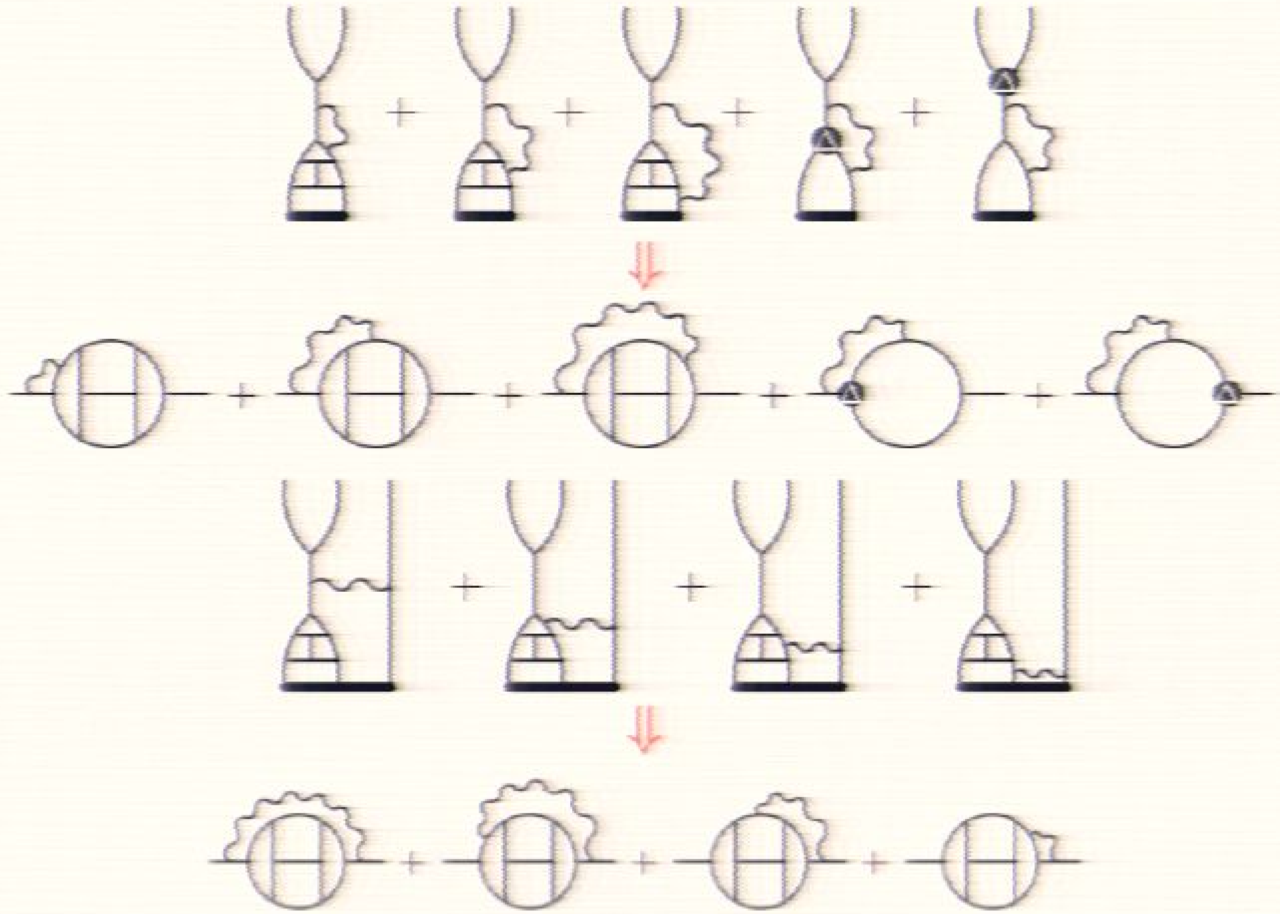

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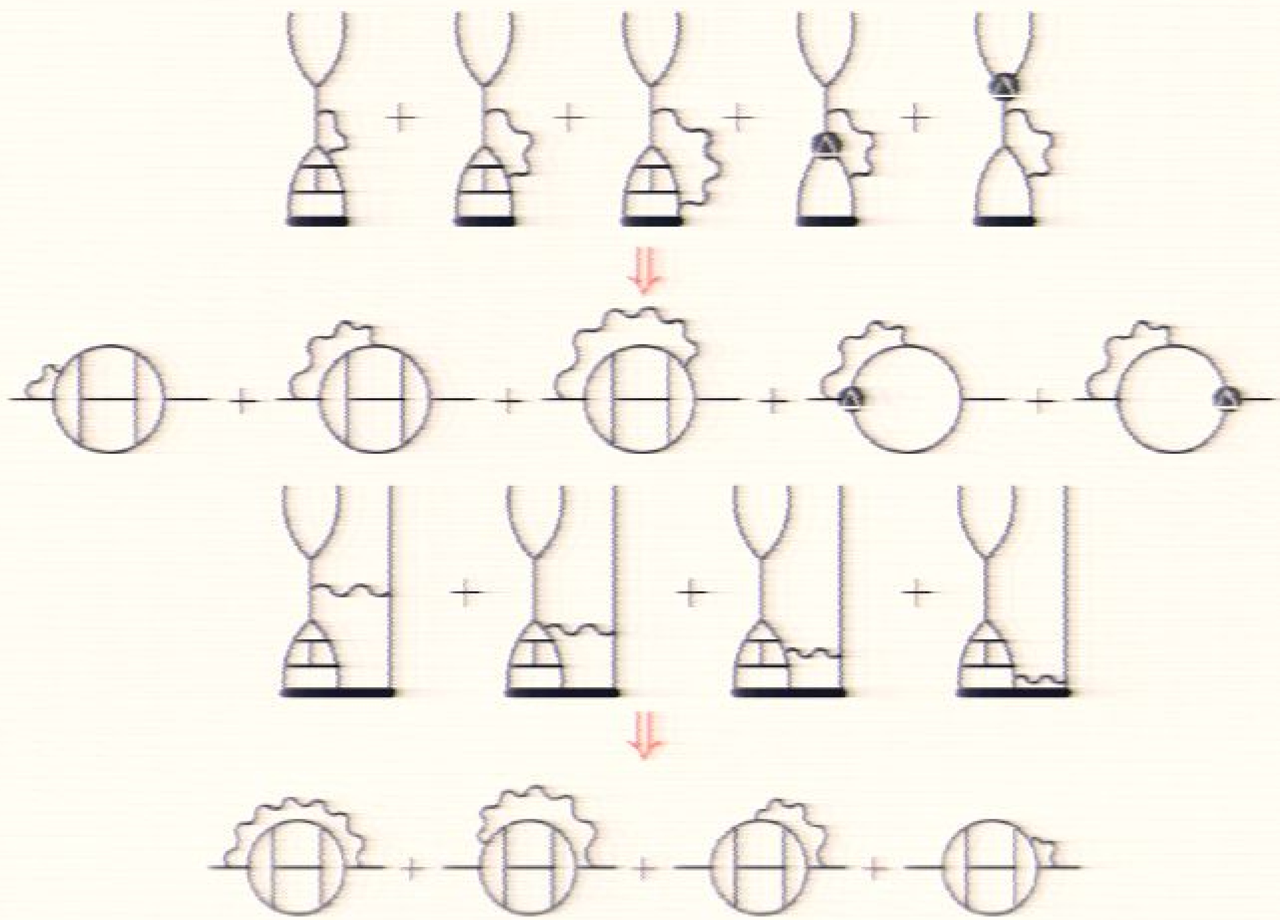

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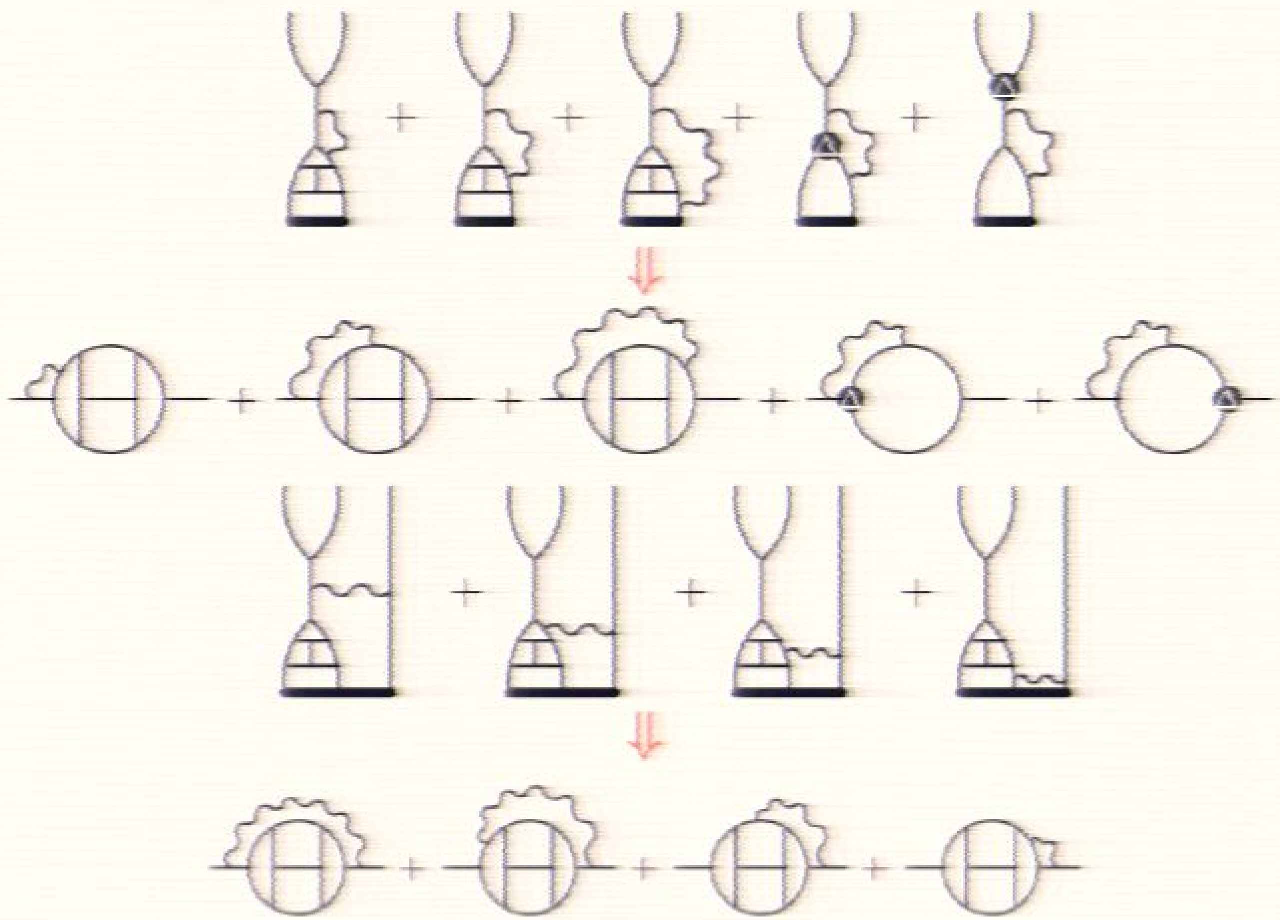

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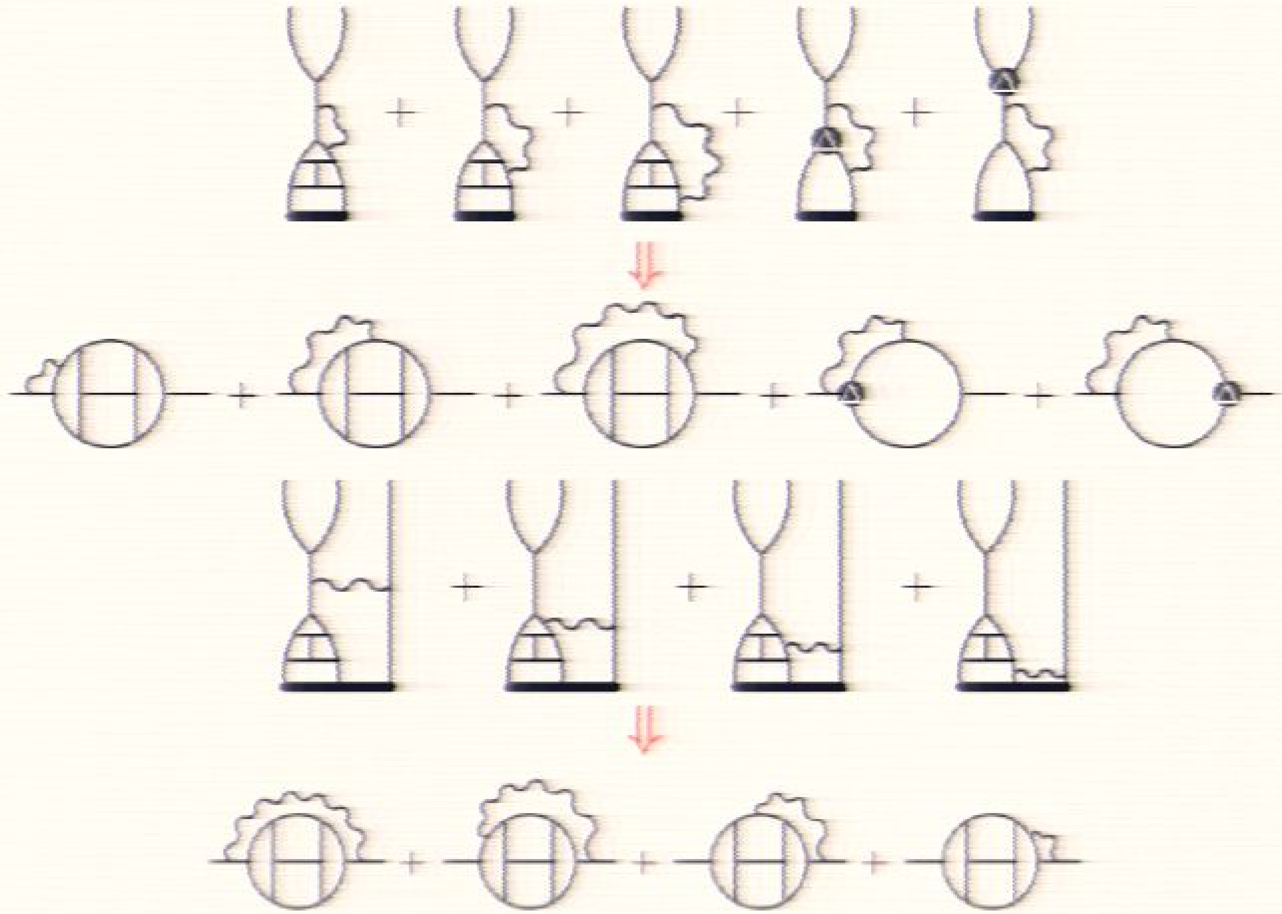

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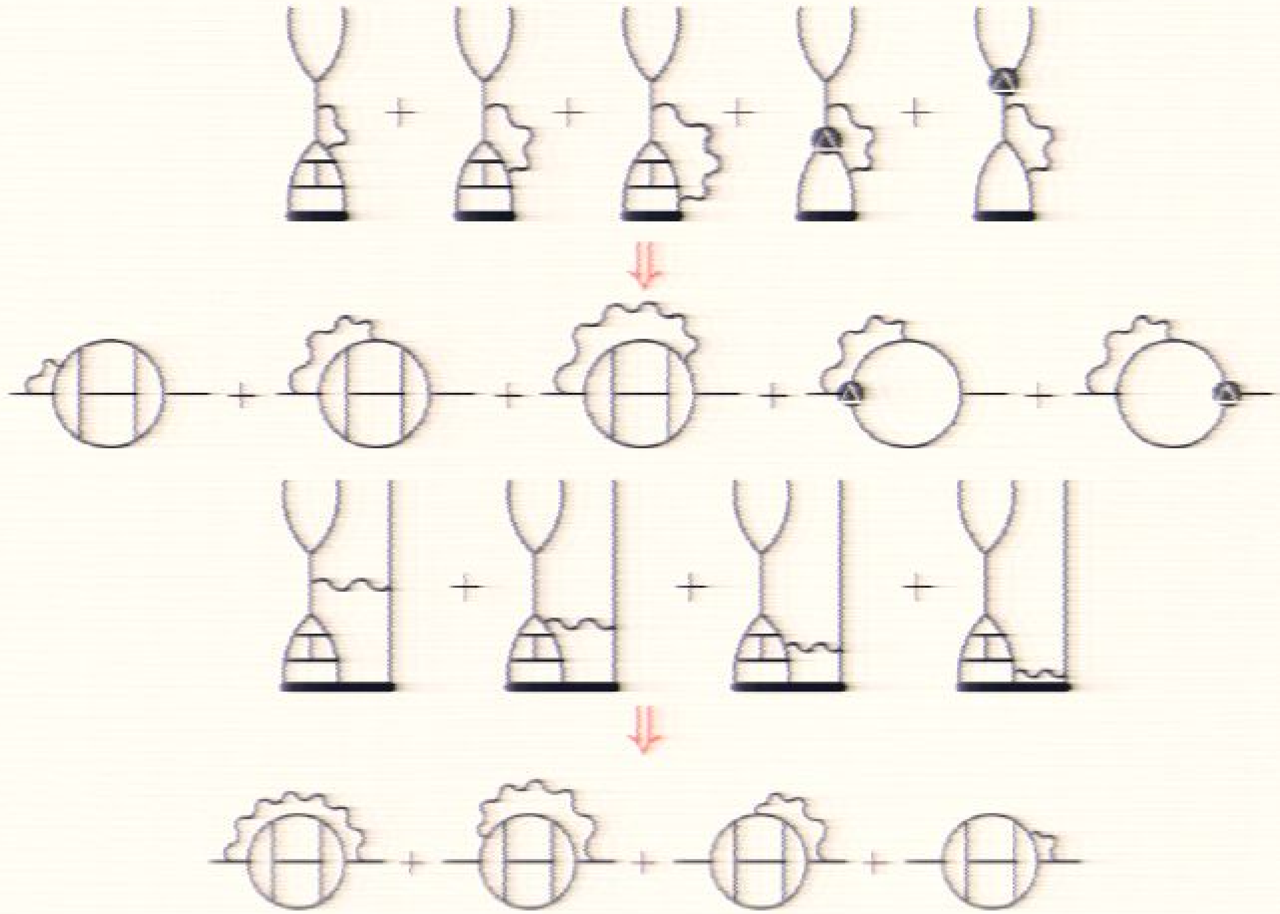

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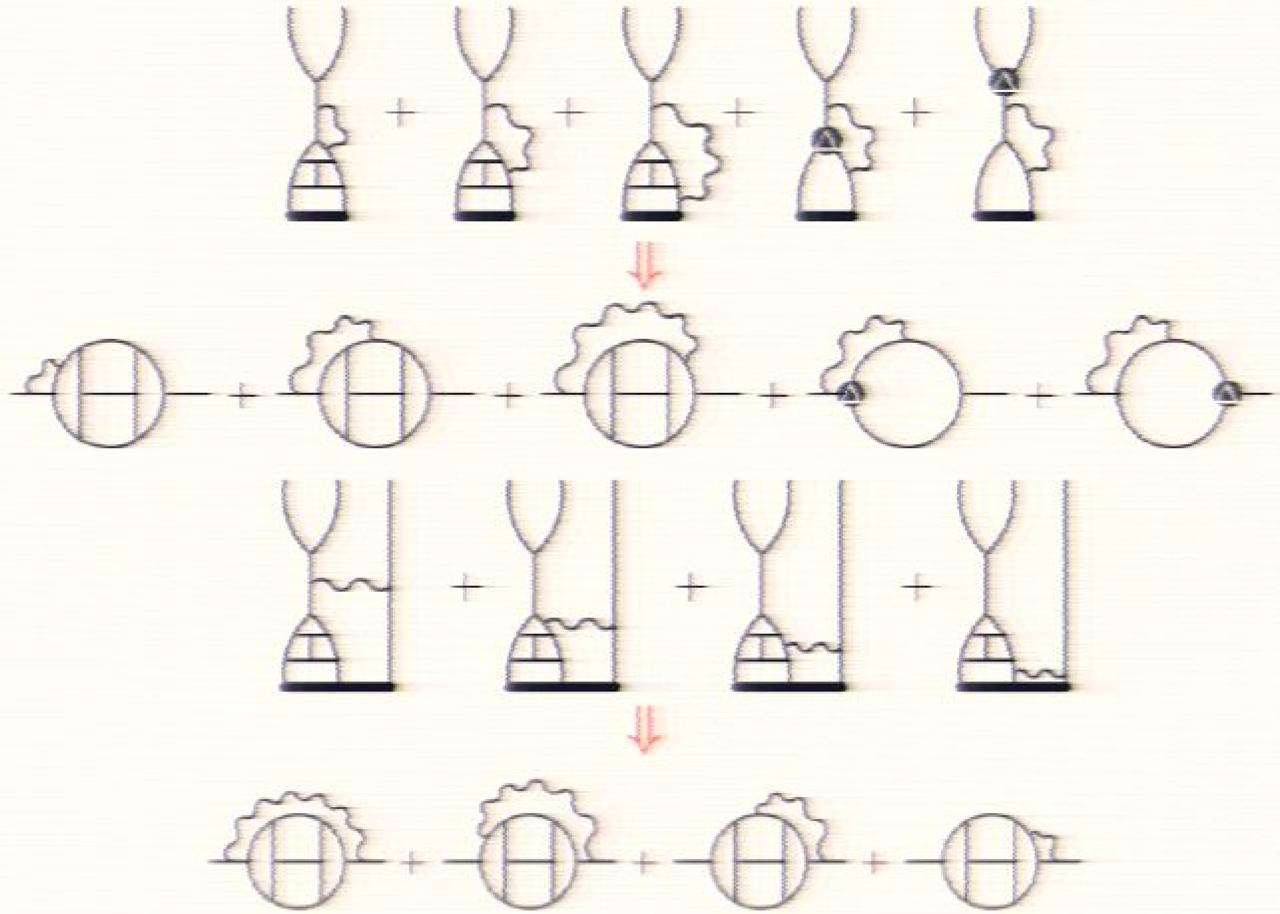

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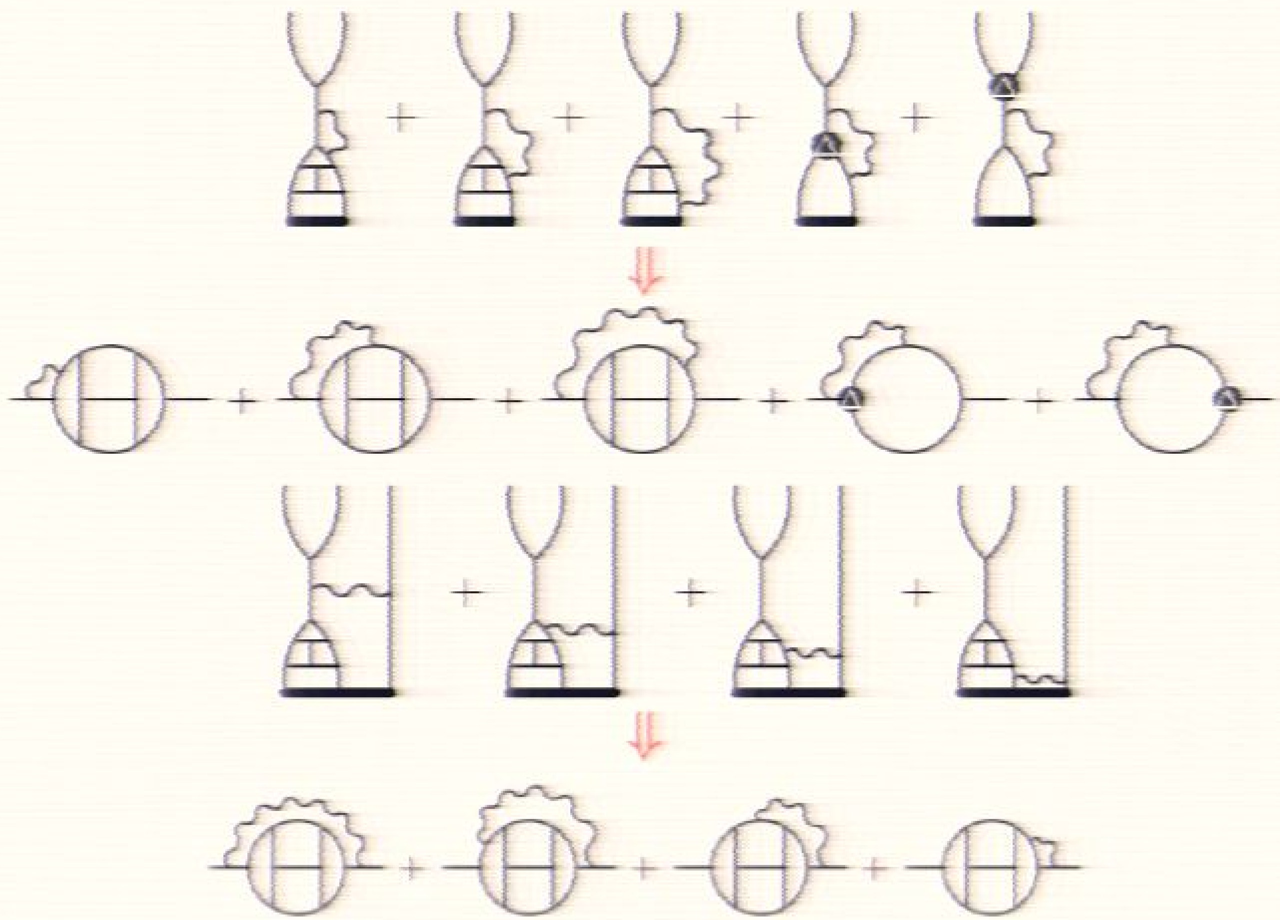

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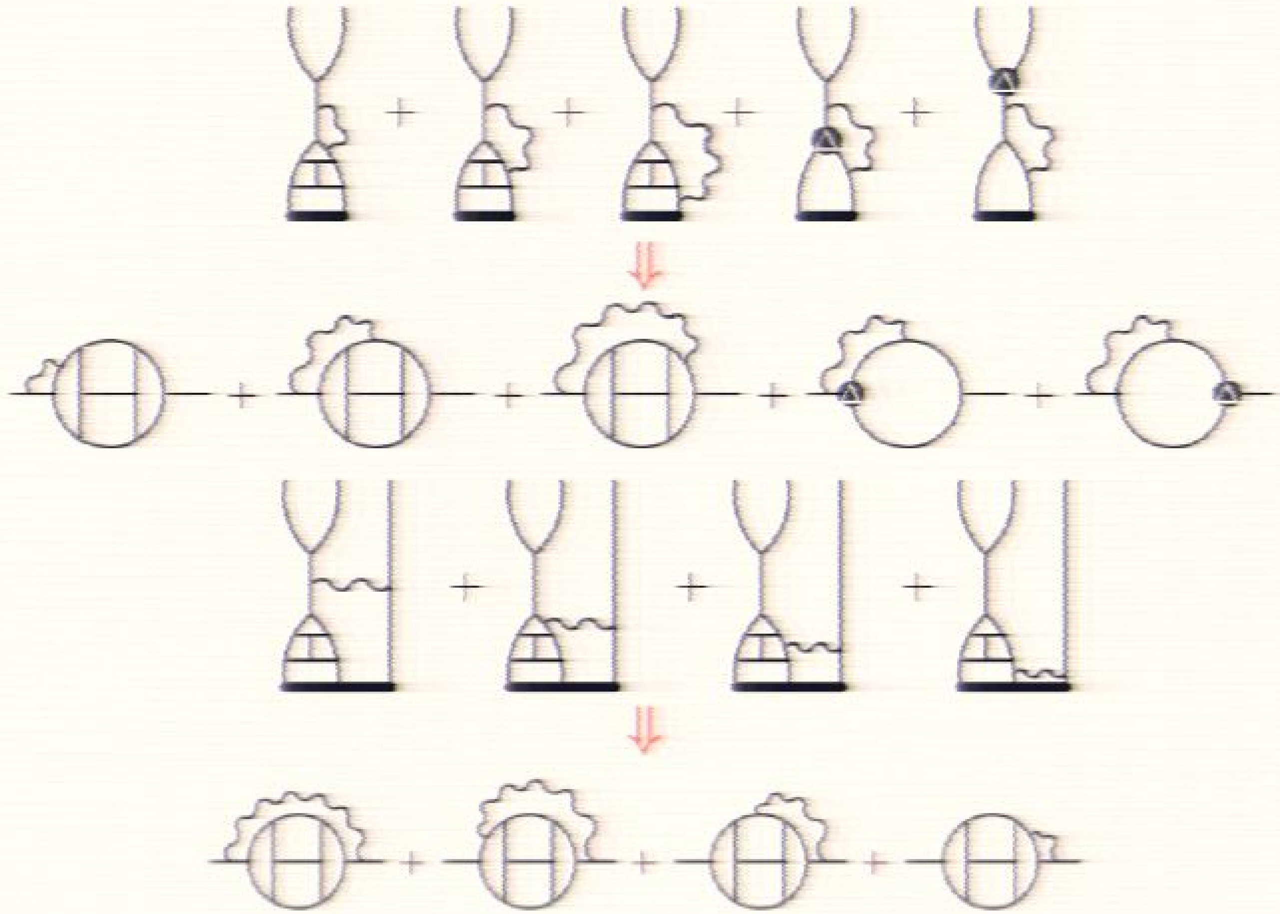

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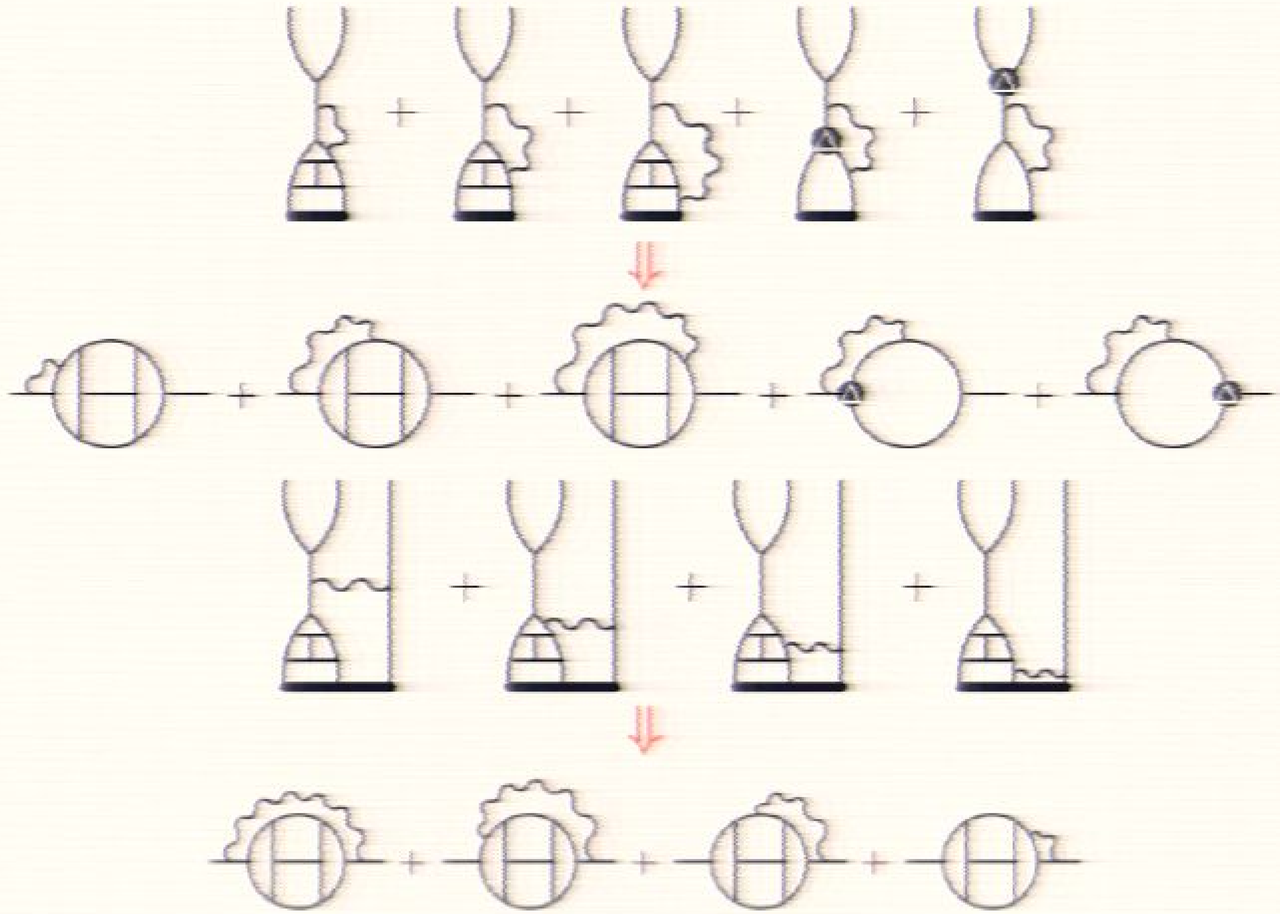

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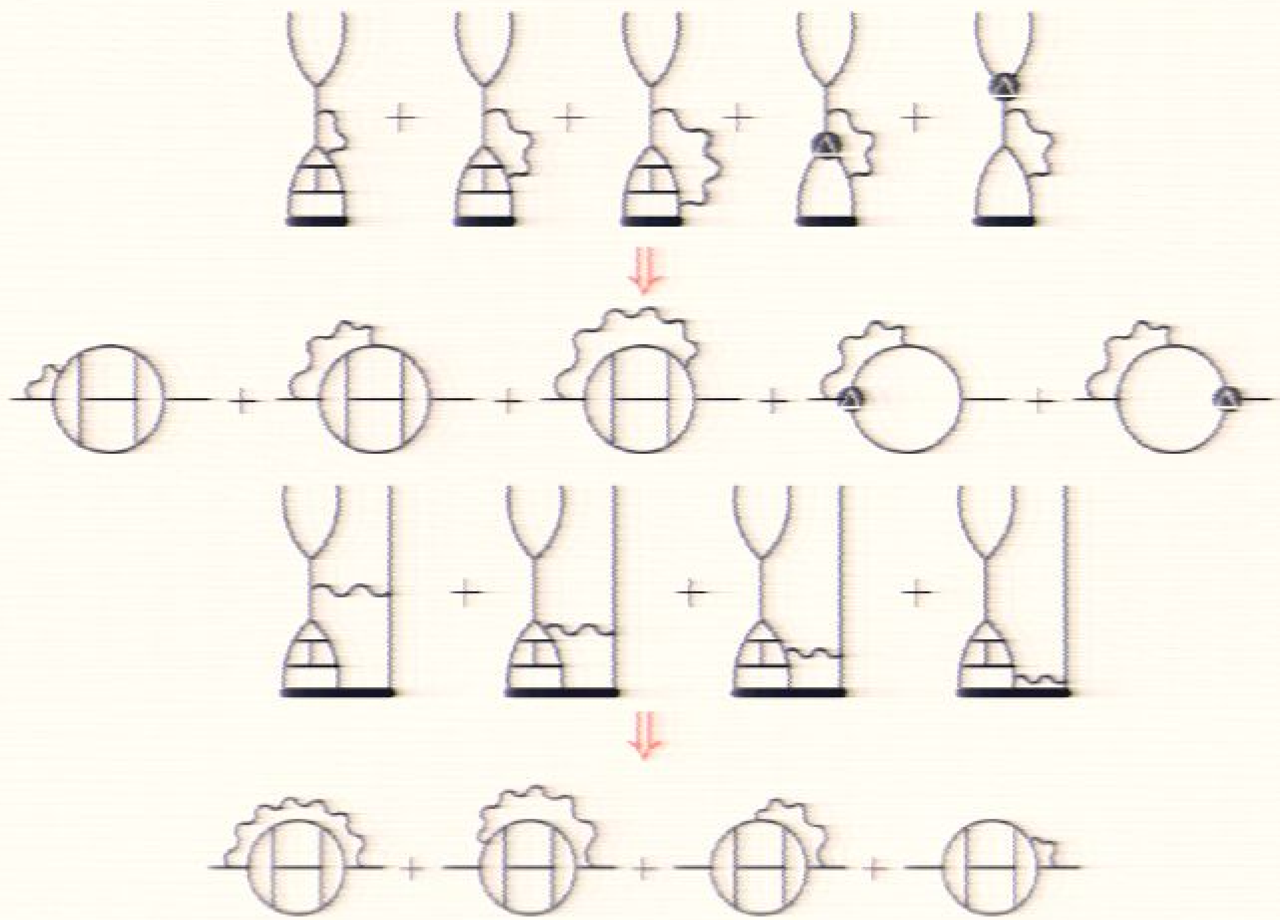

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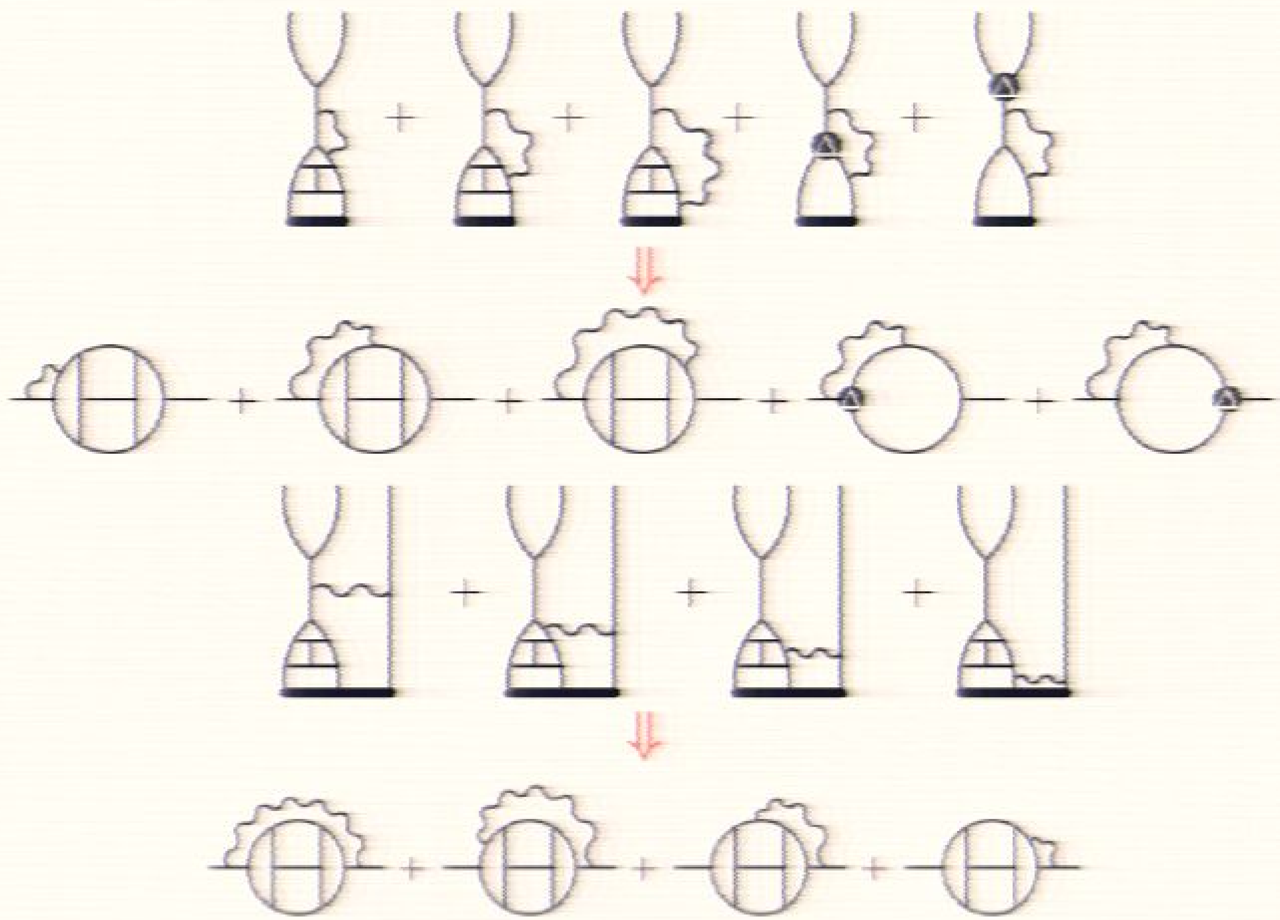

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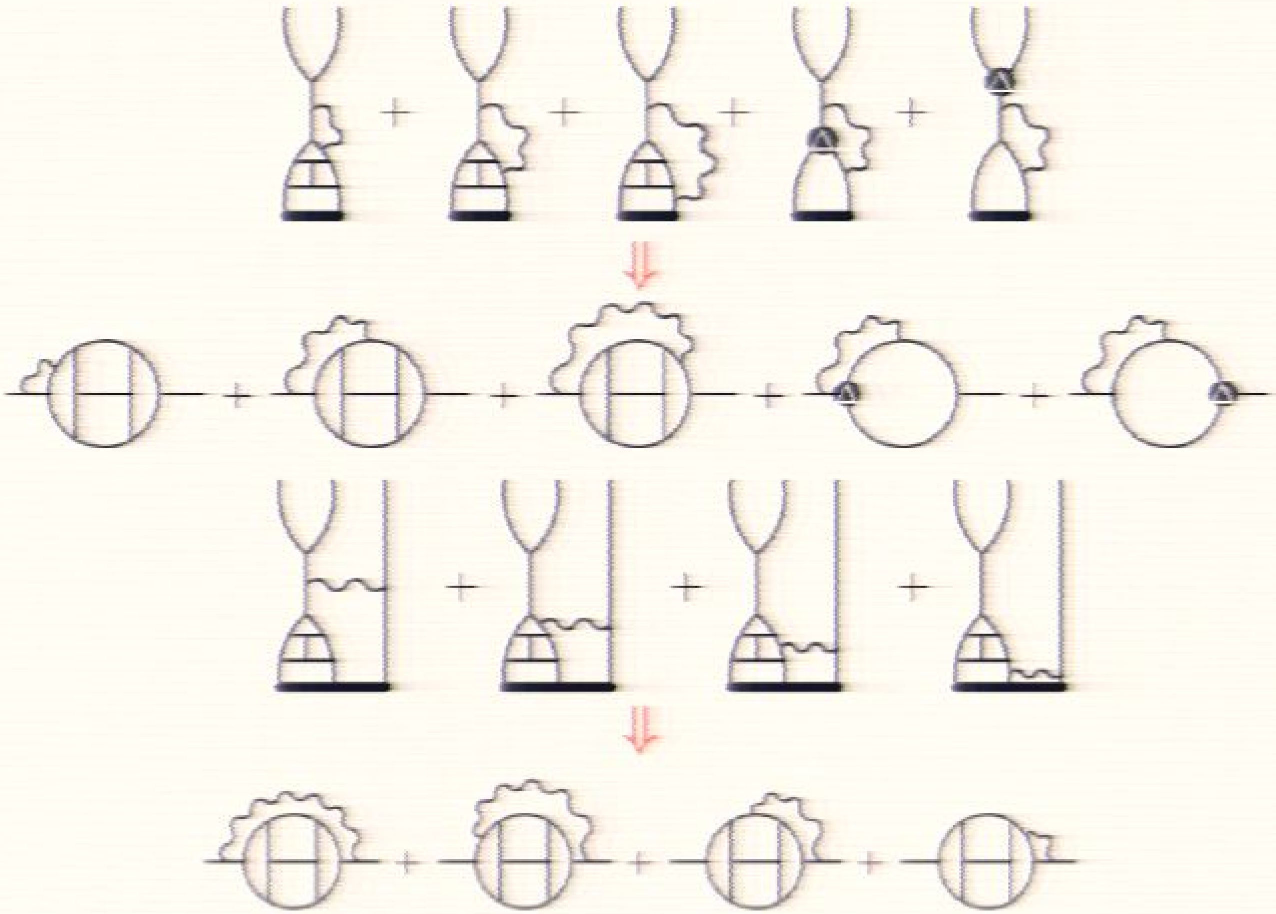

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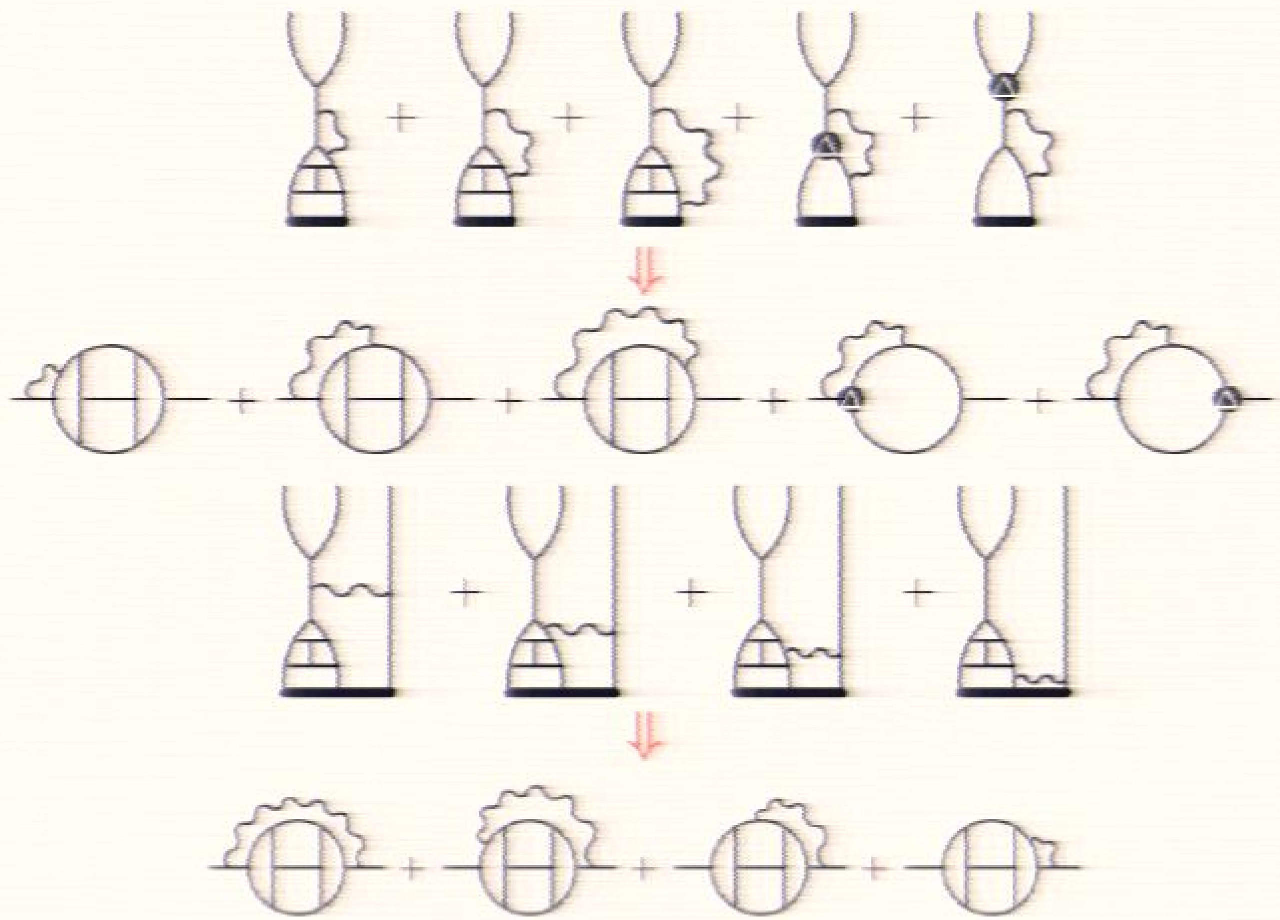

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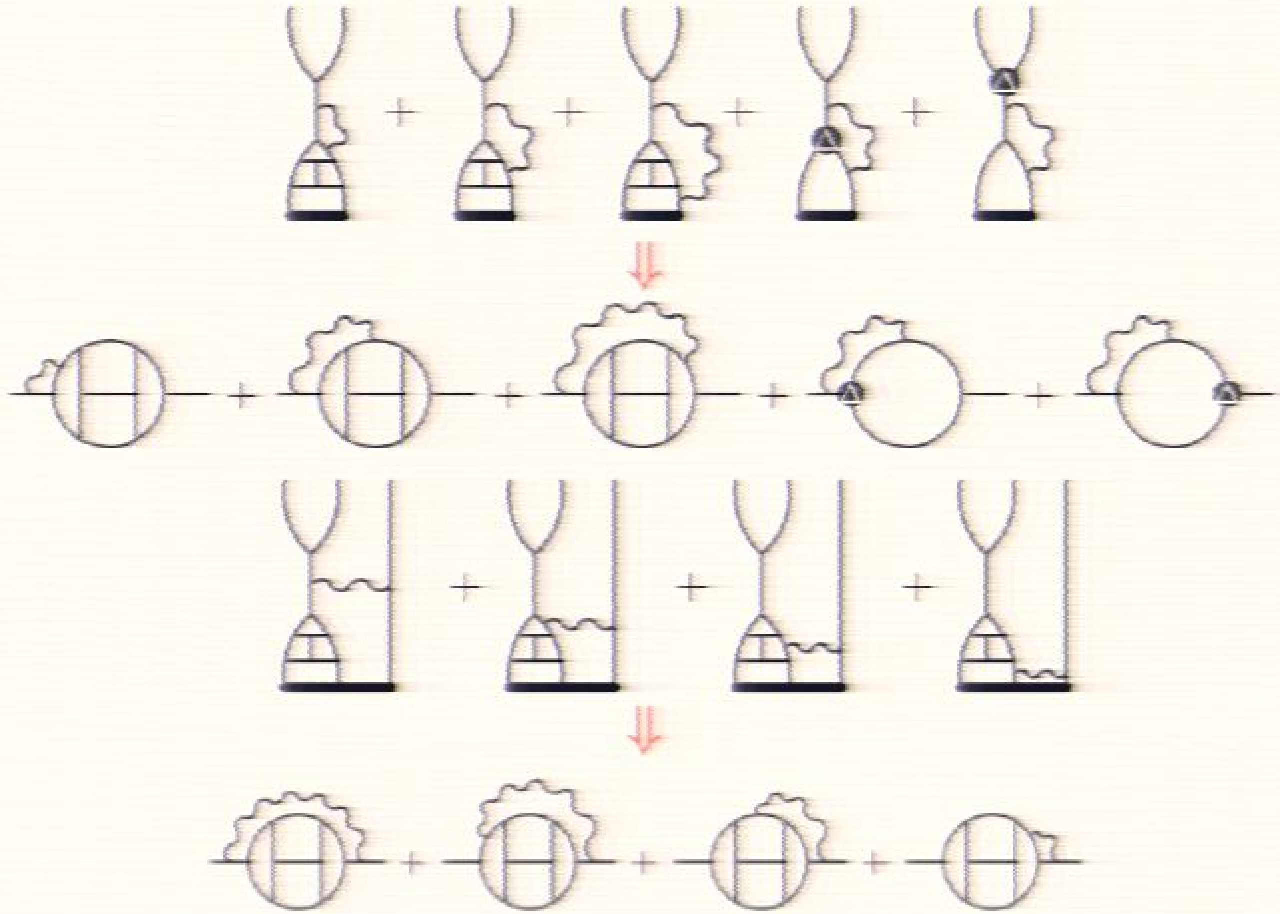

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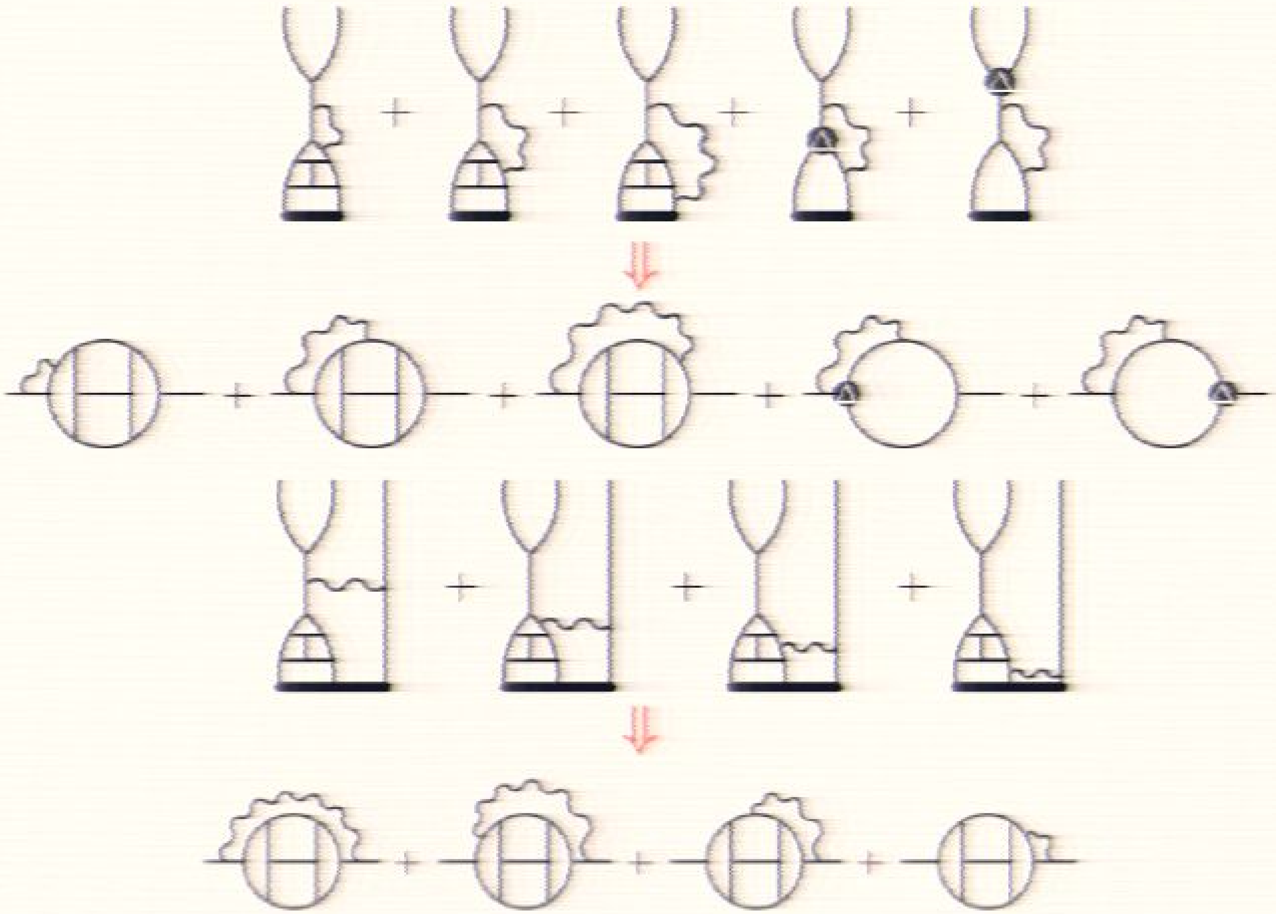

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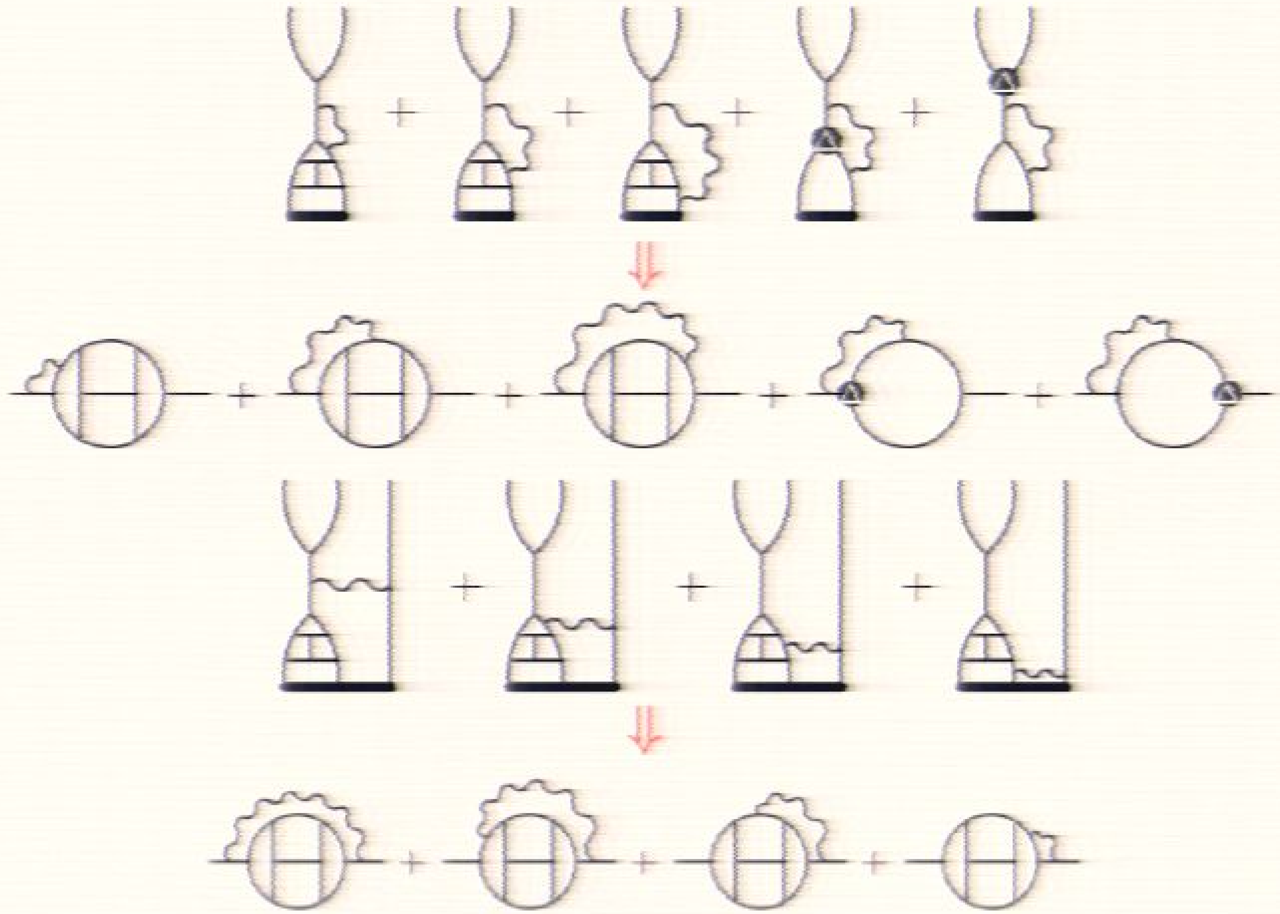

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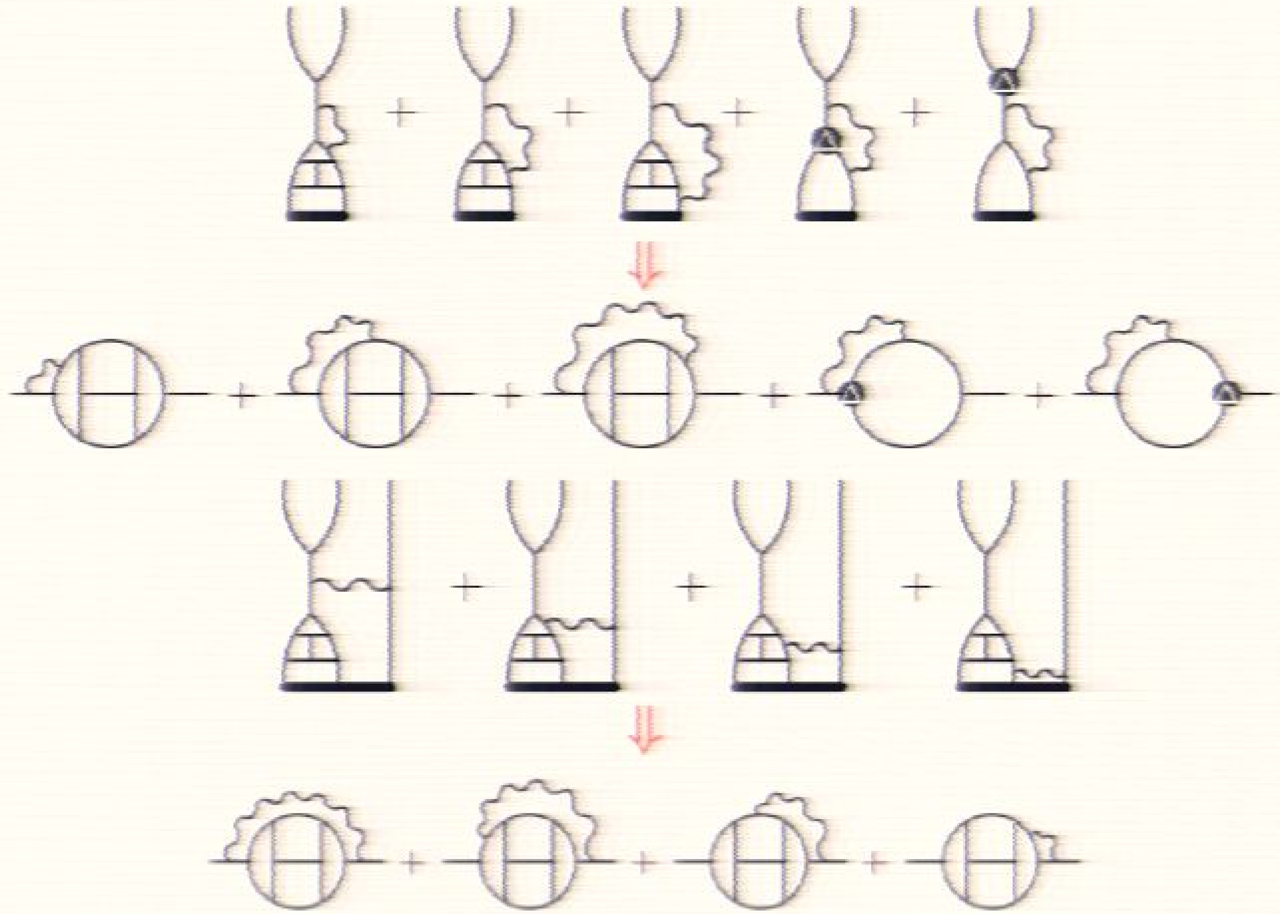

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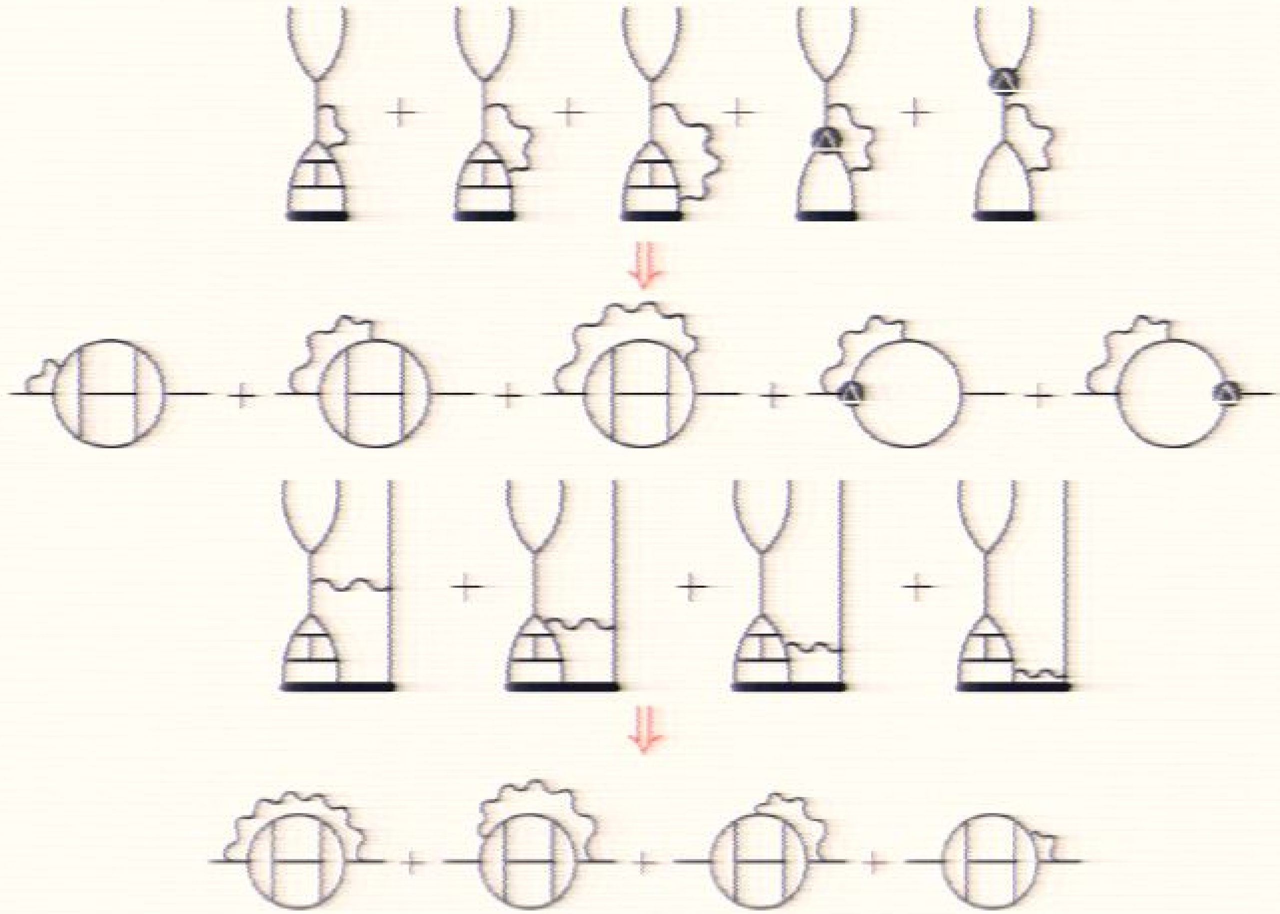

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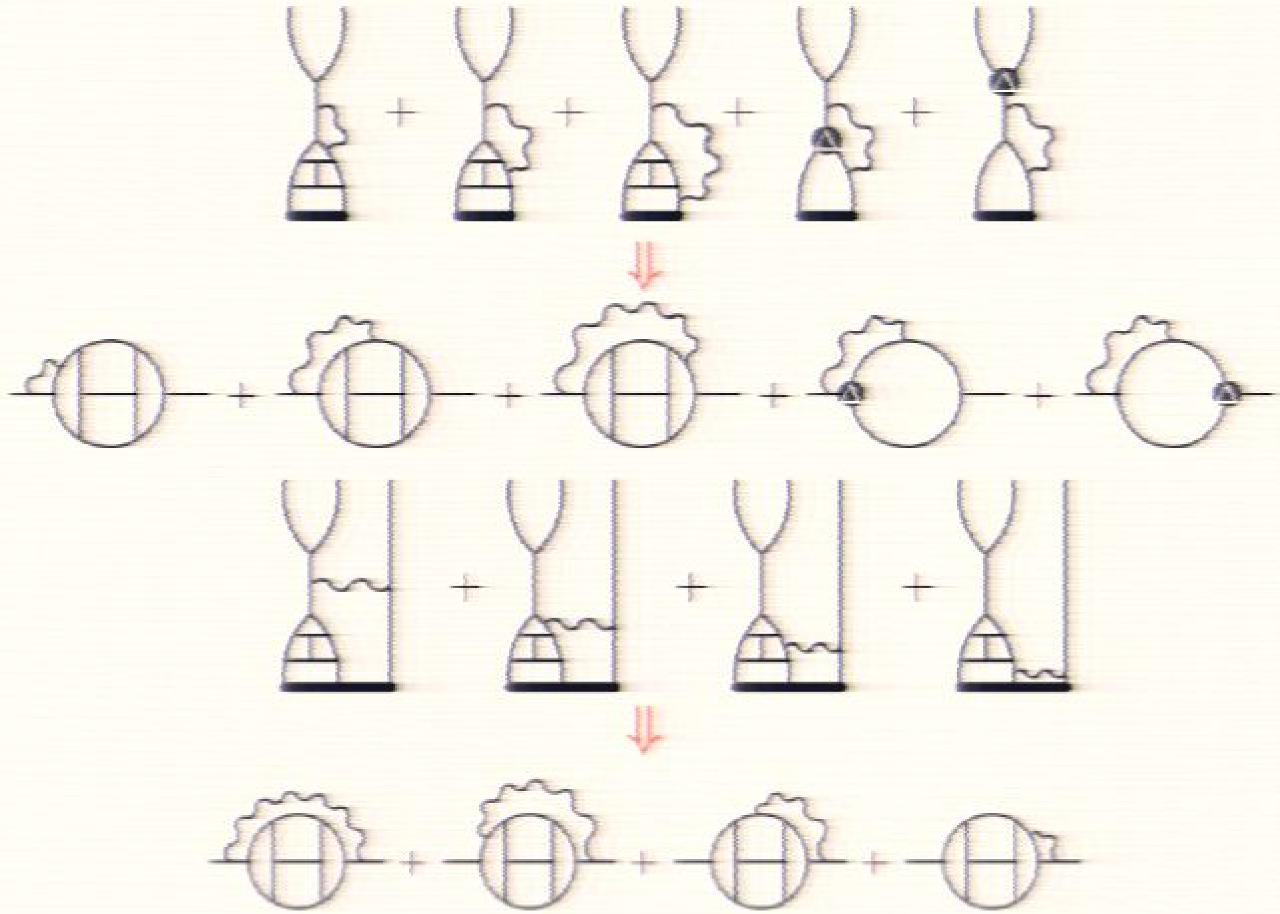

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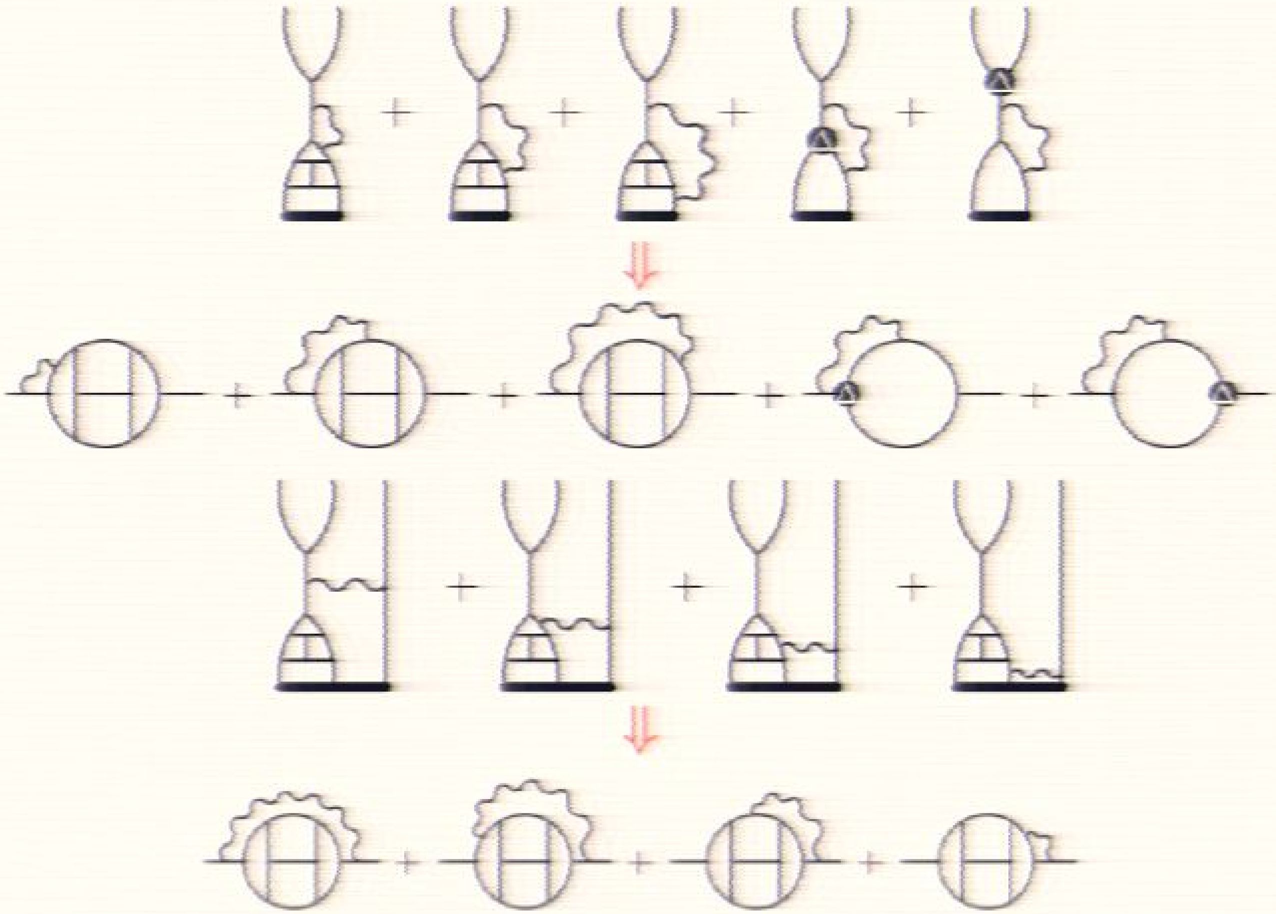

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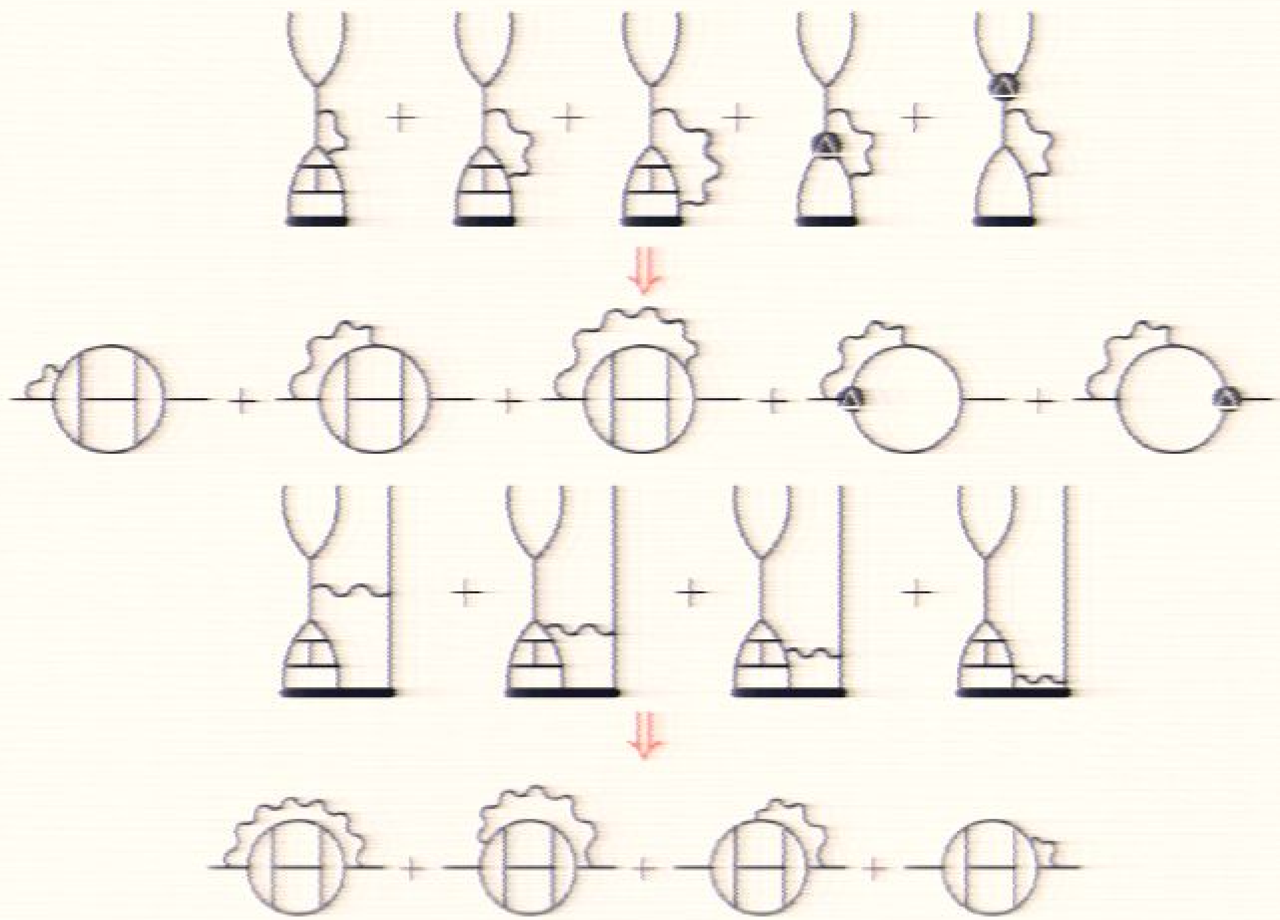

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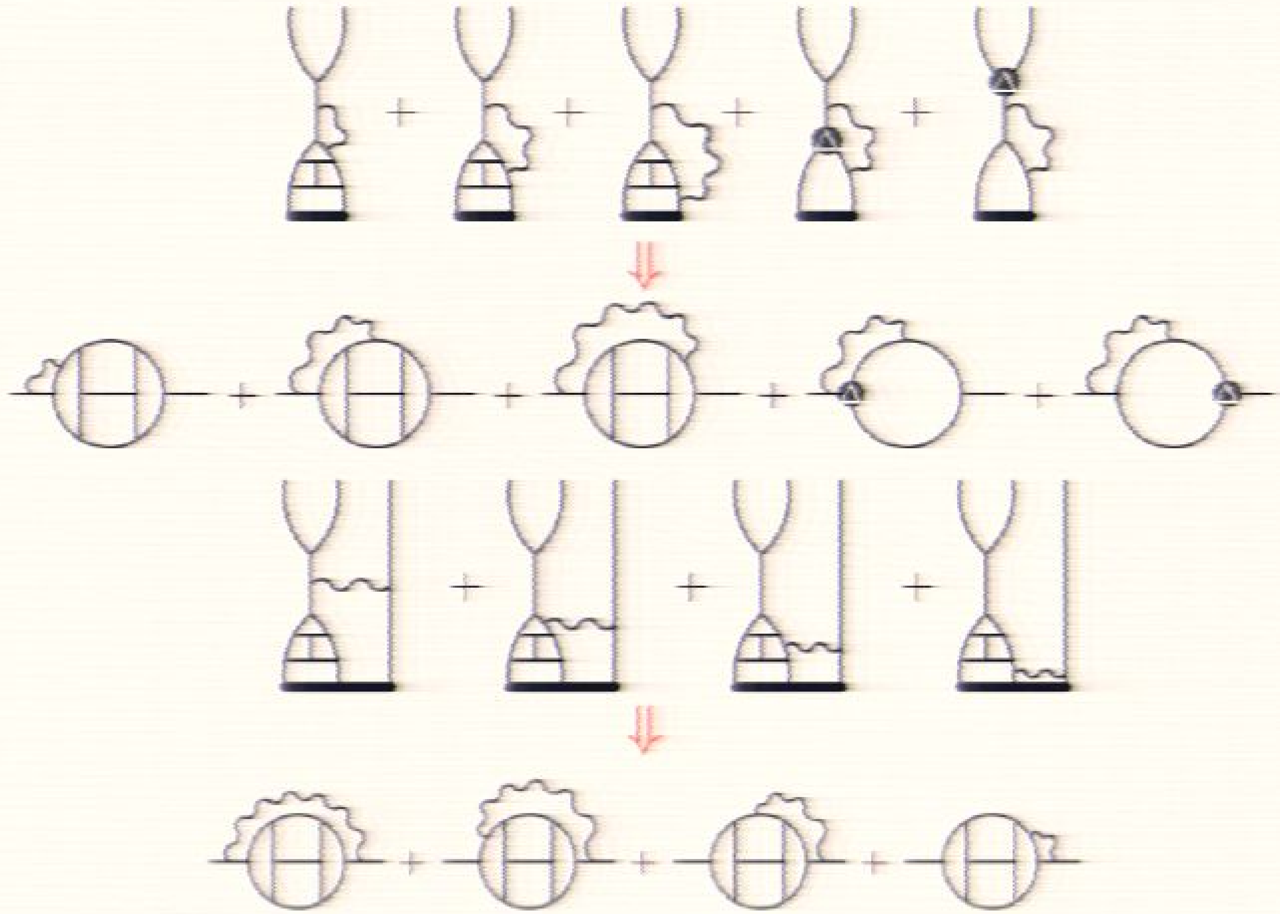

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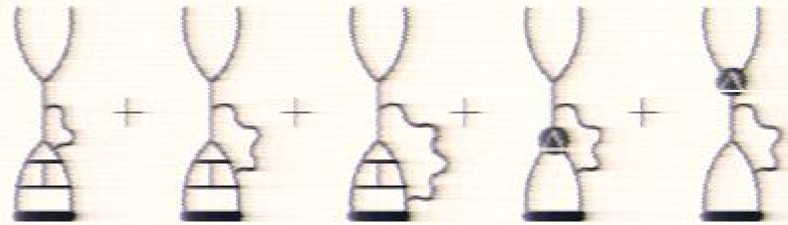

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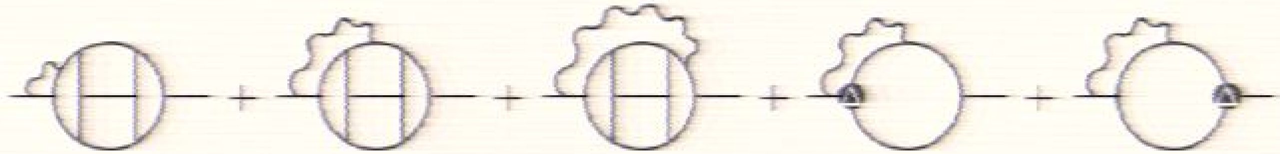

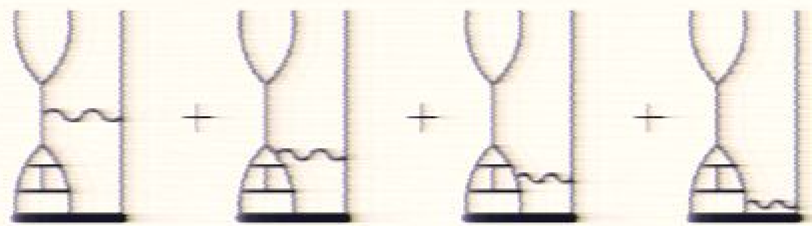

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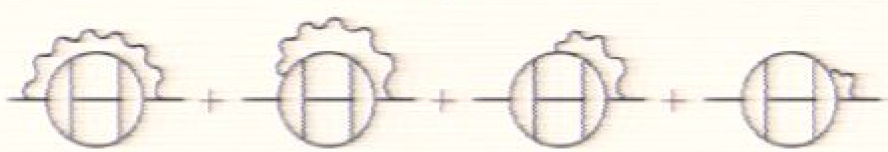

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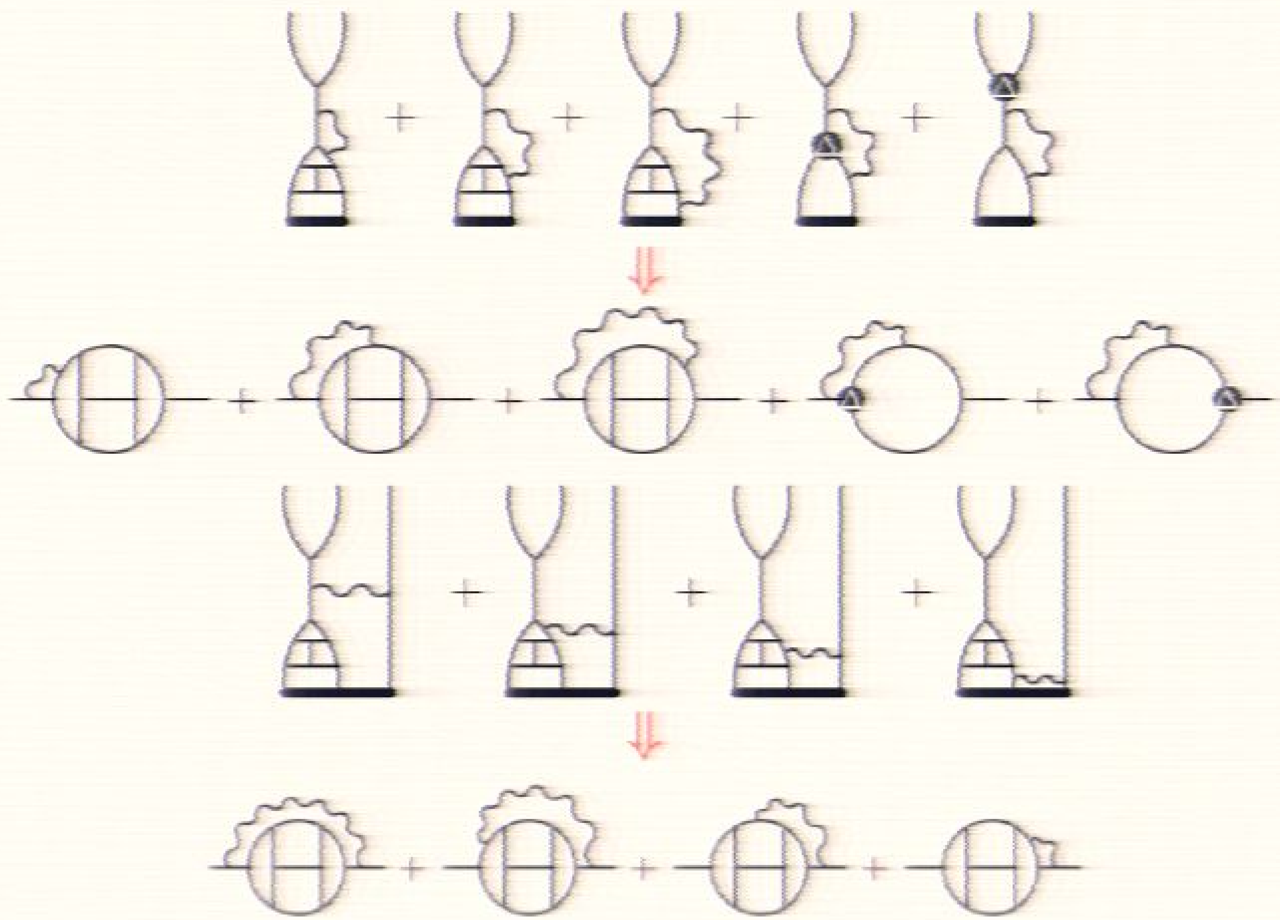

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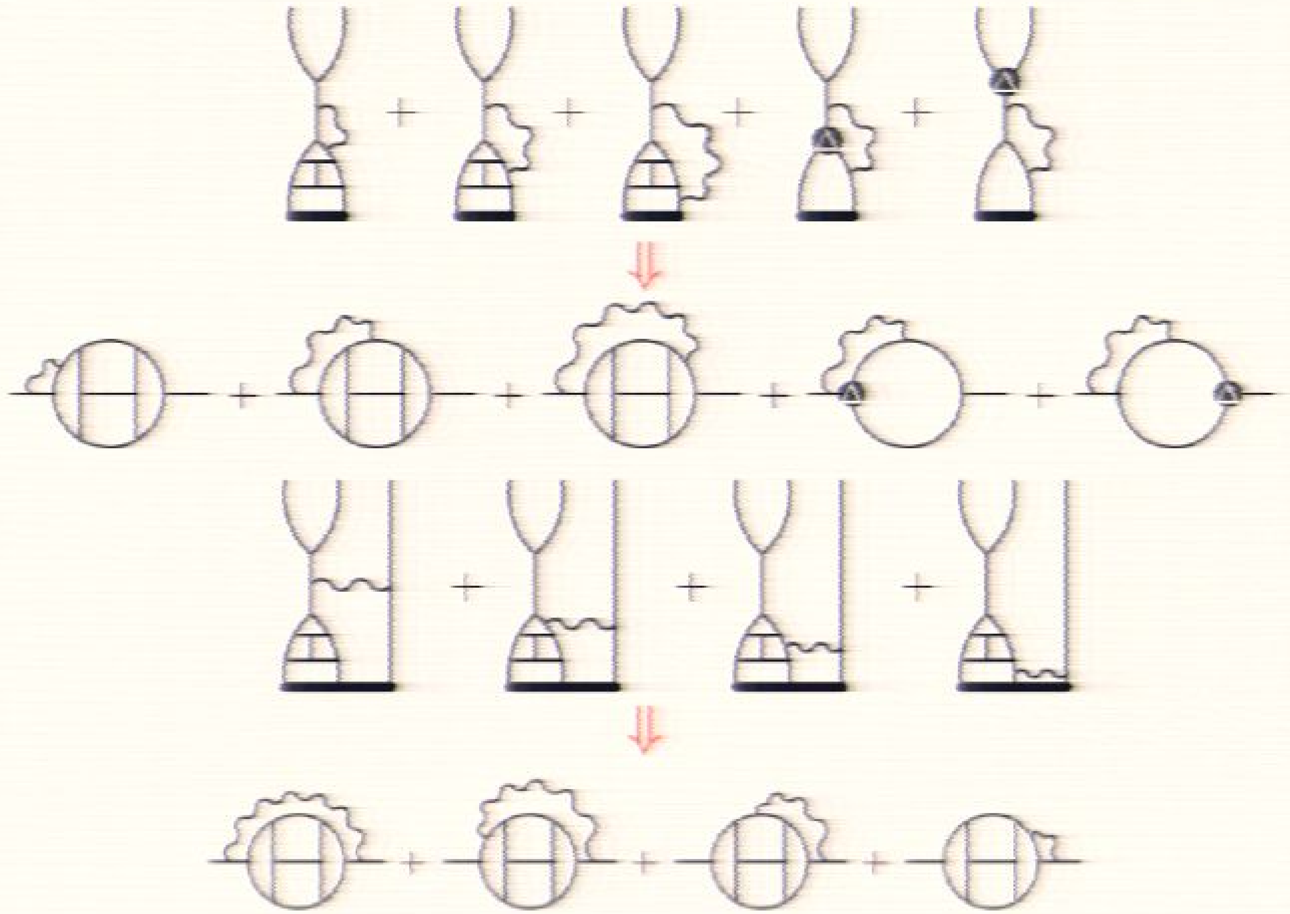

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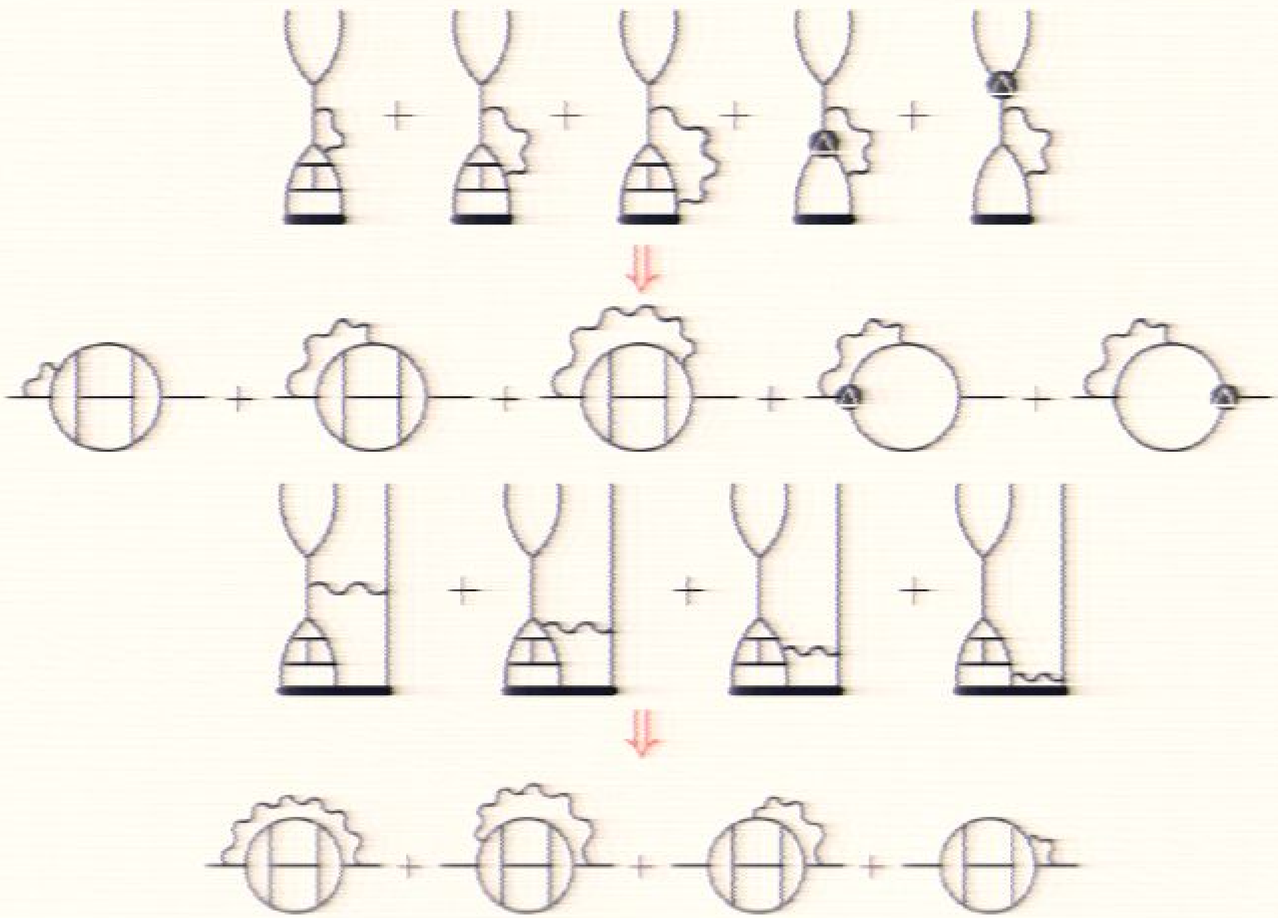

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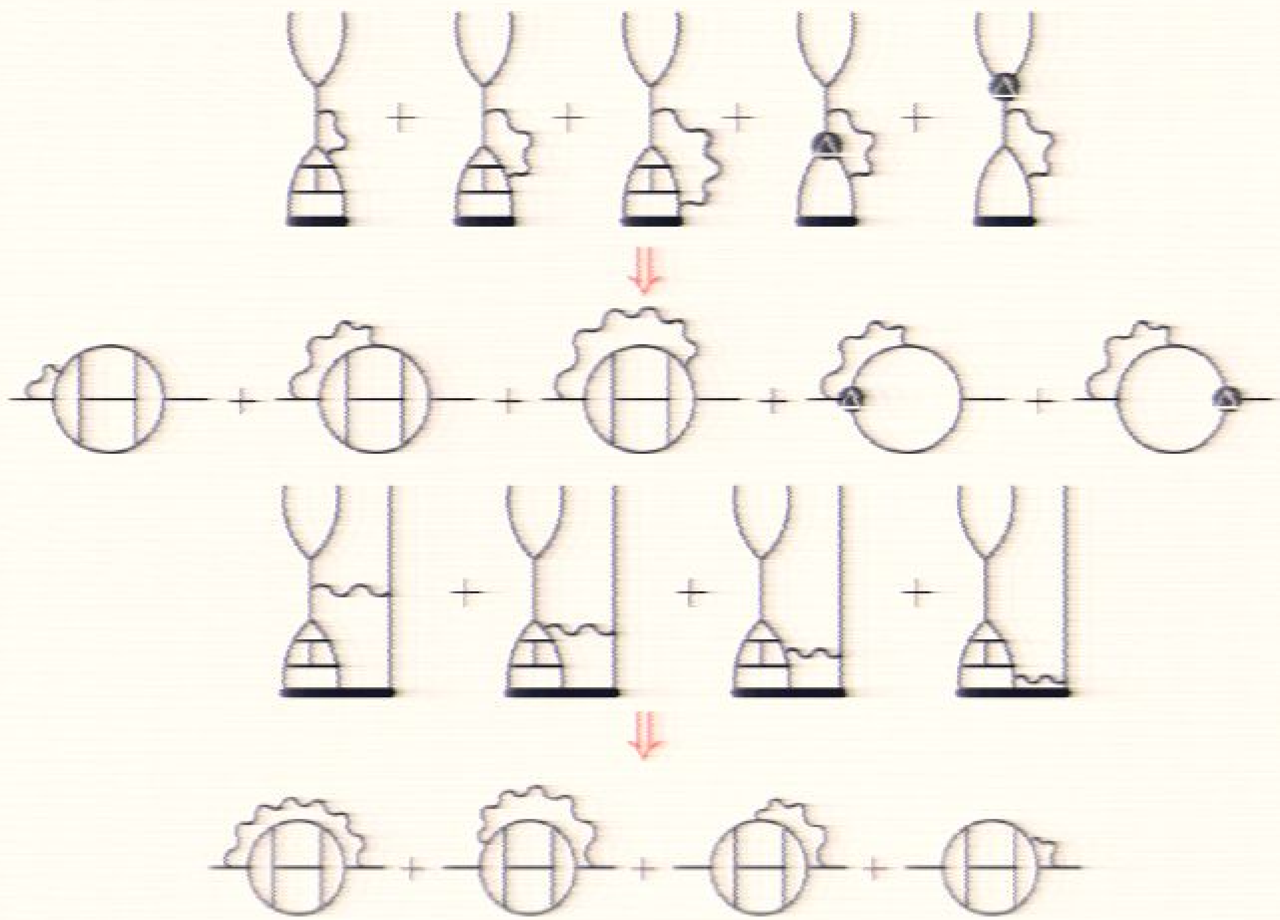

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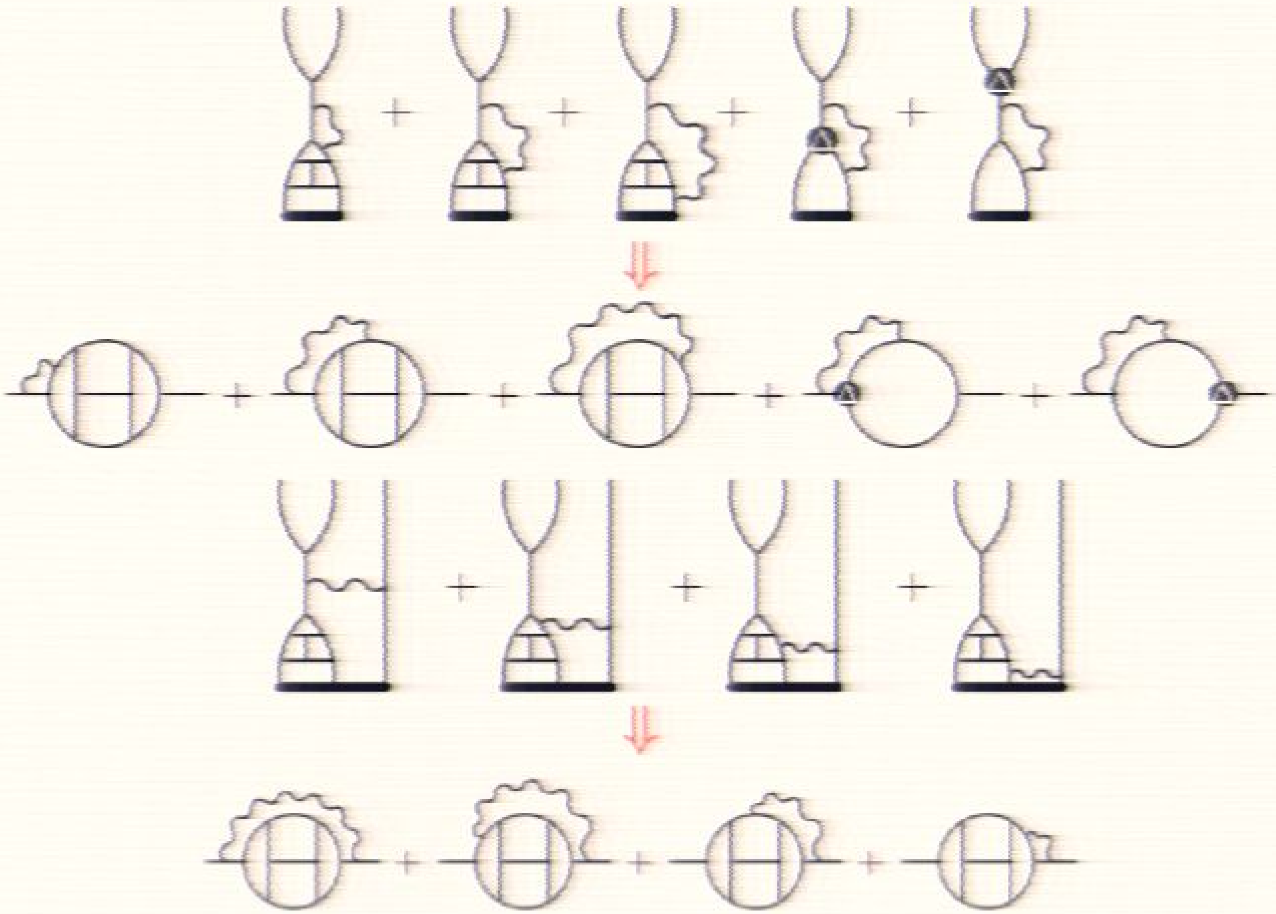

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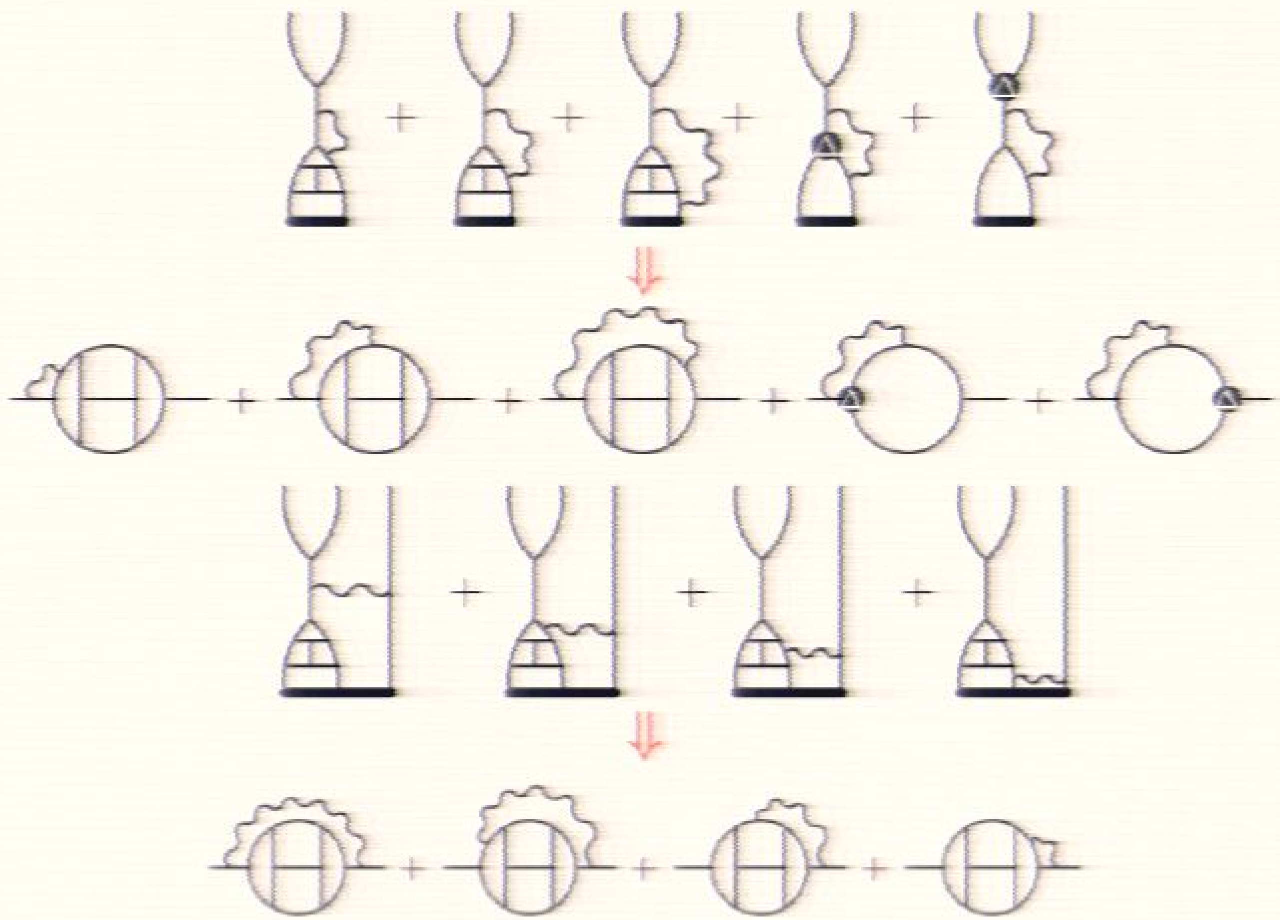

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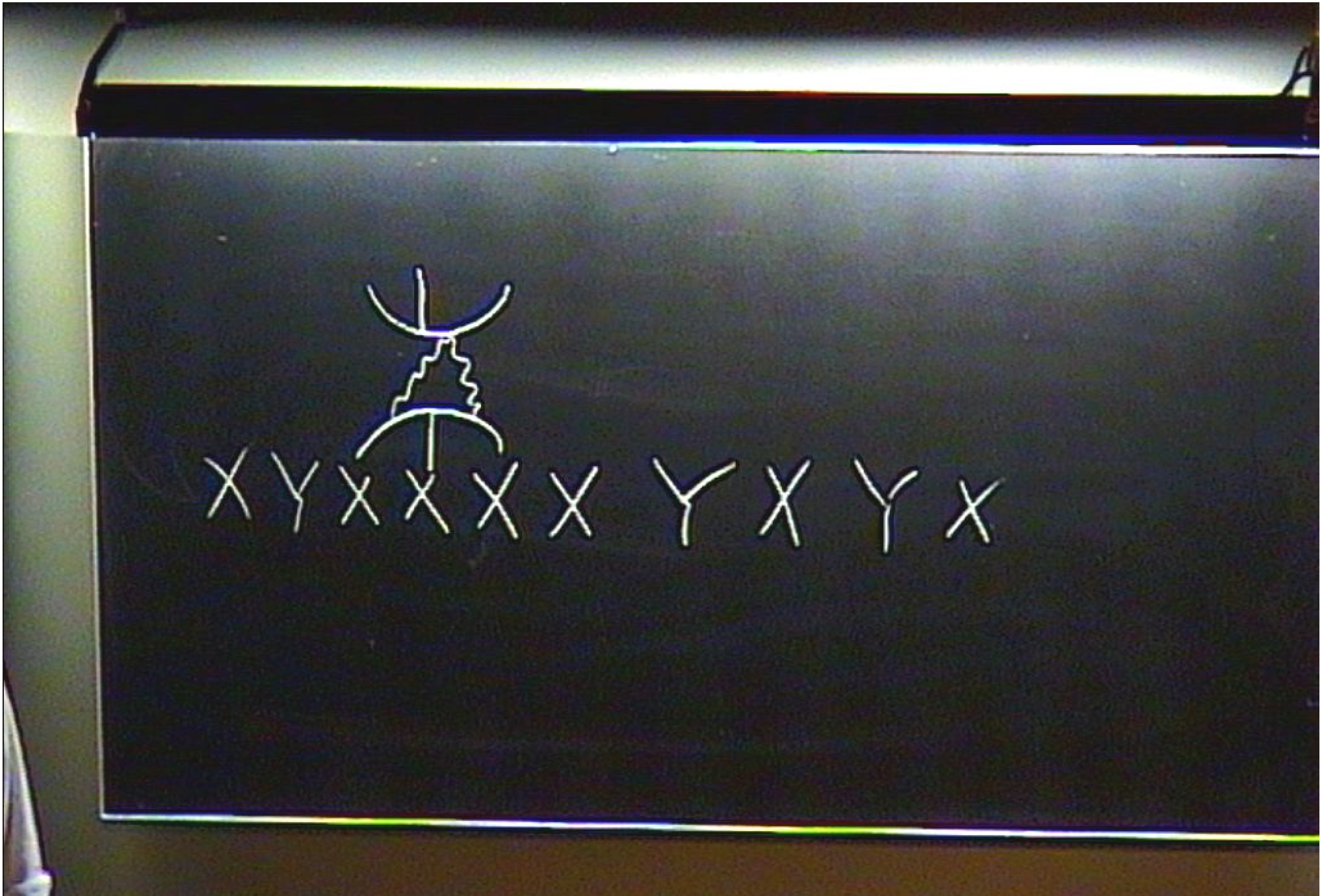
Thanks!

Thanks!

Merci!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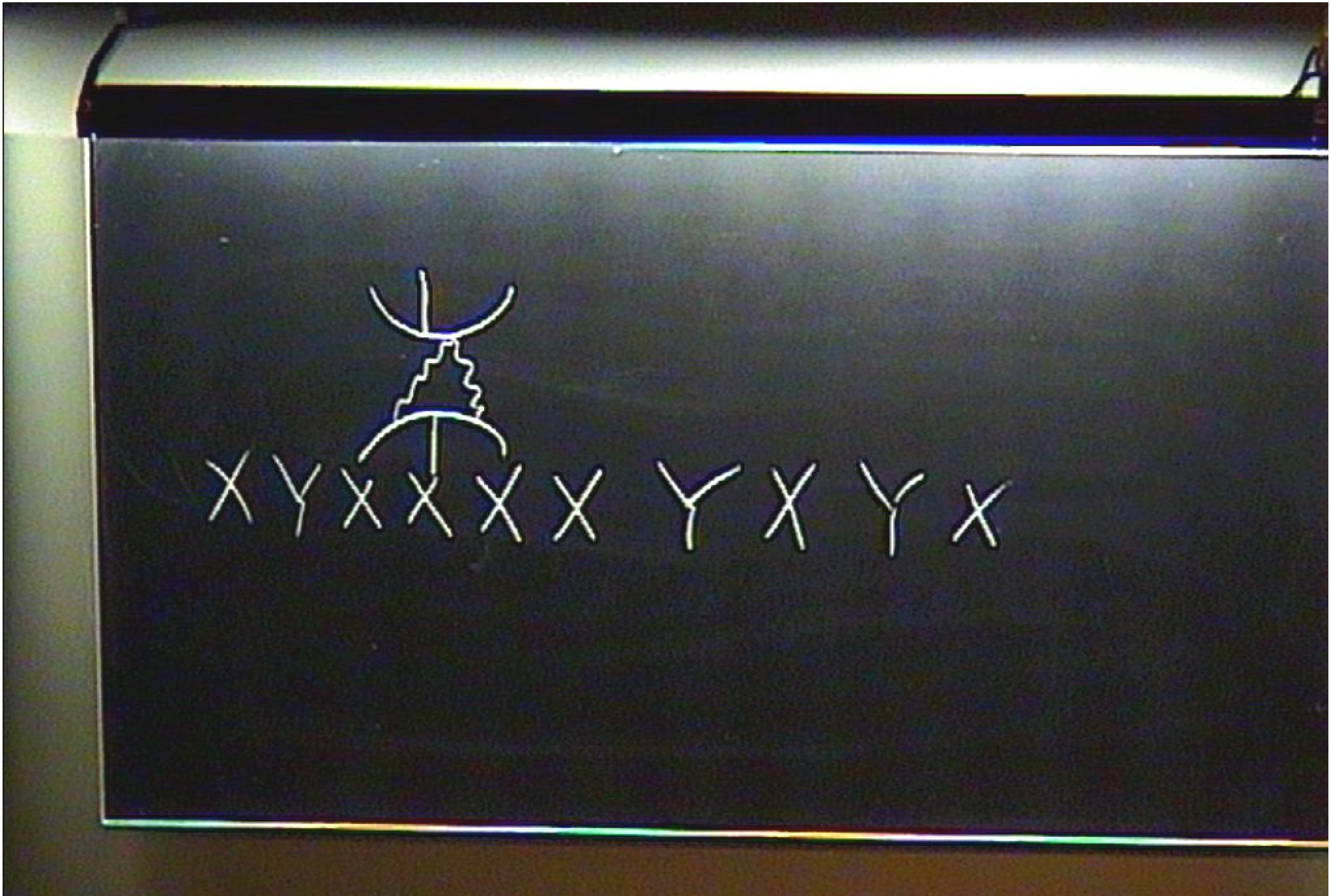
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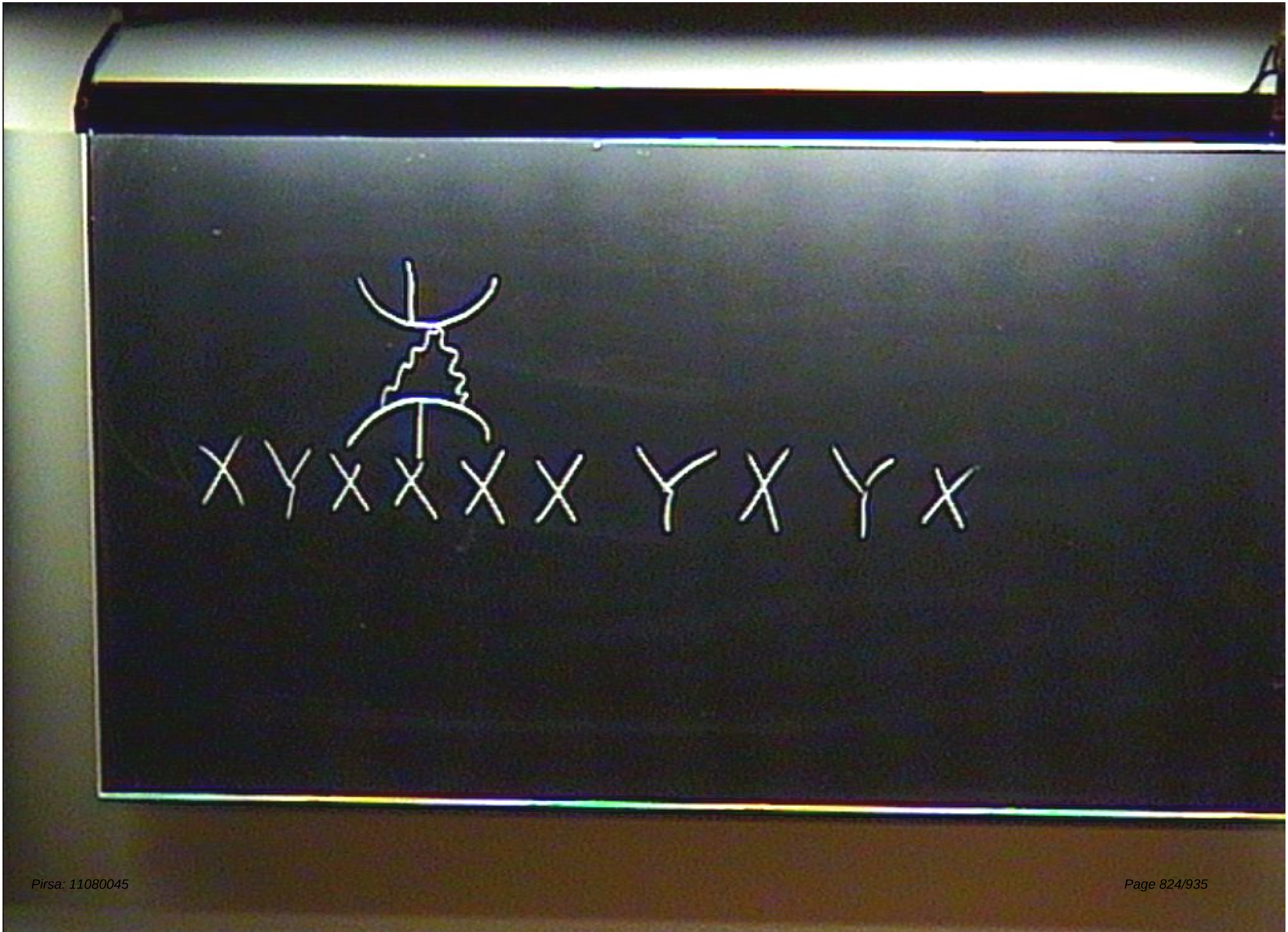
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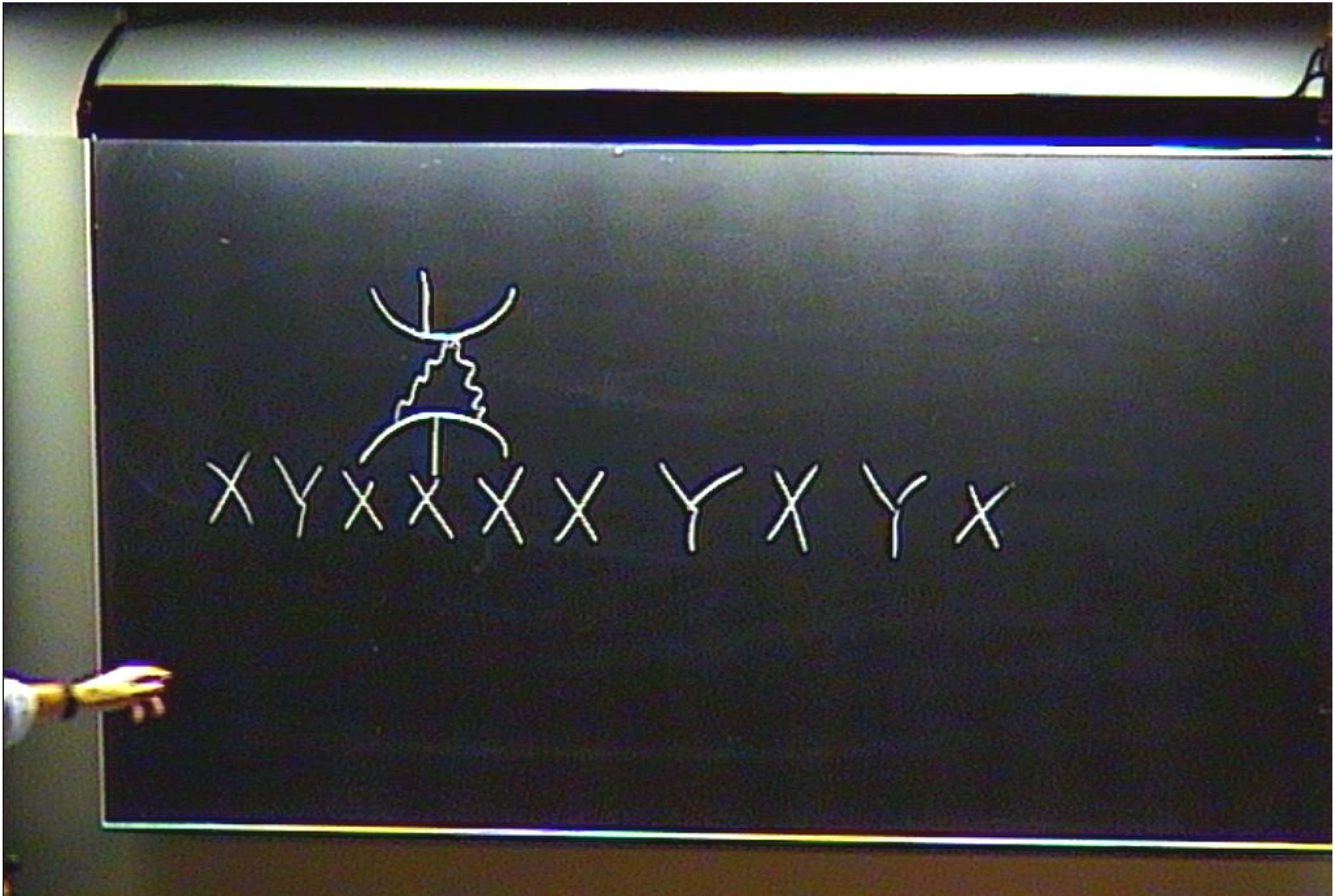

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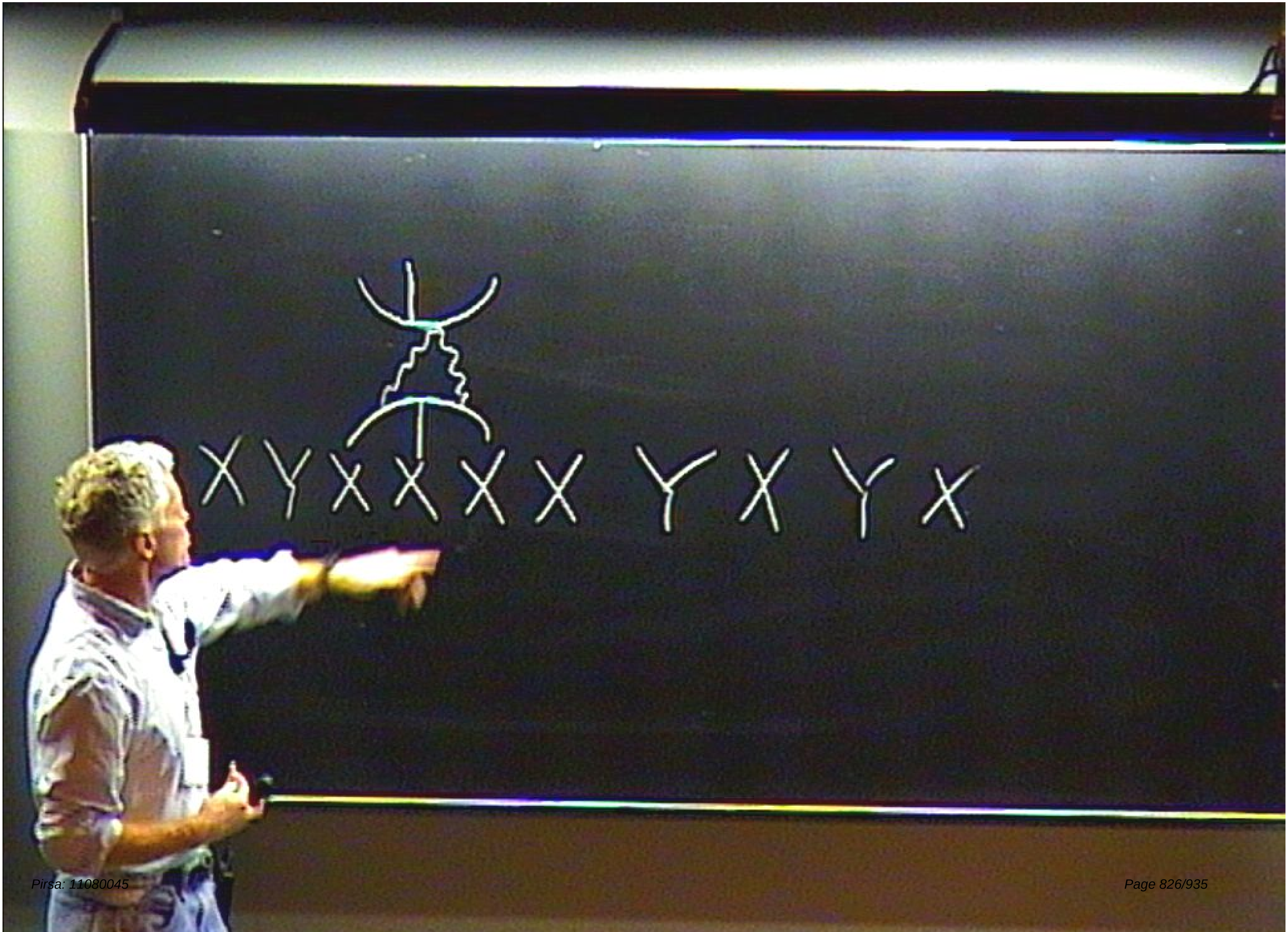
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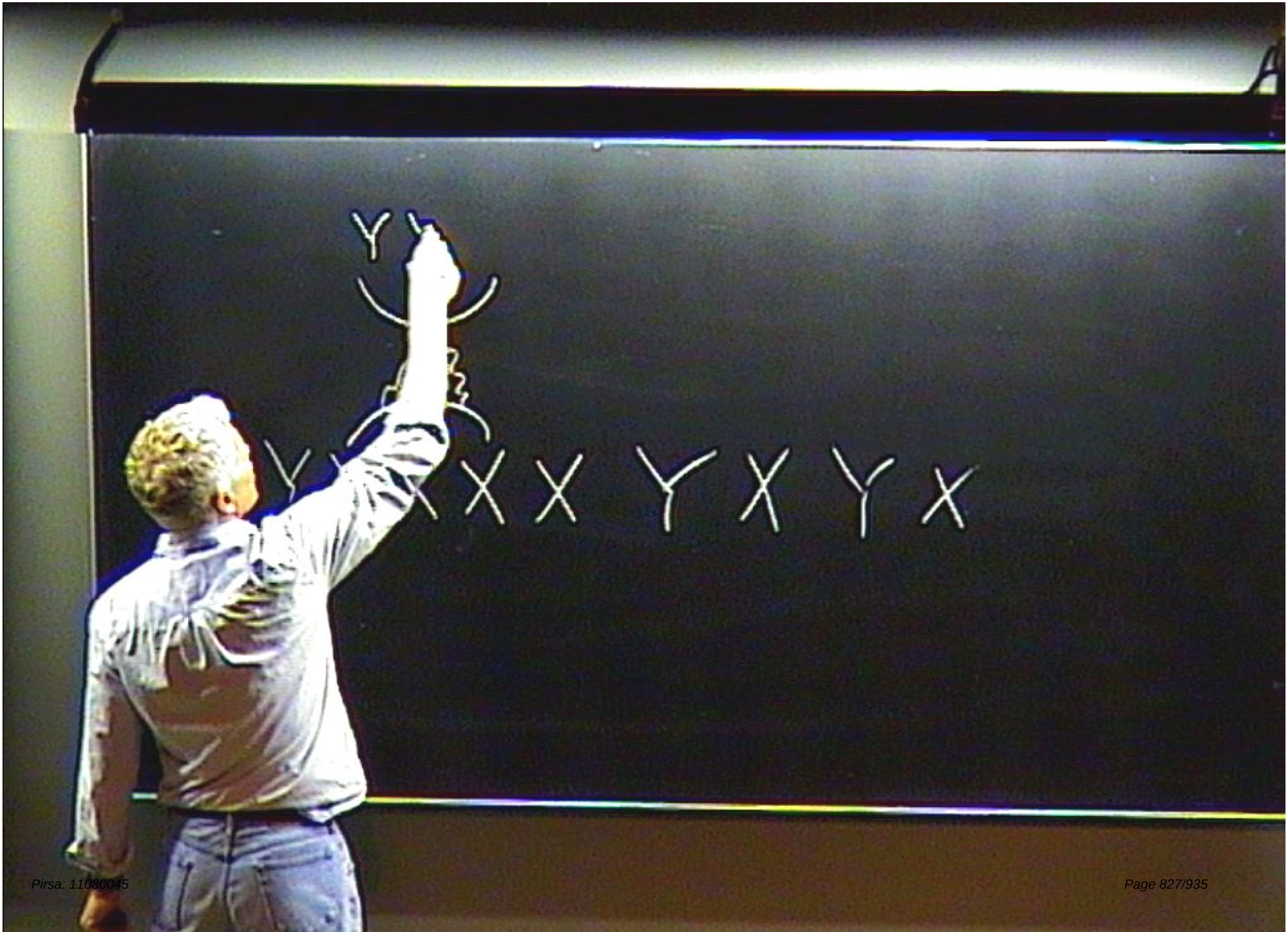

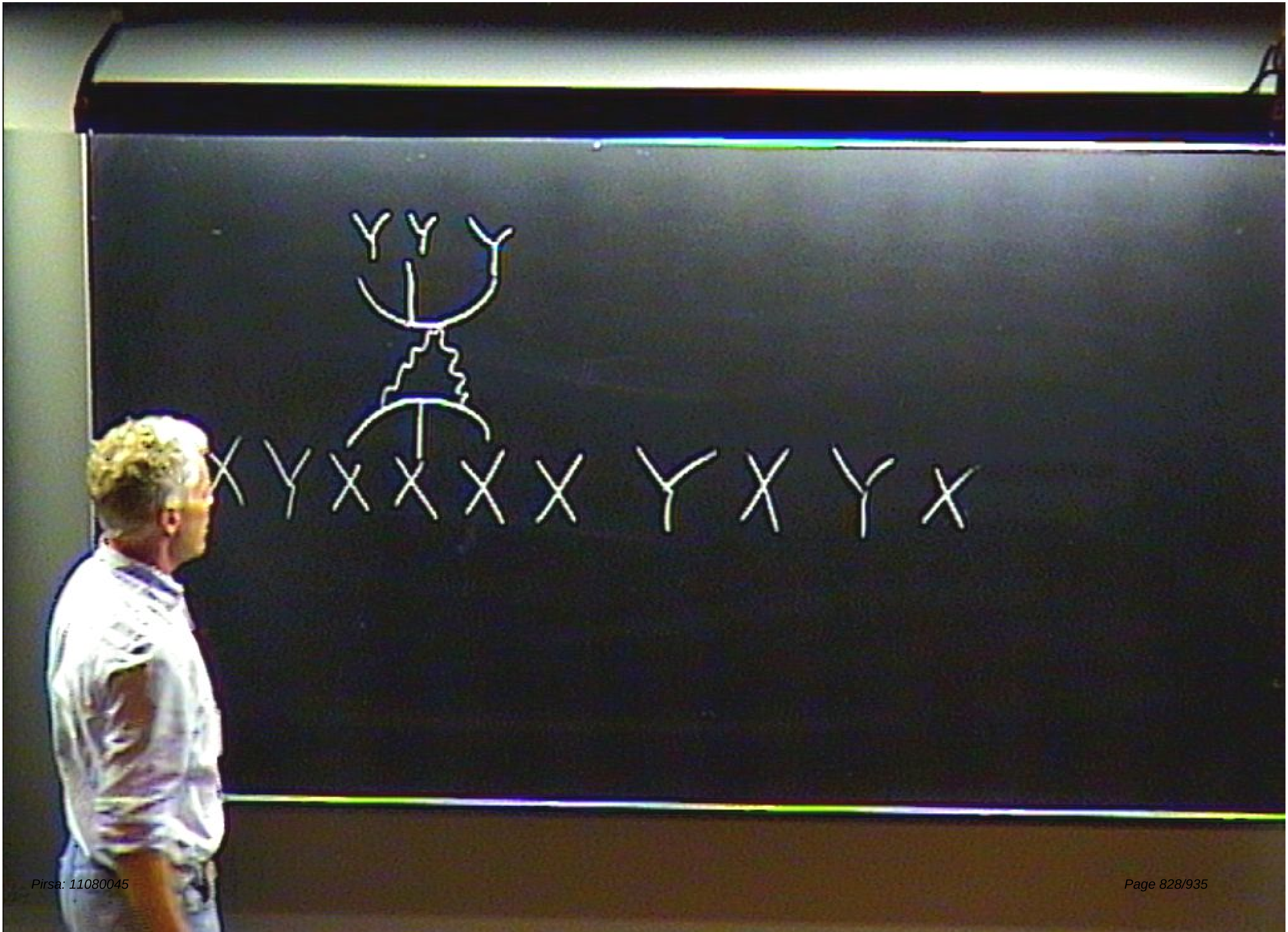
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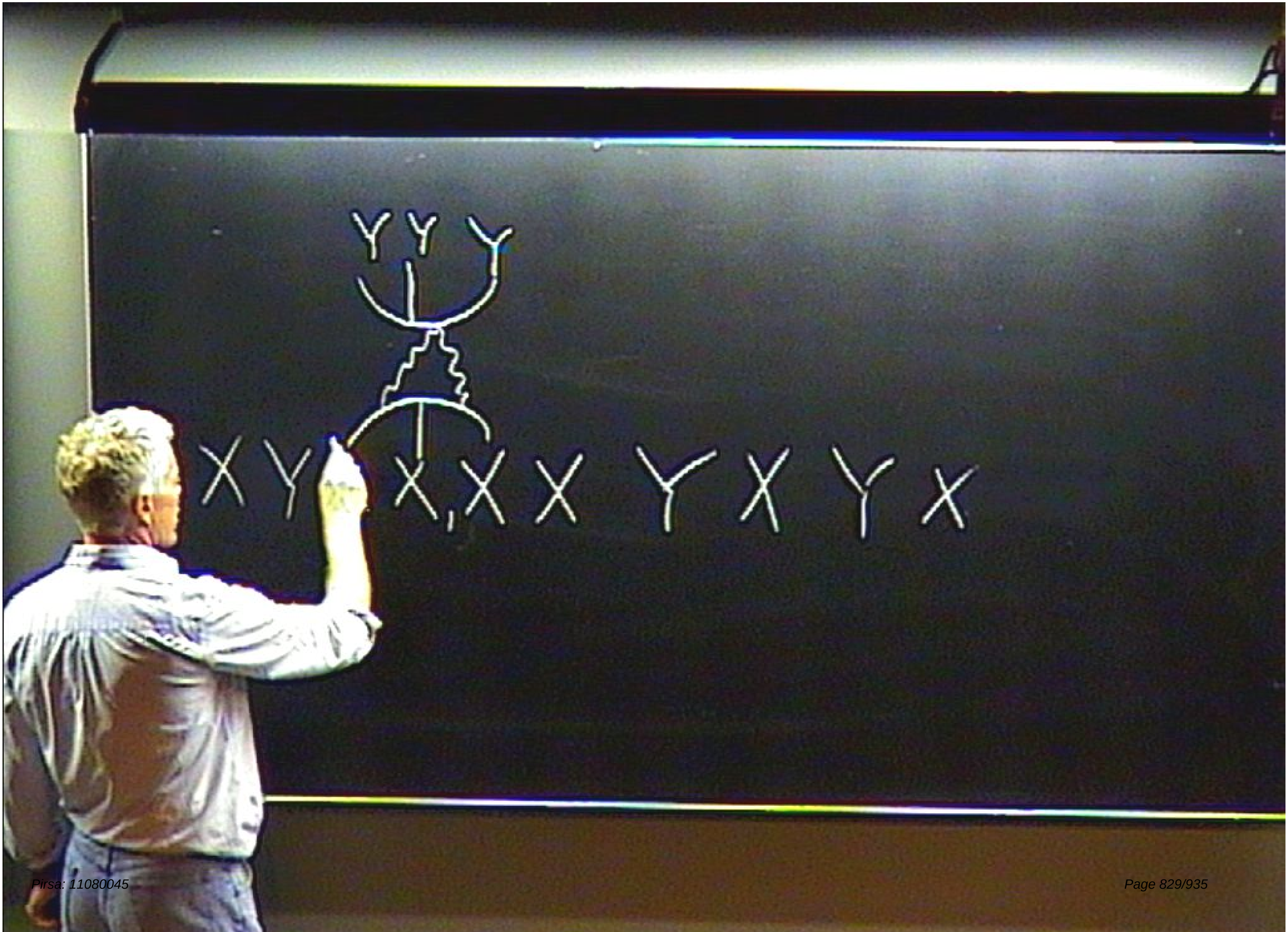
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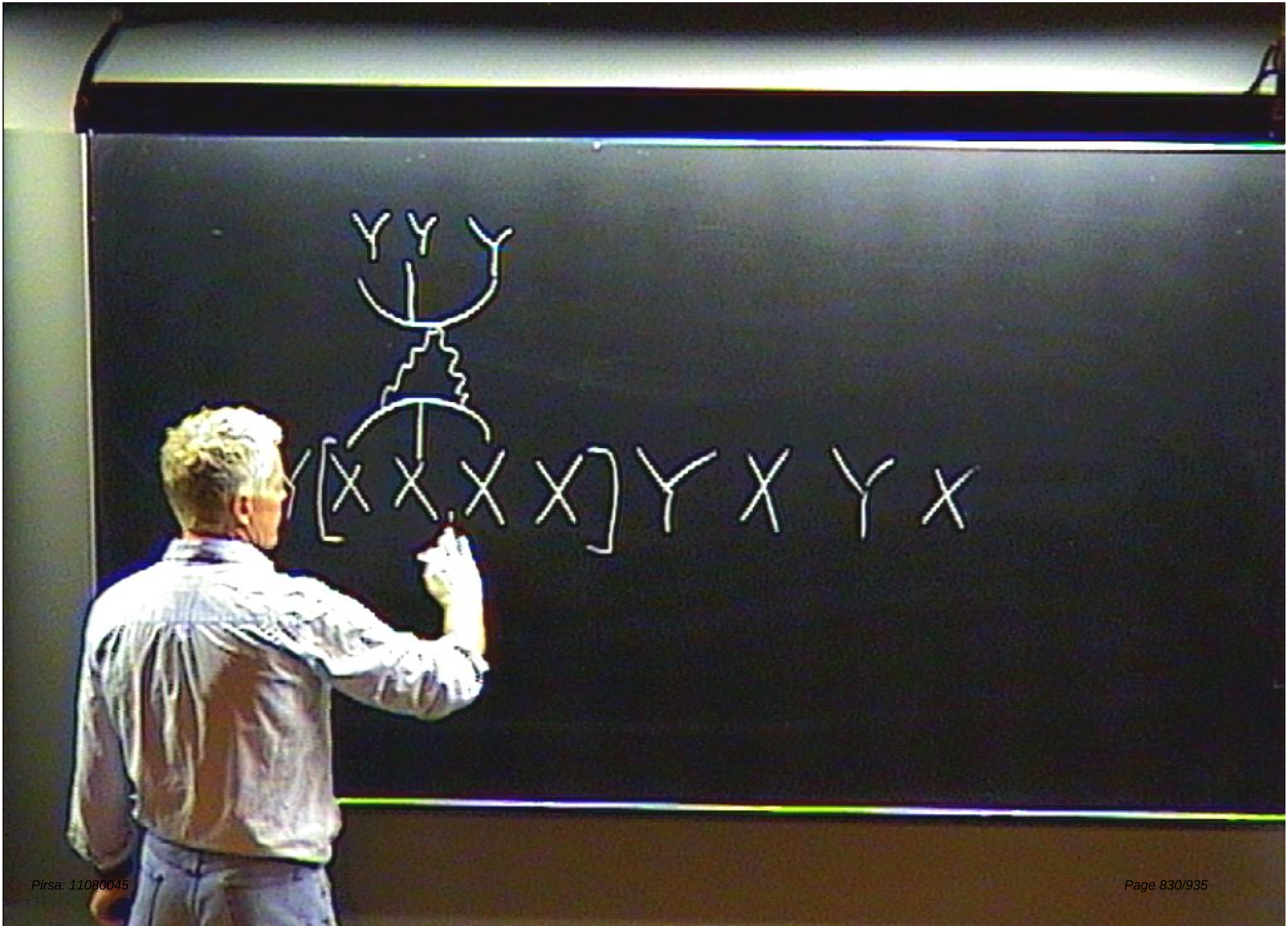
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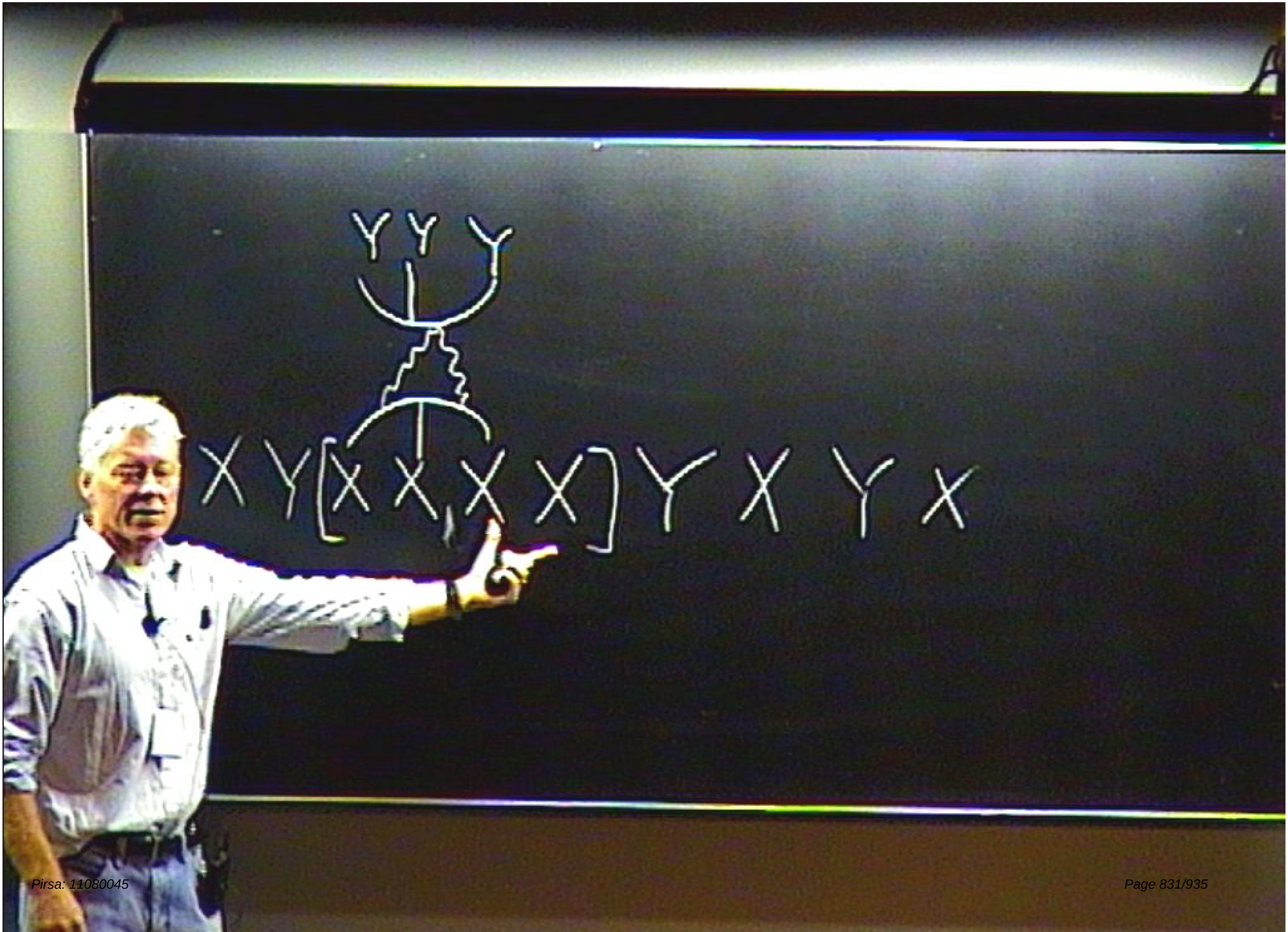
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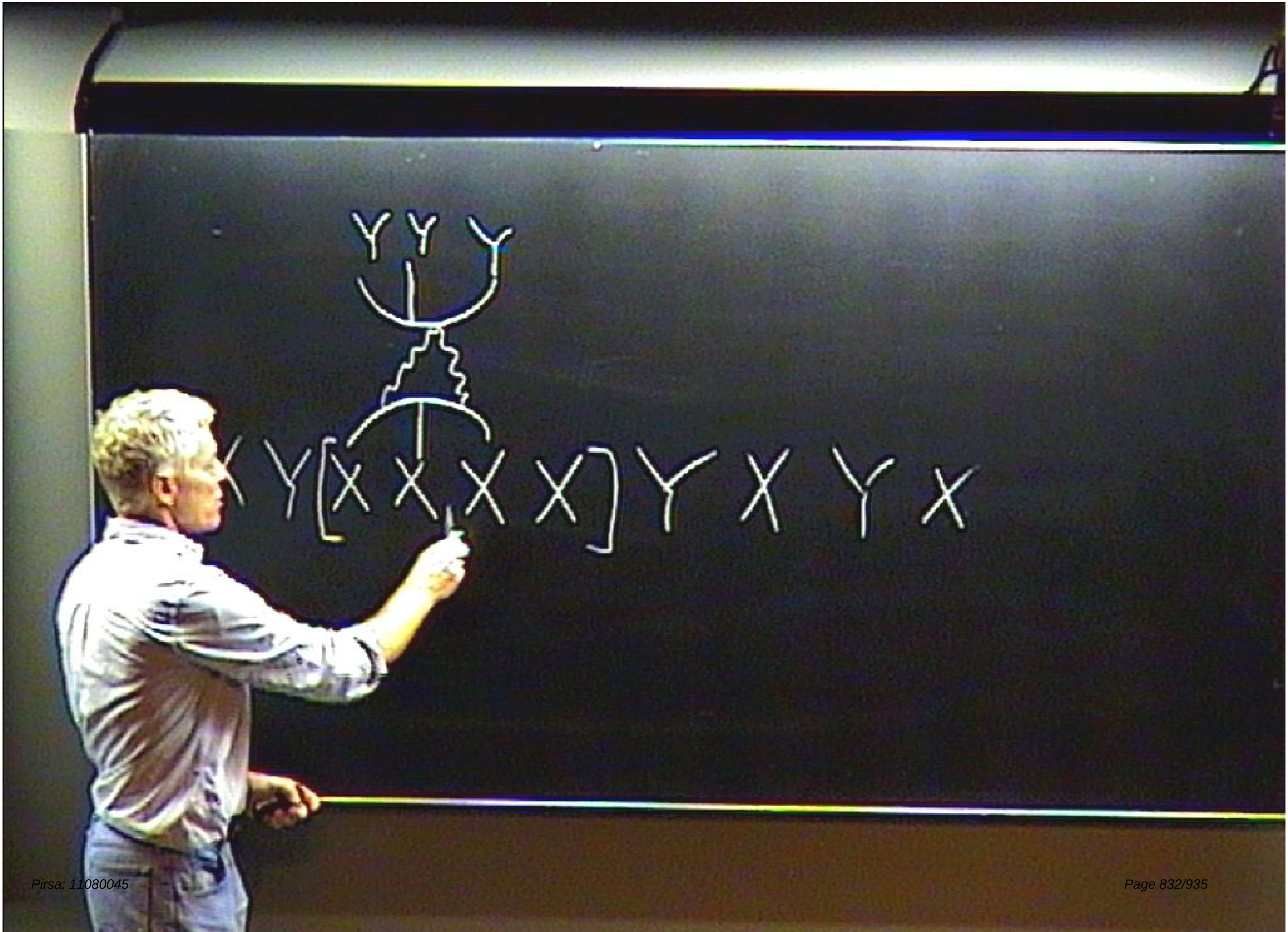
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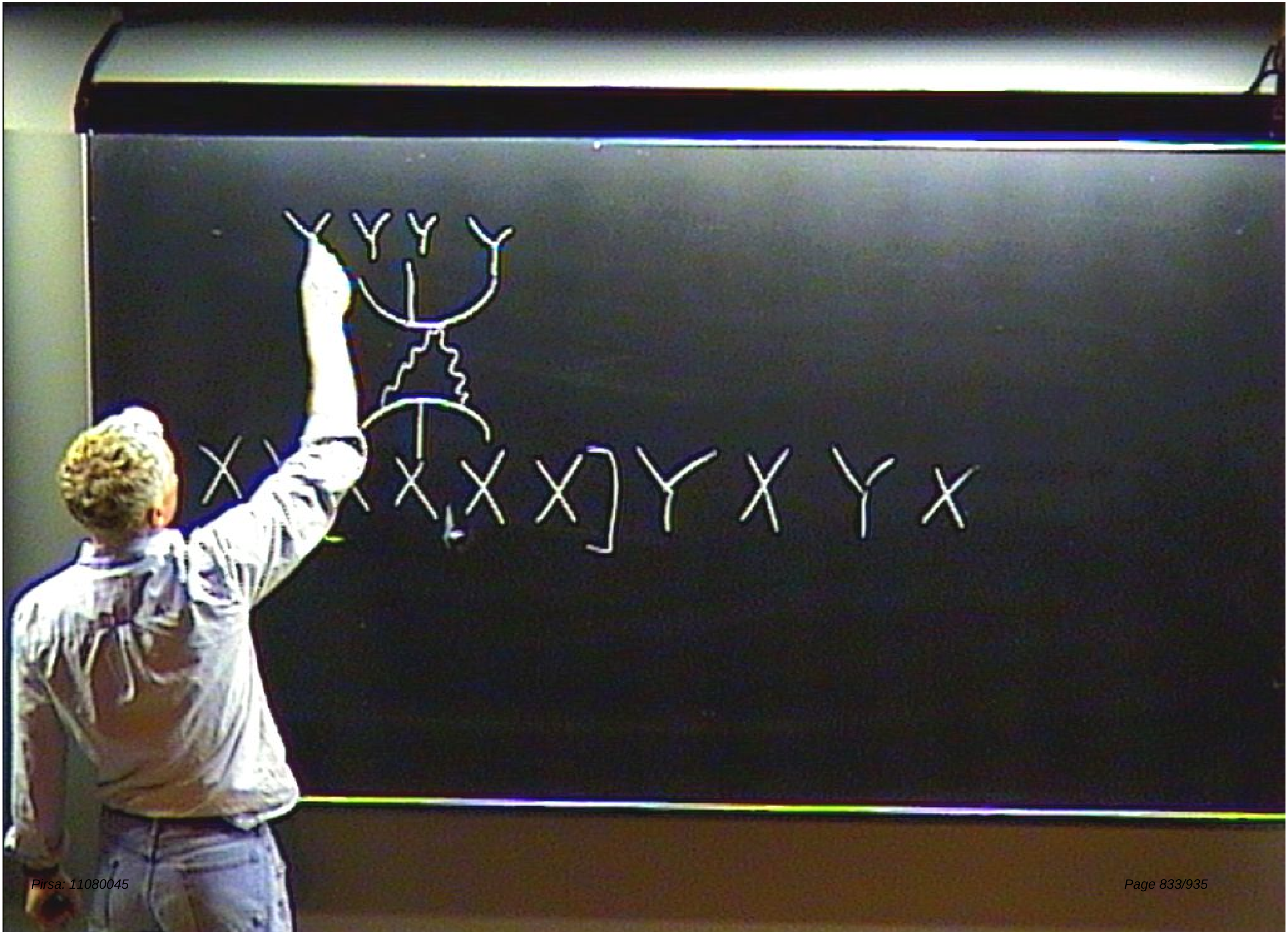
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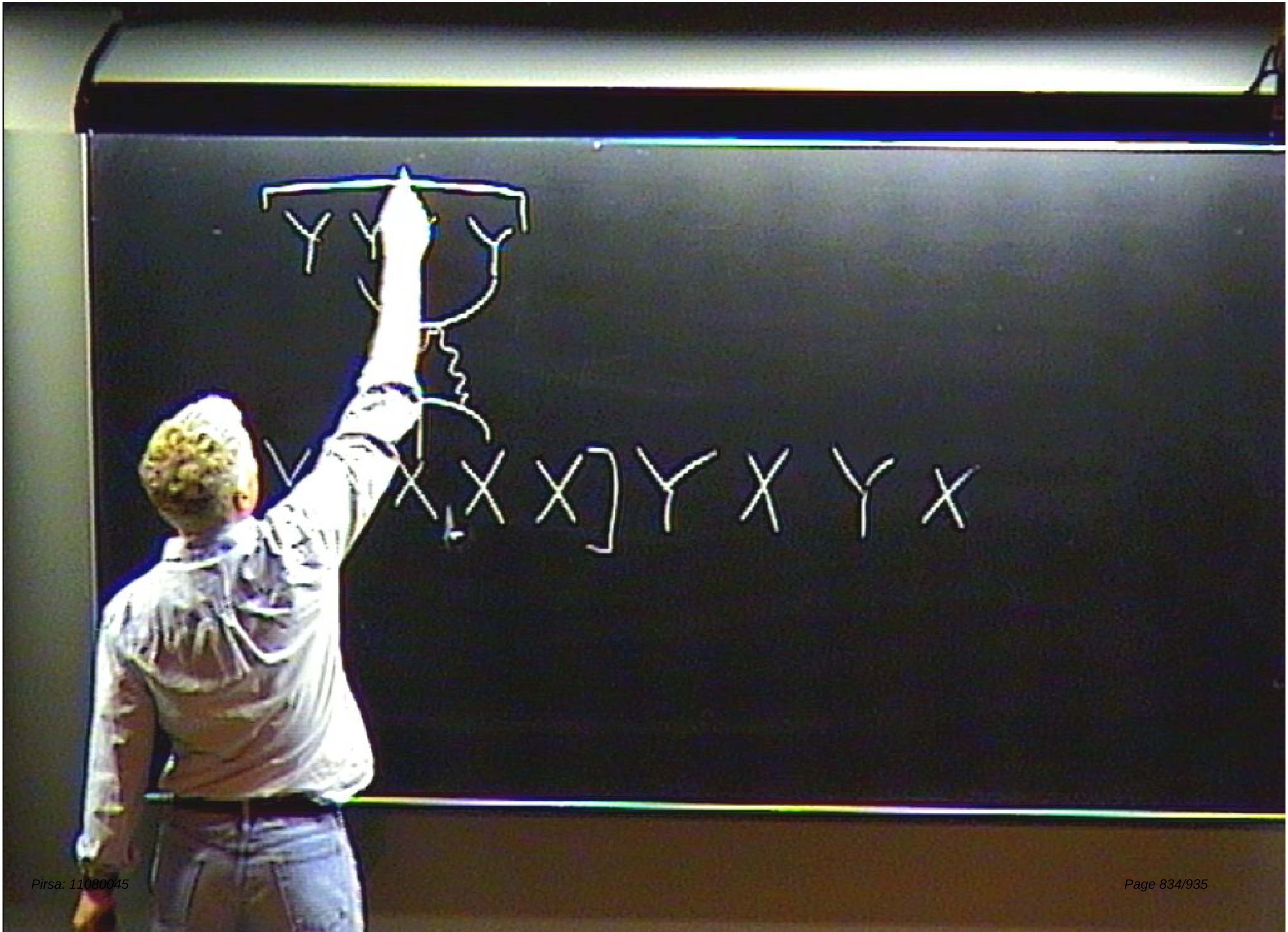

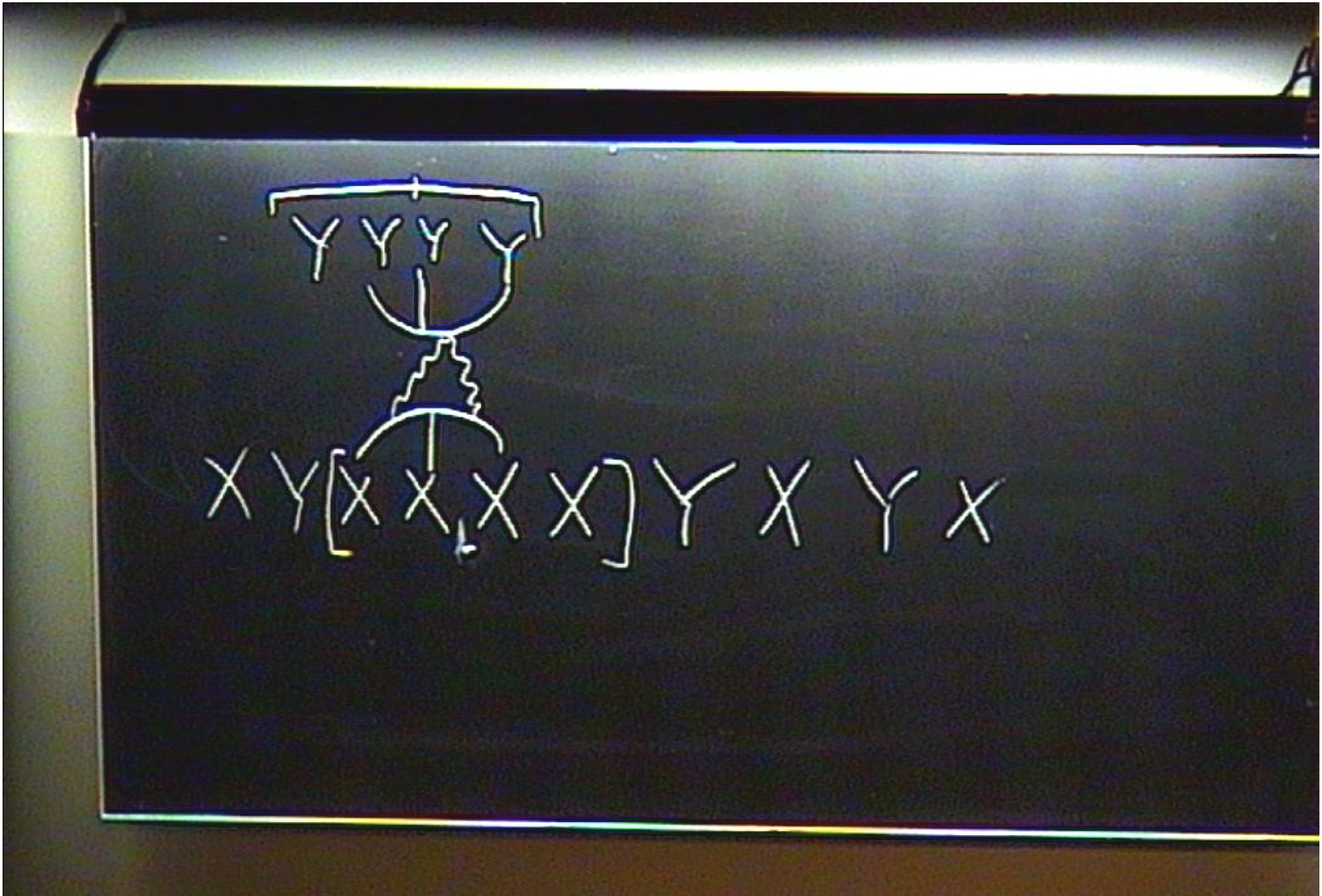
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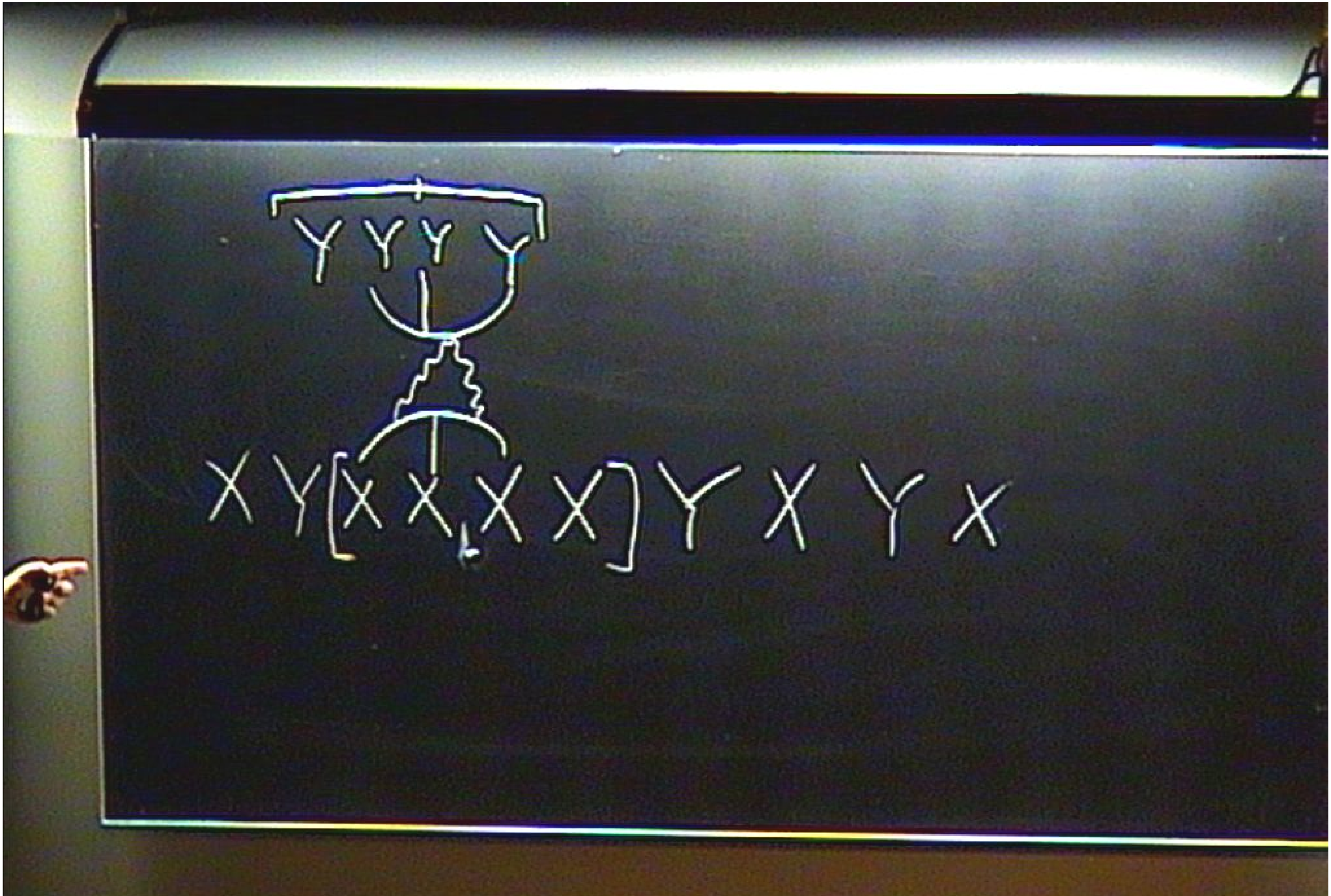
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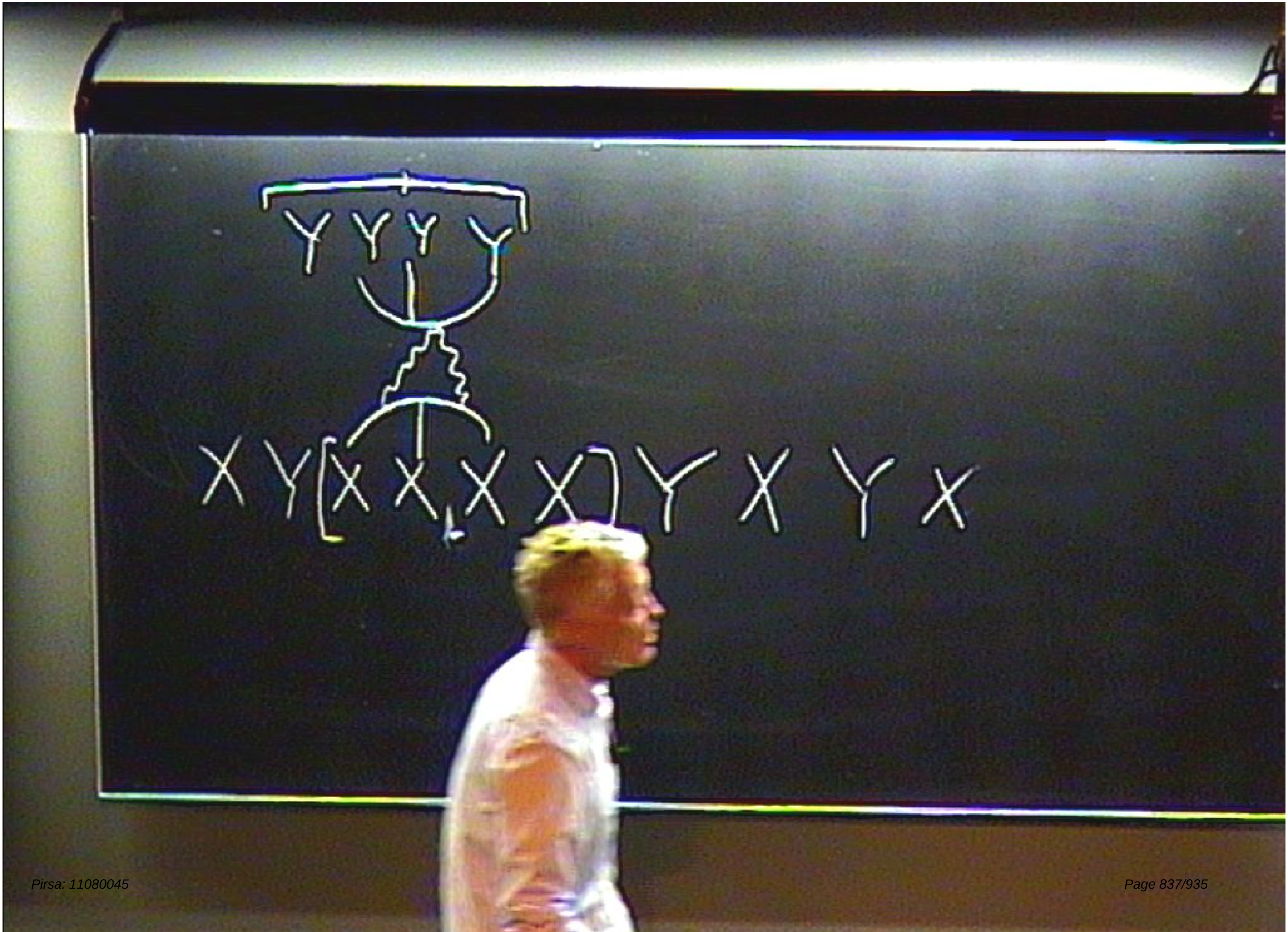
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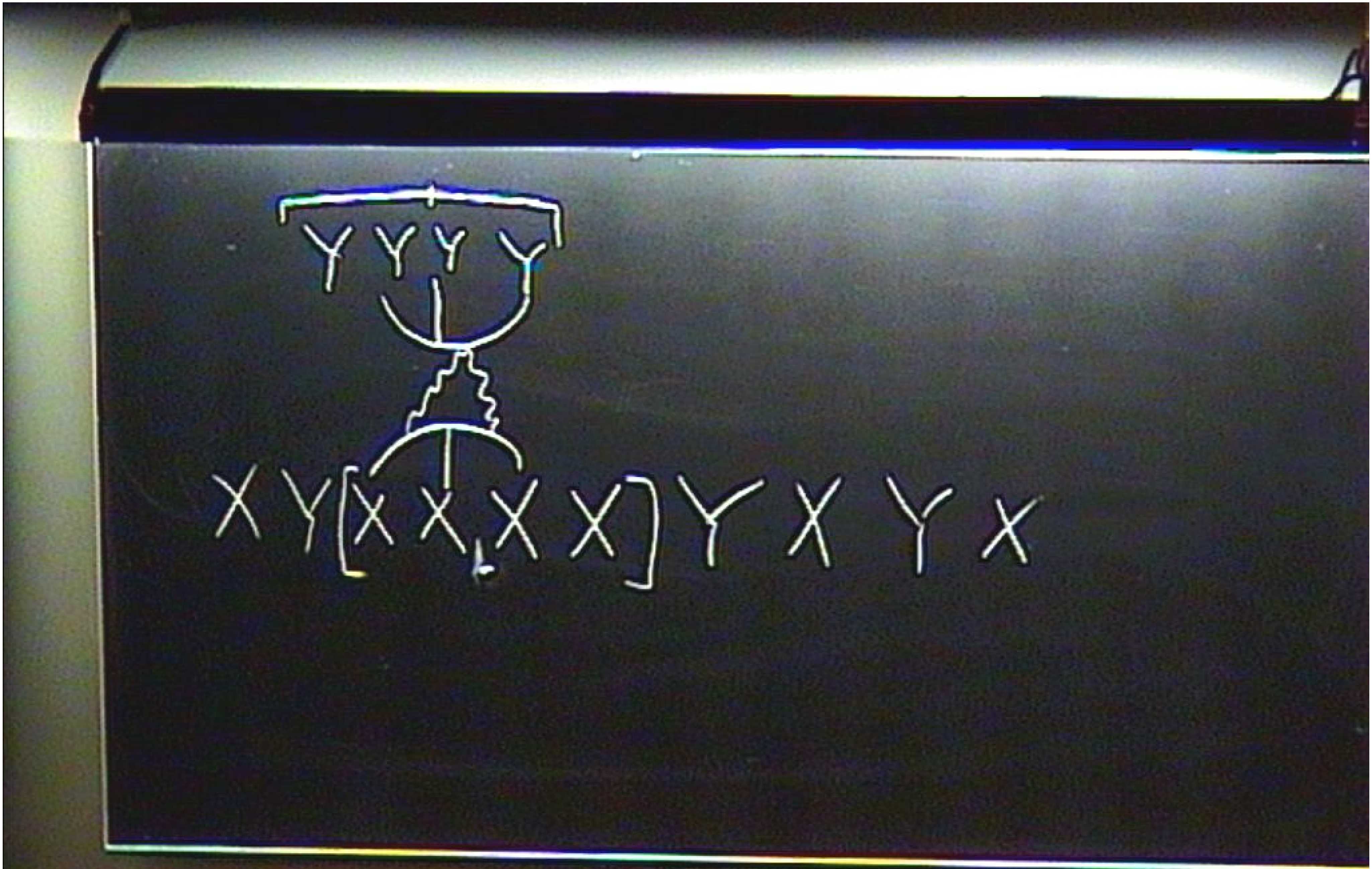

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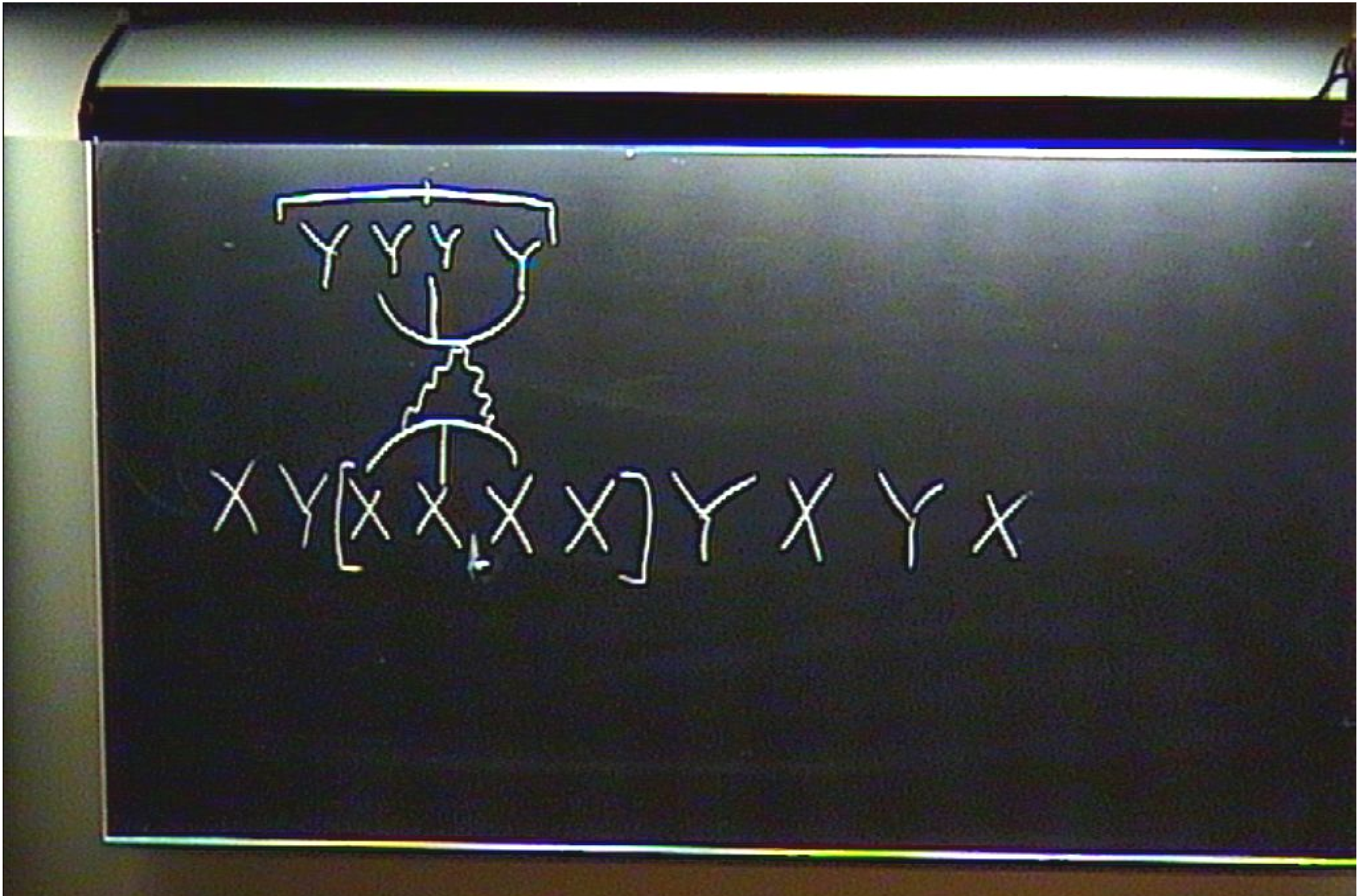
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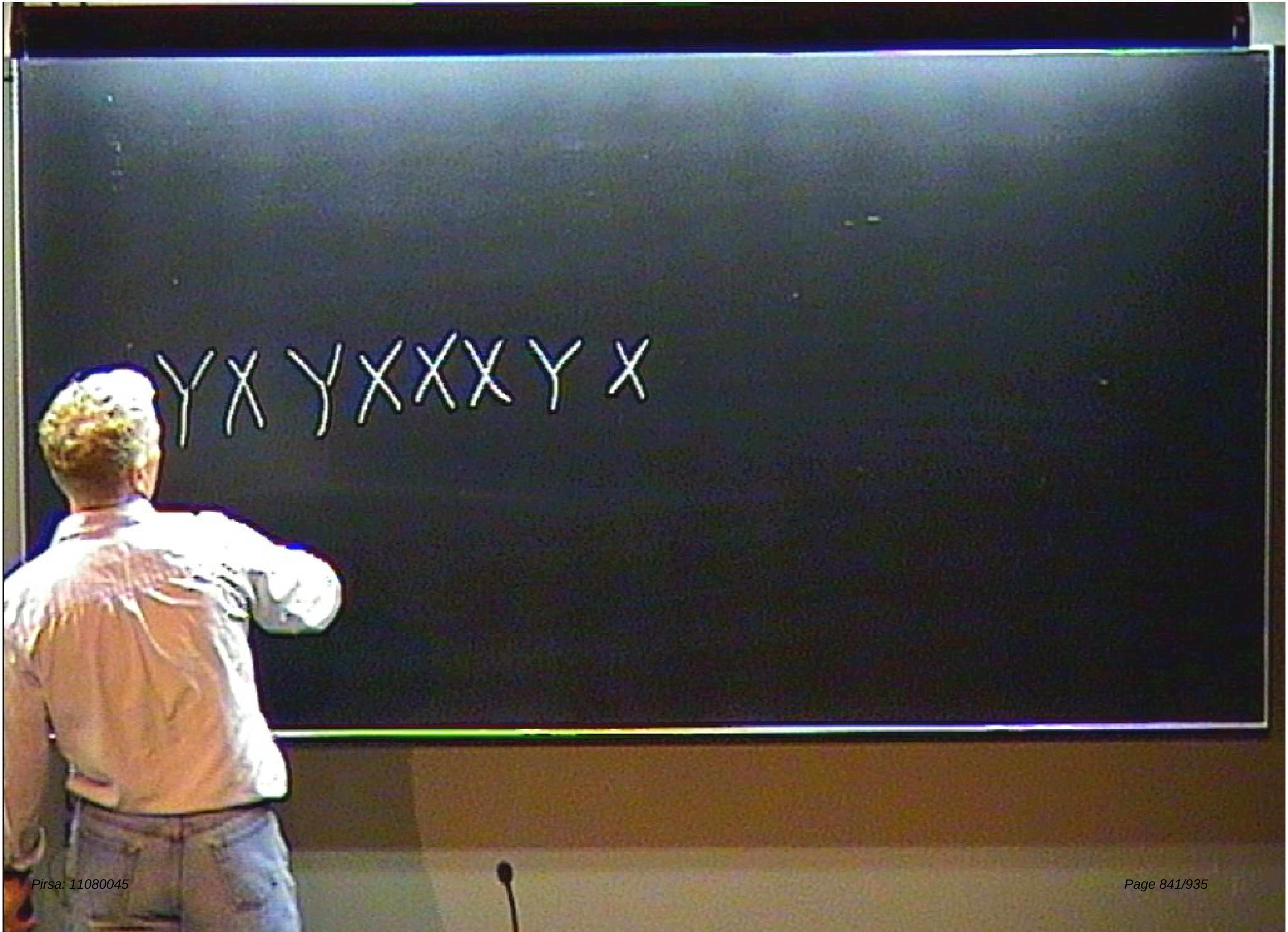
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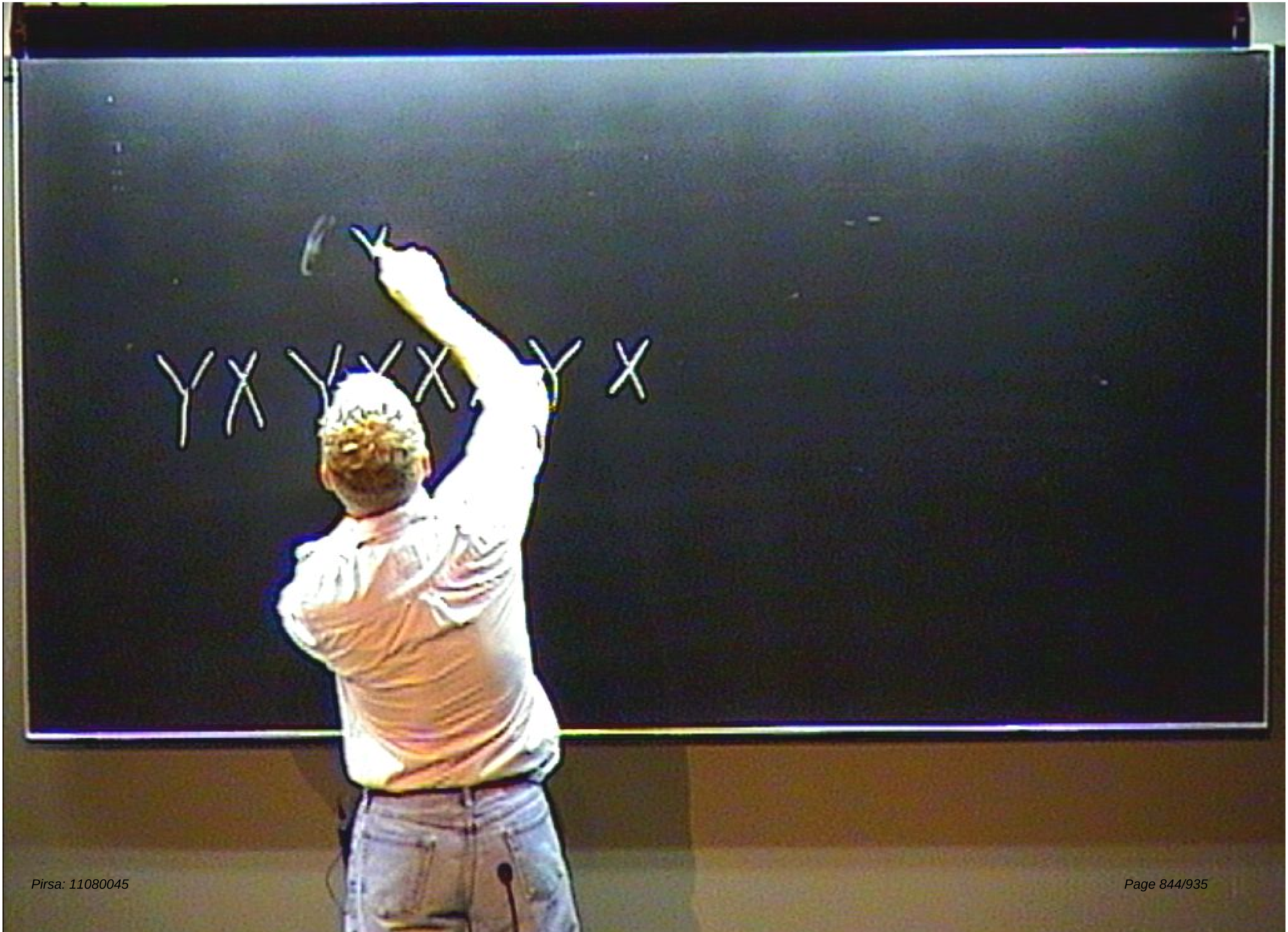

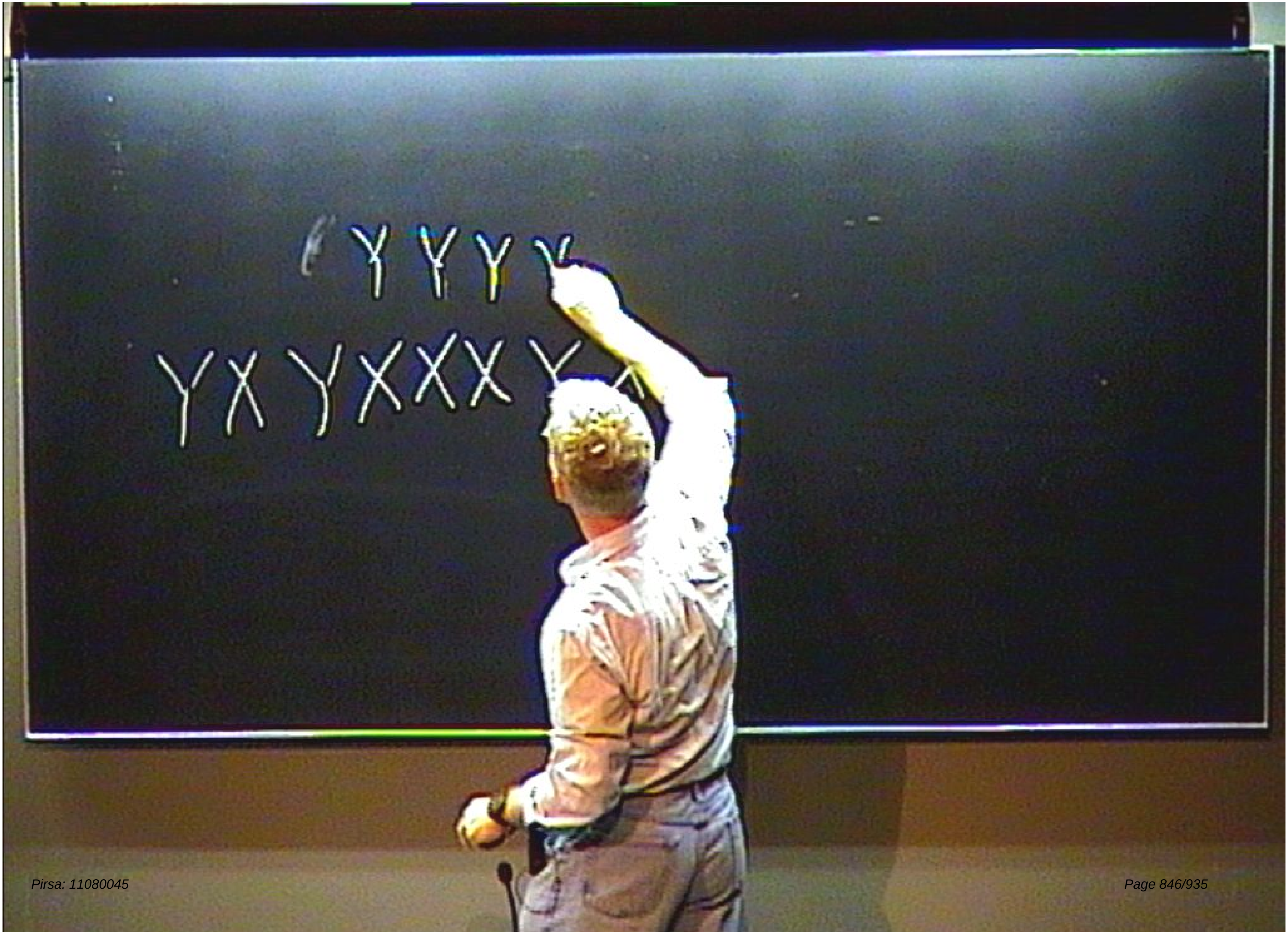

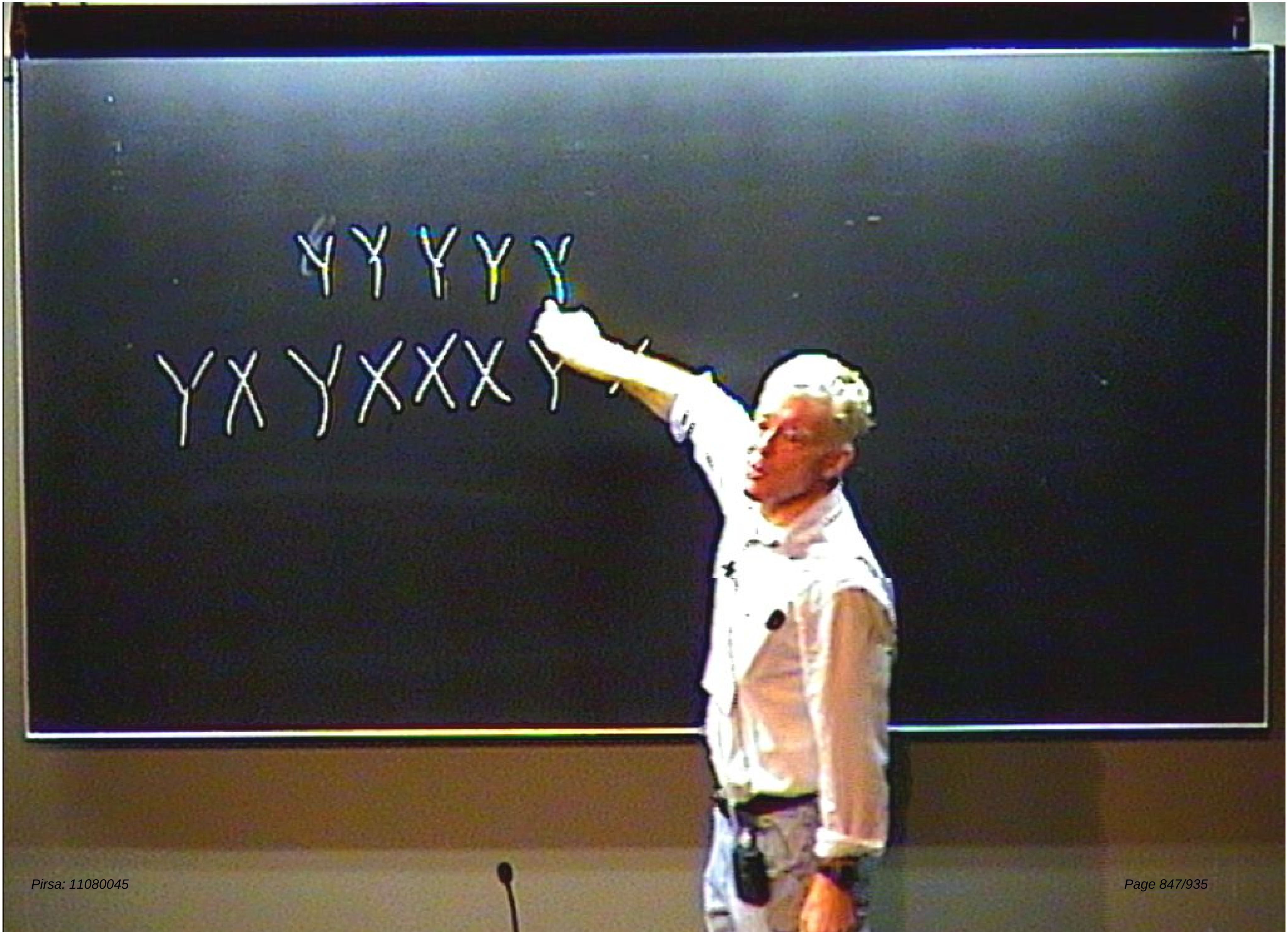

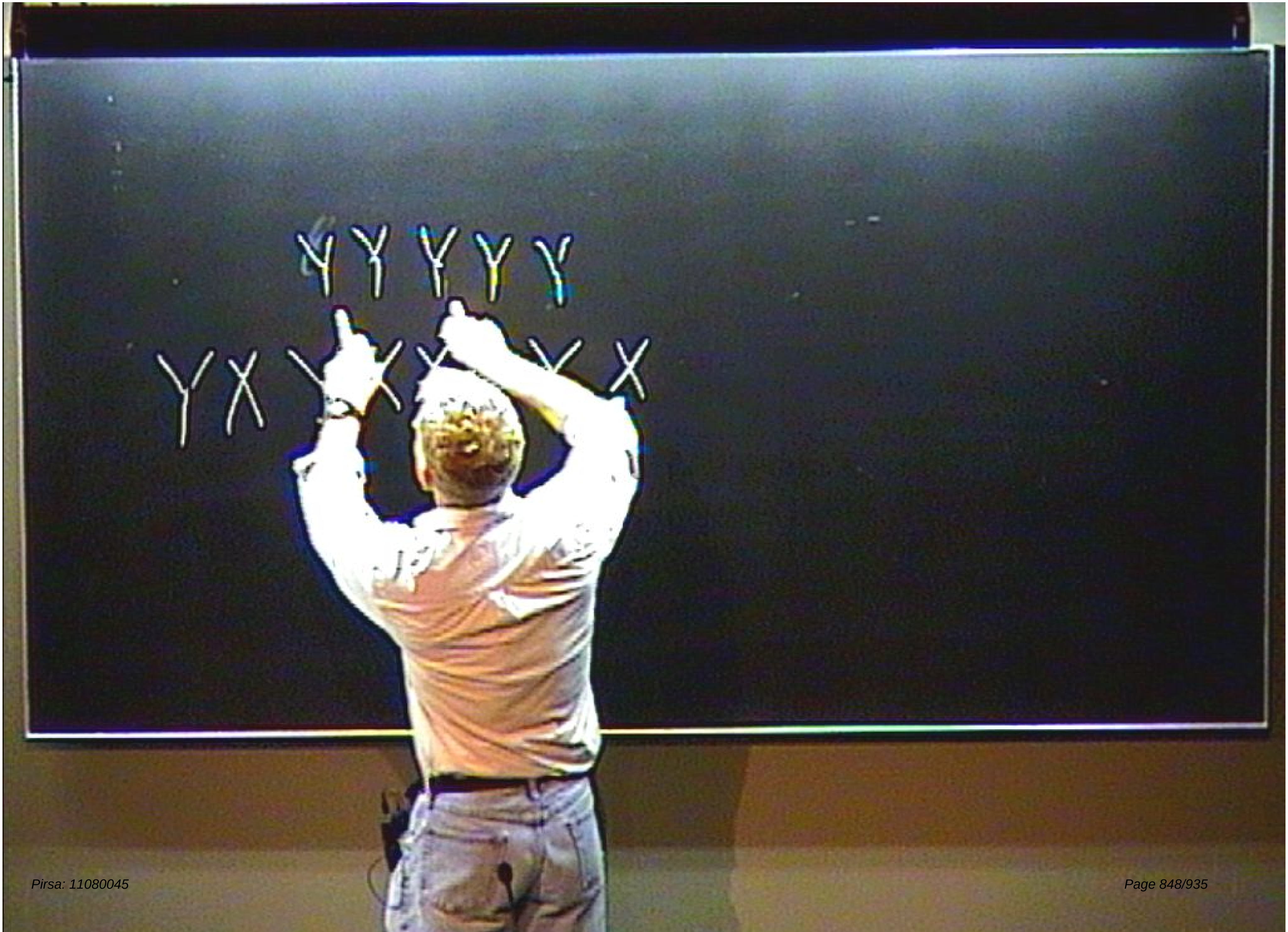

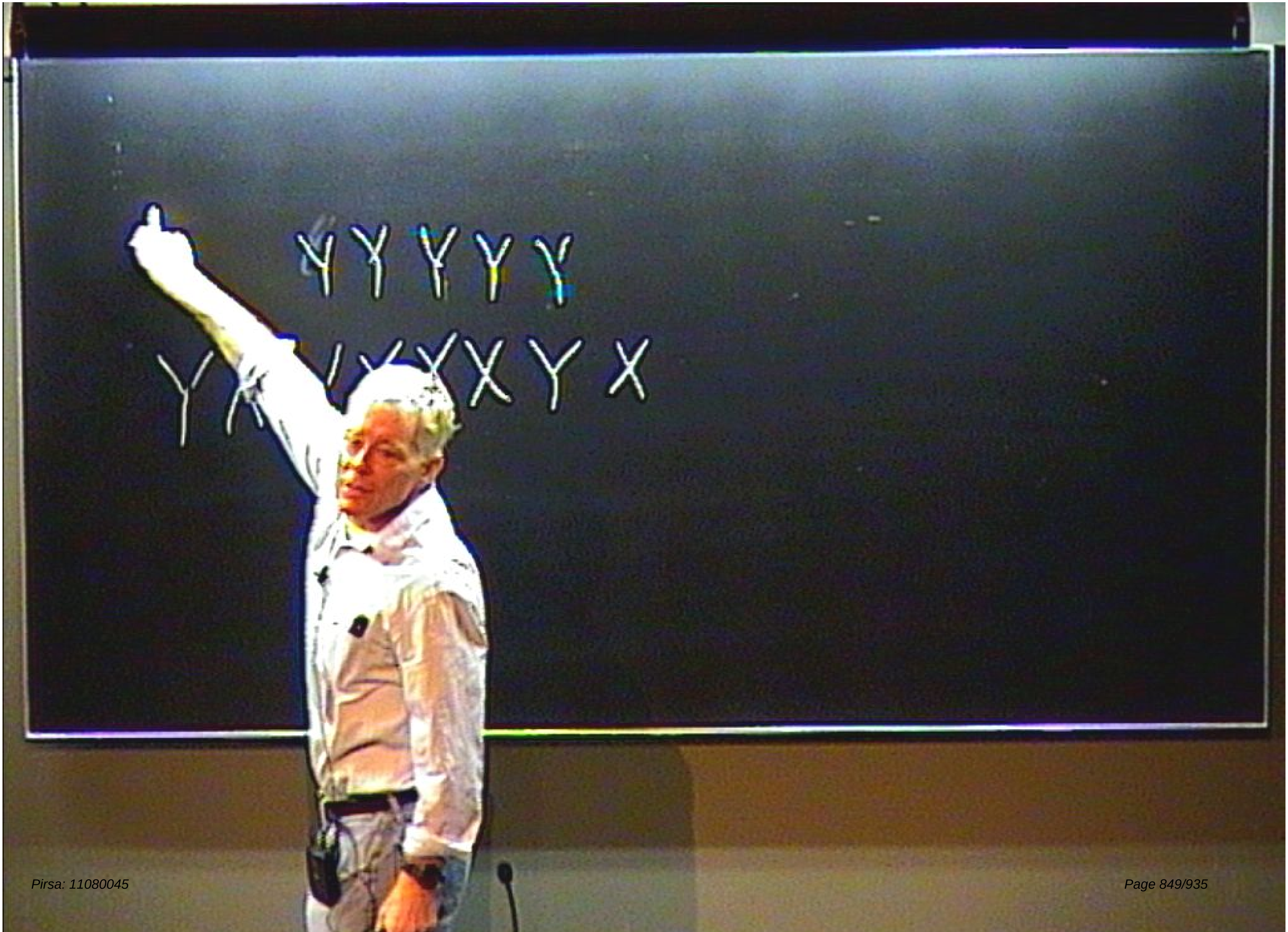

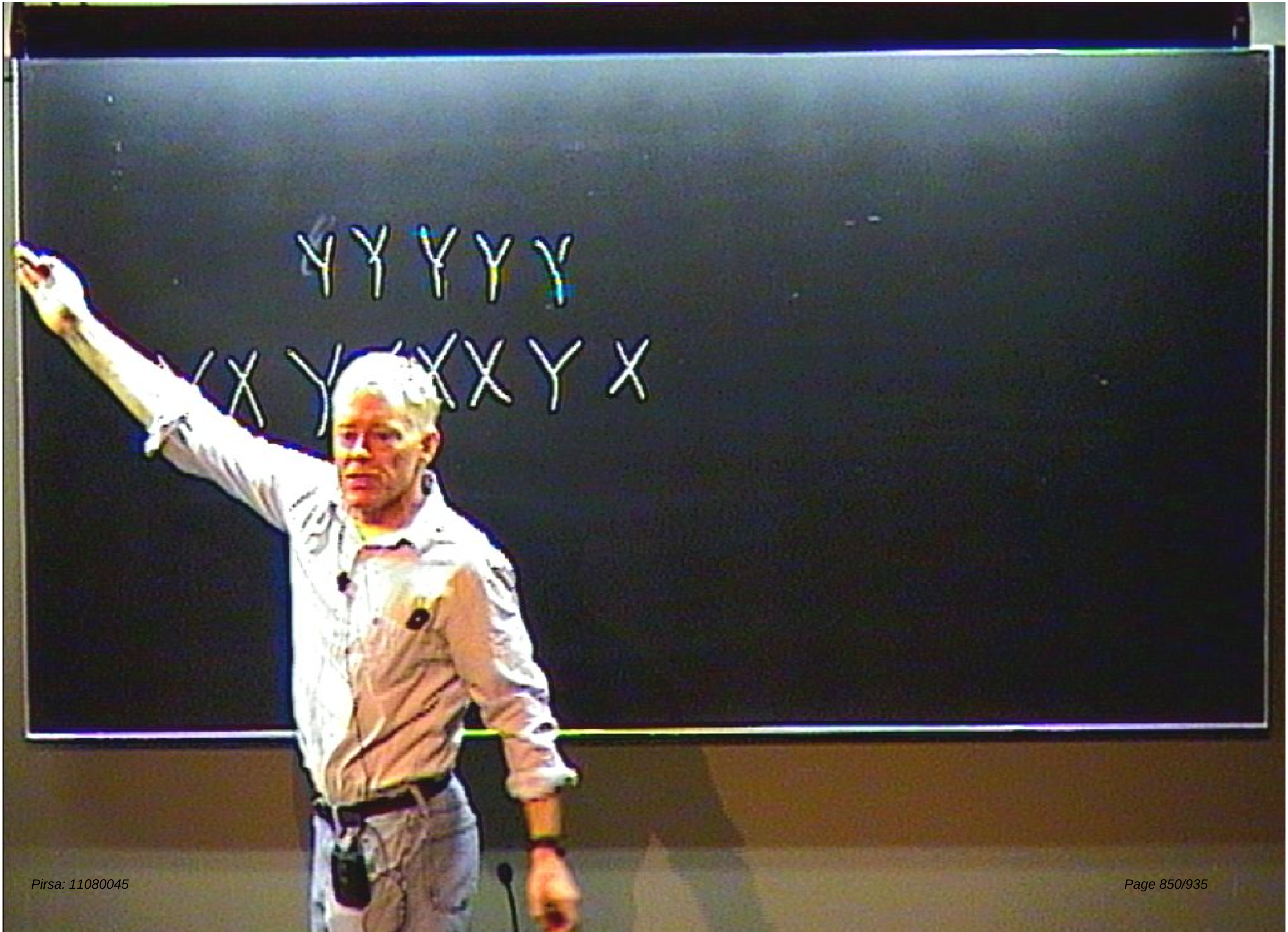

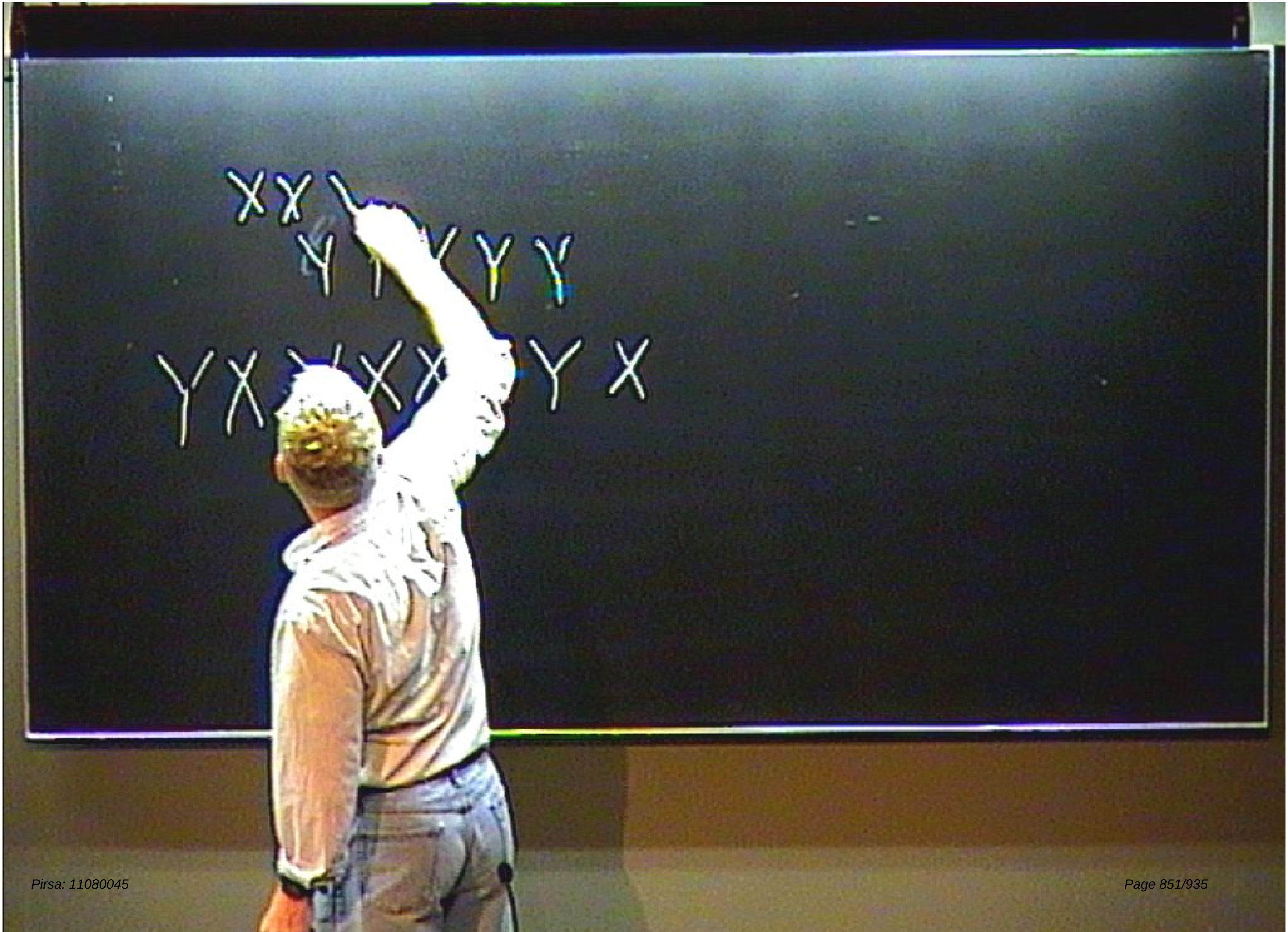

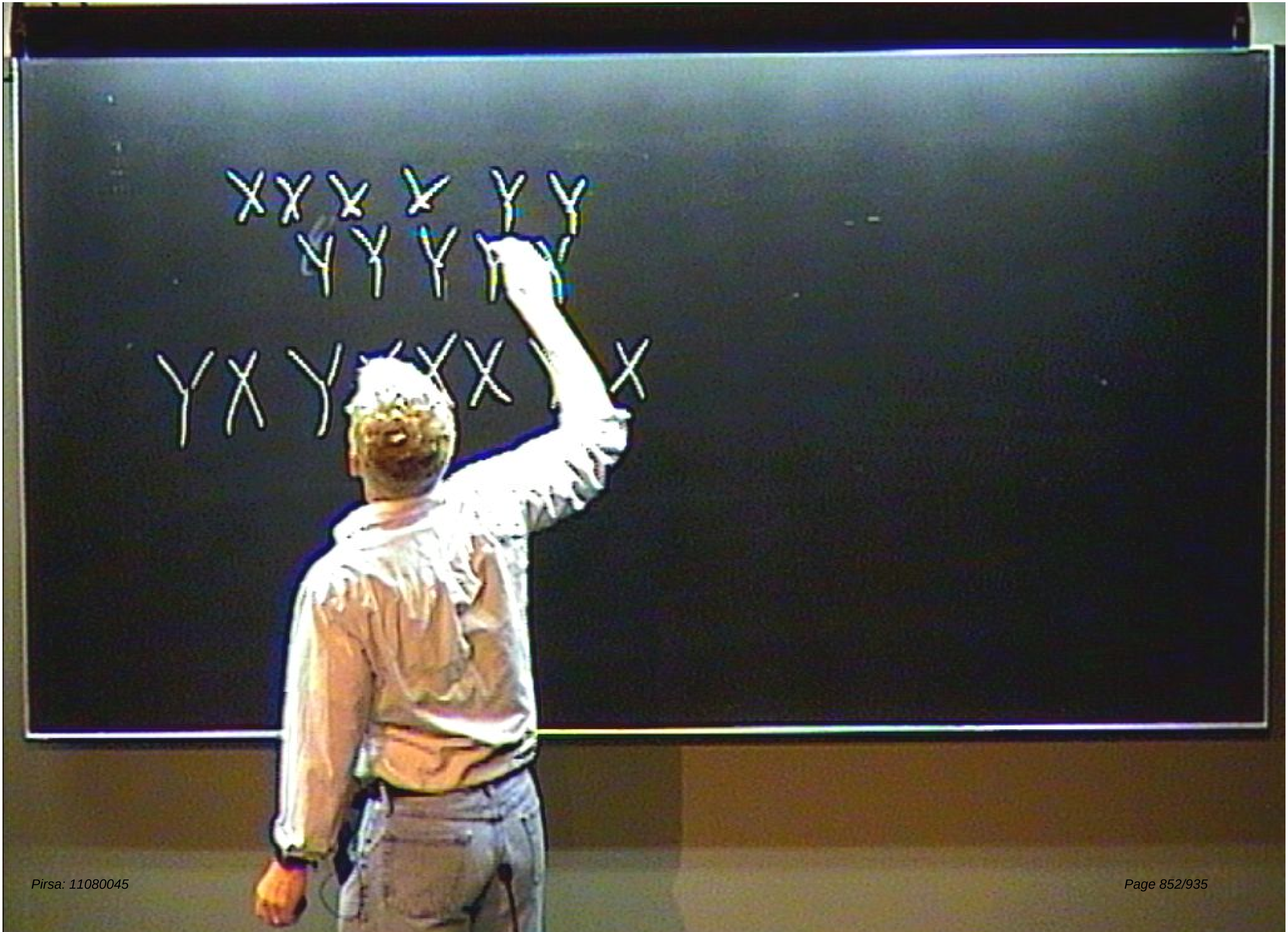

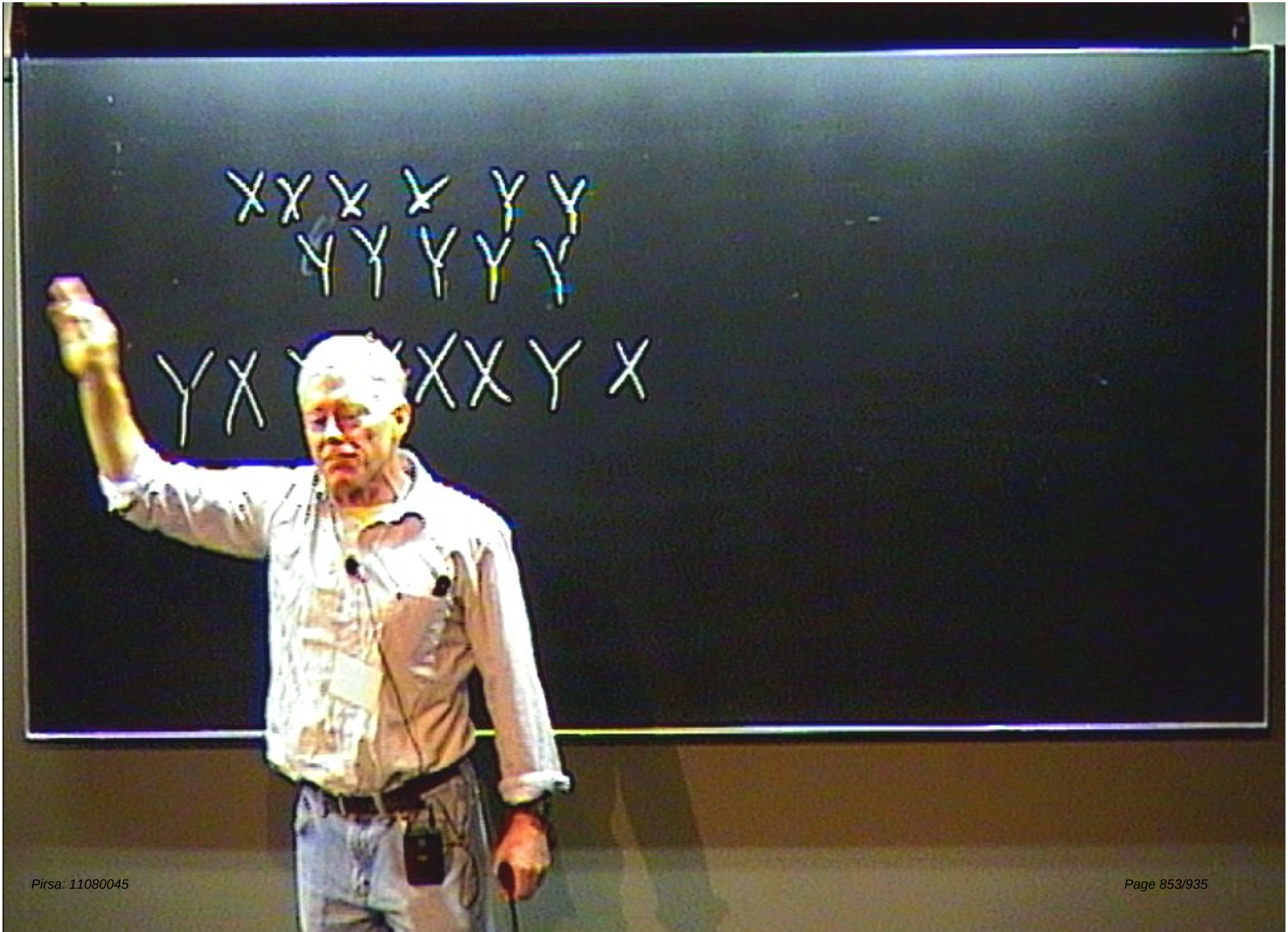

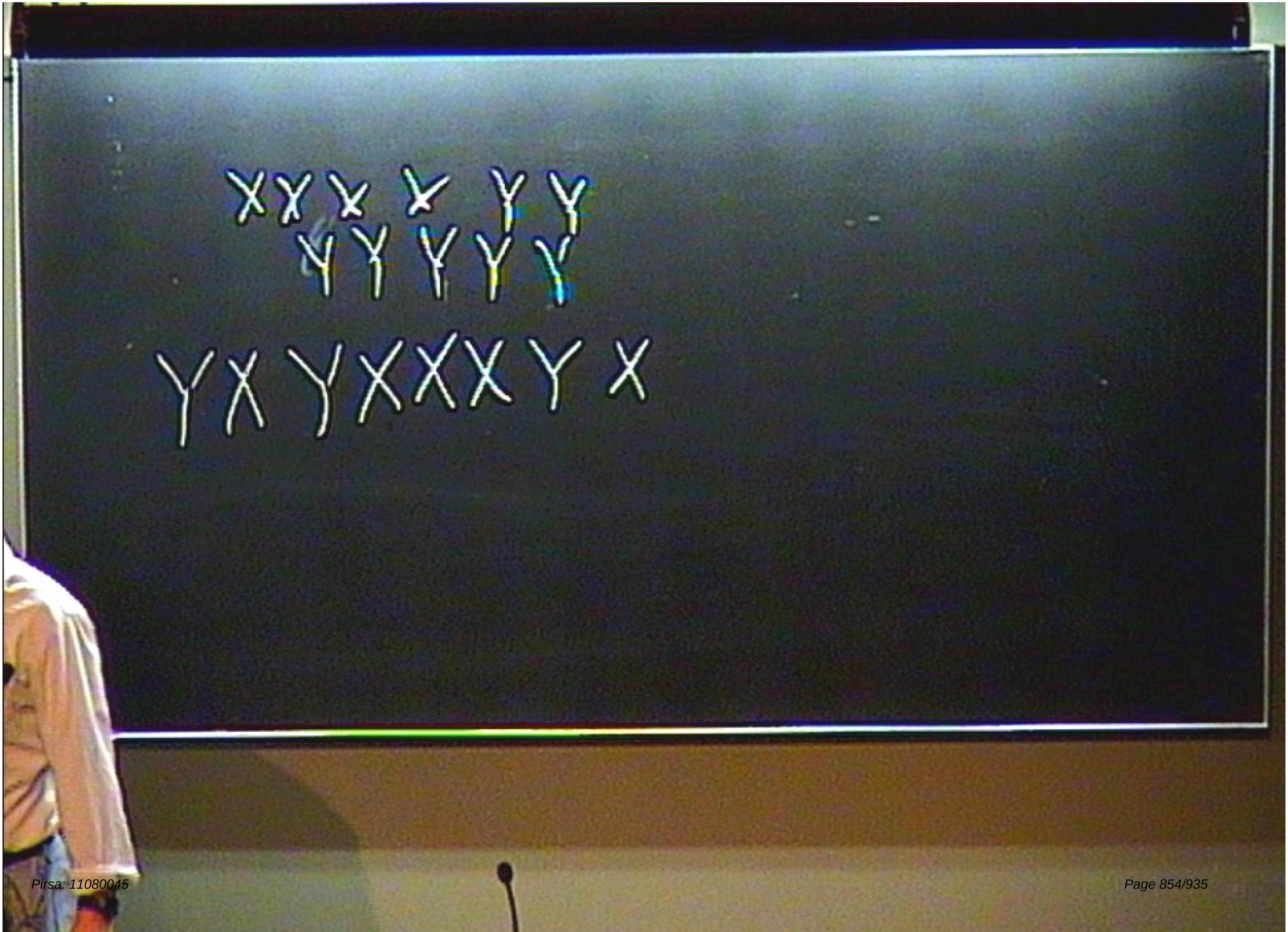

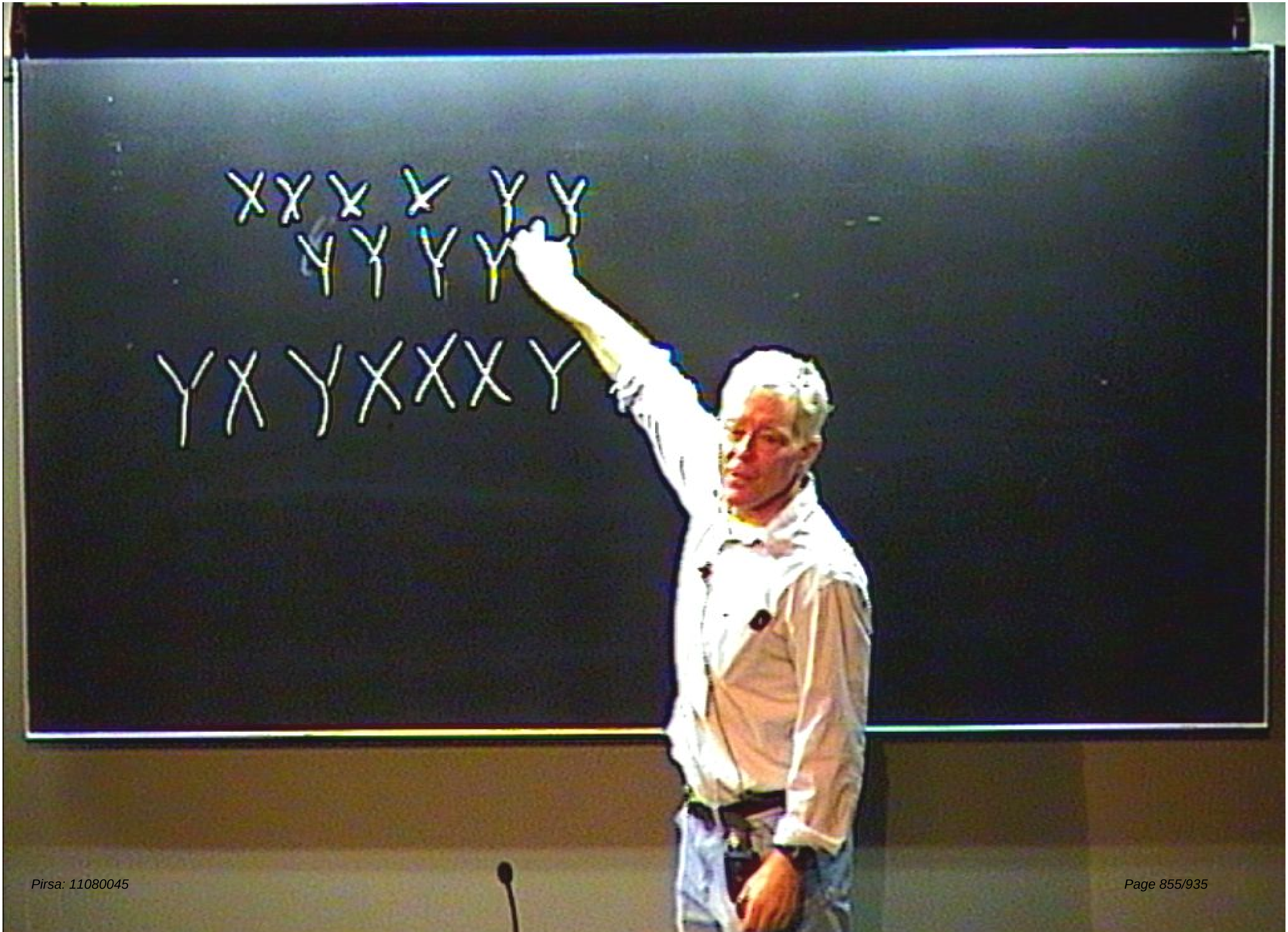

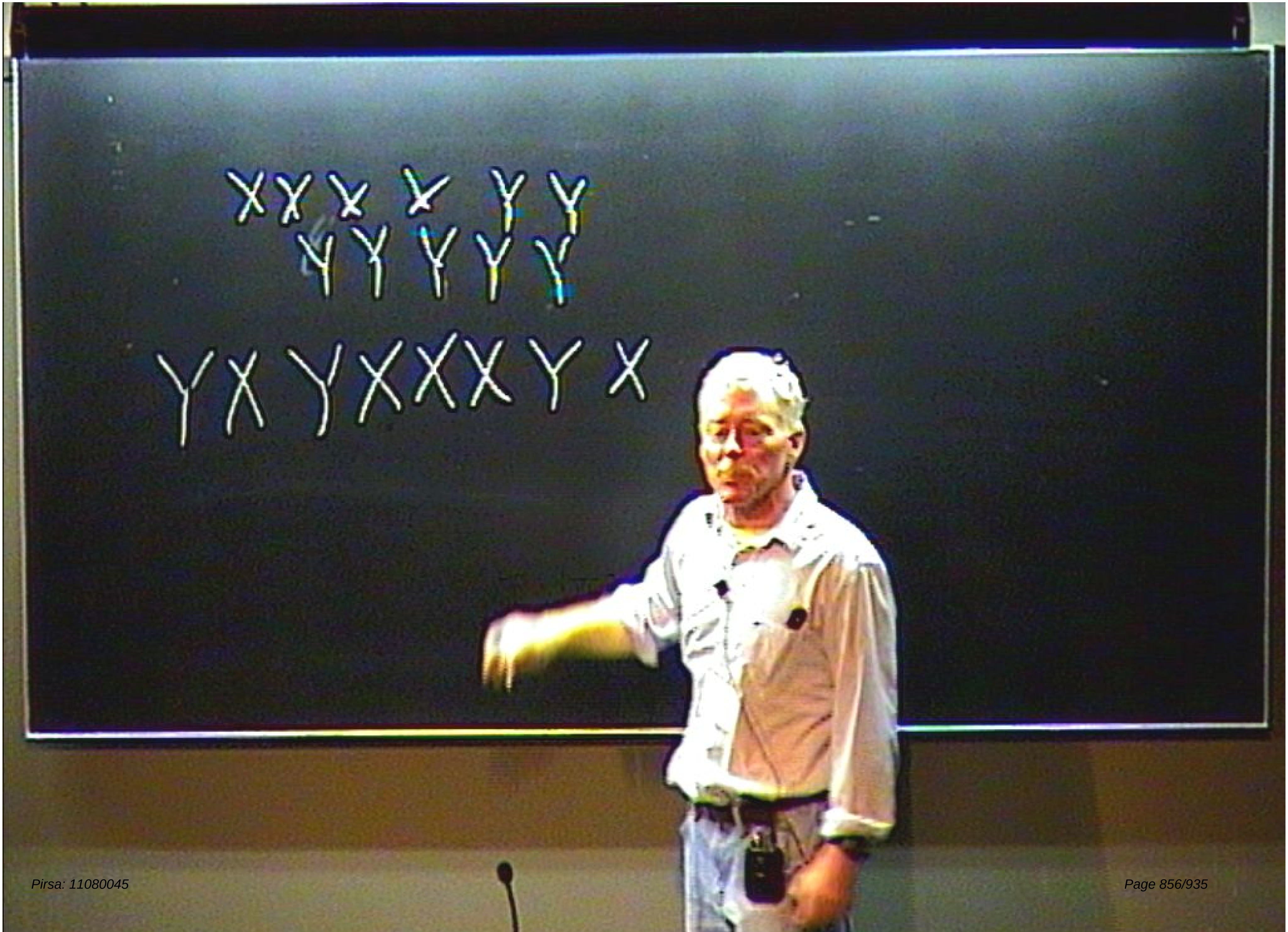

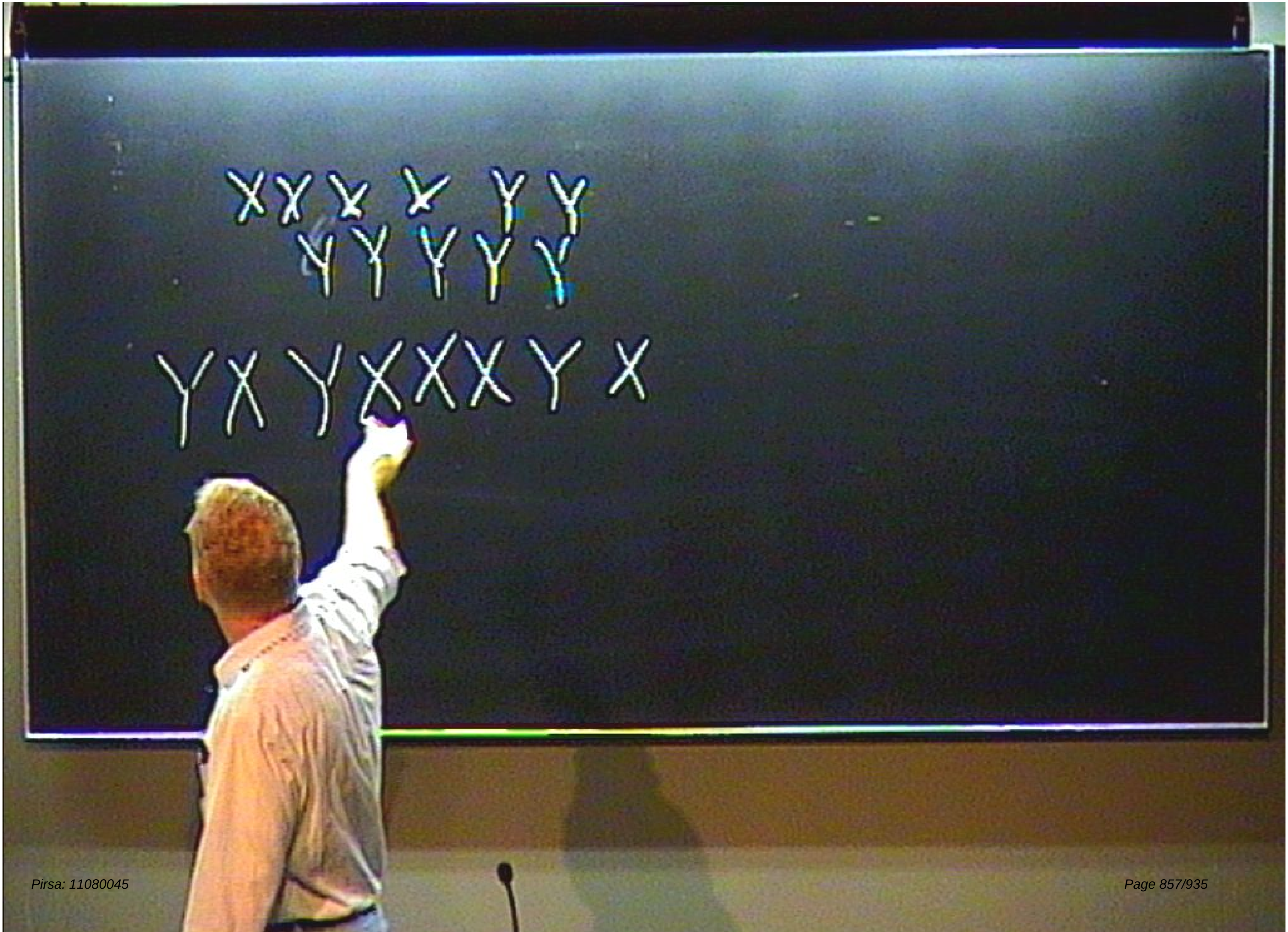

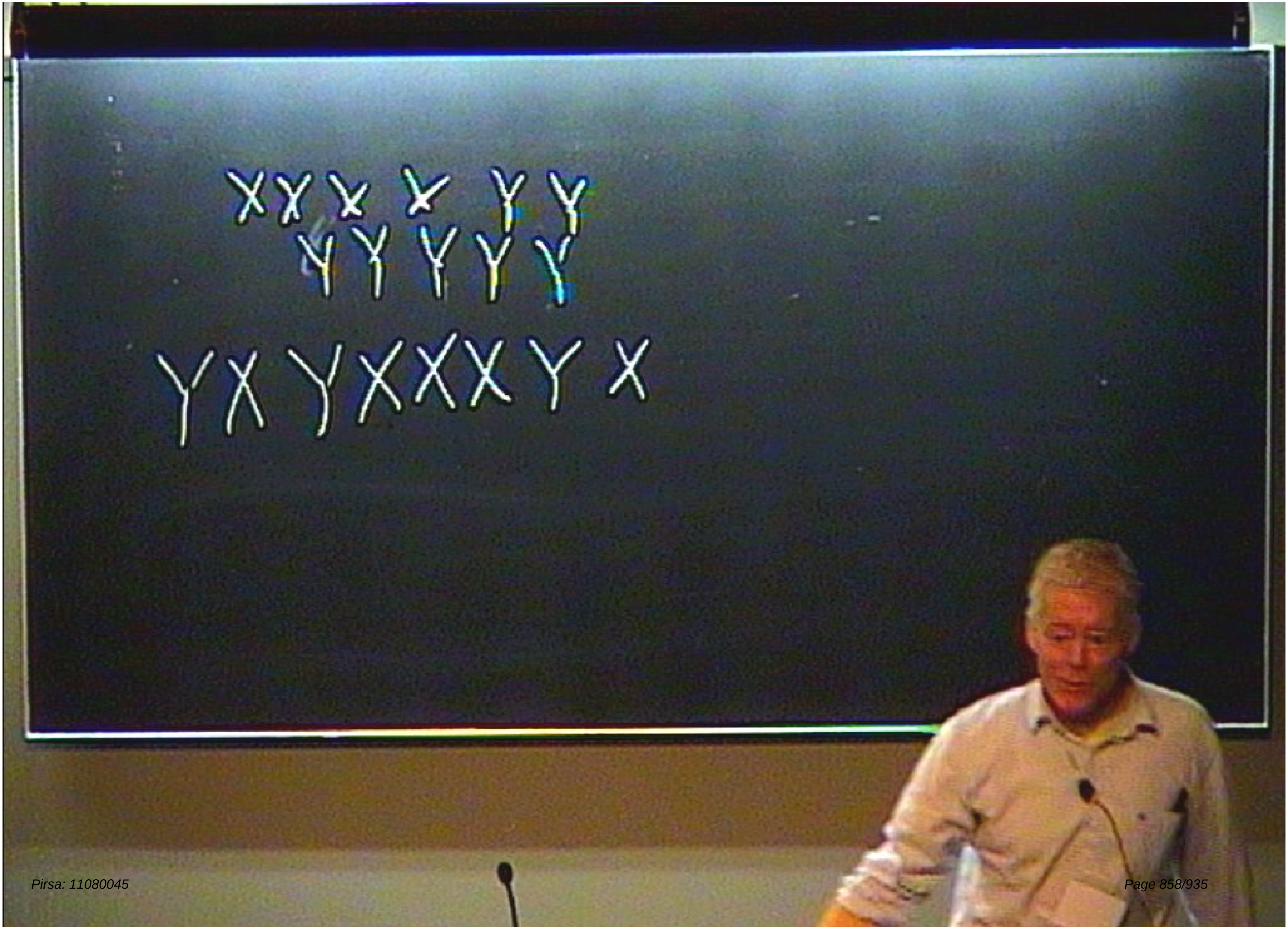

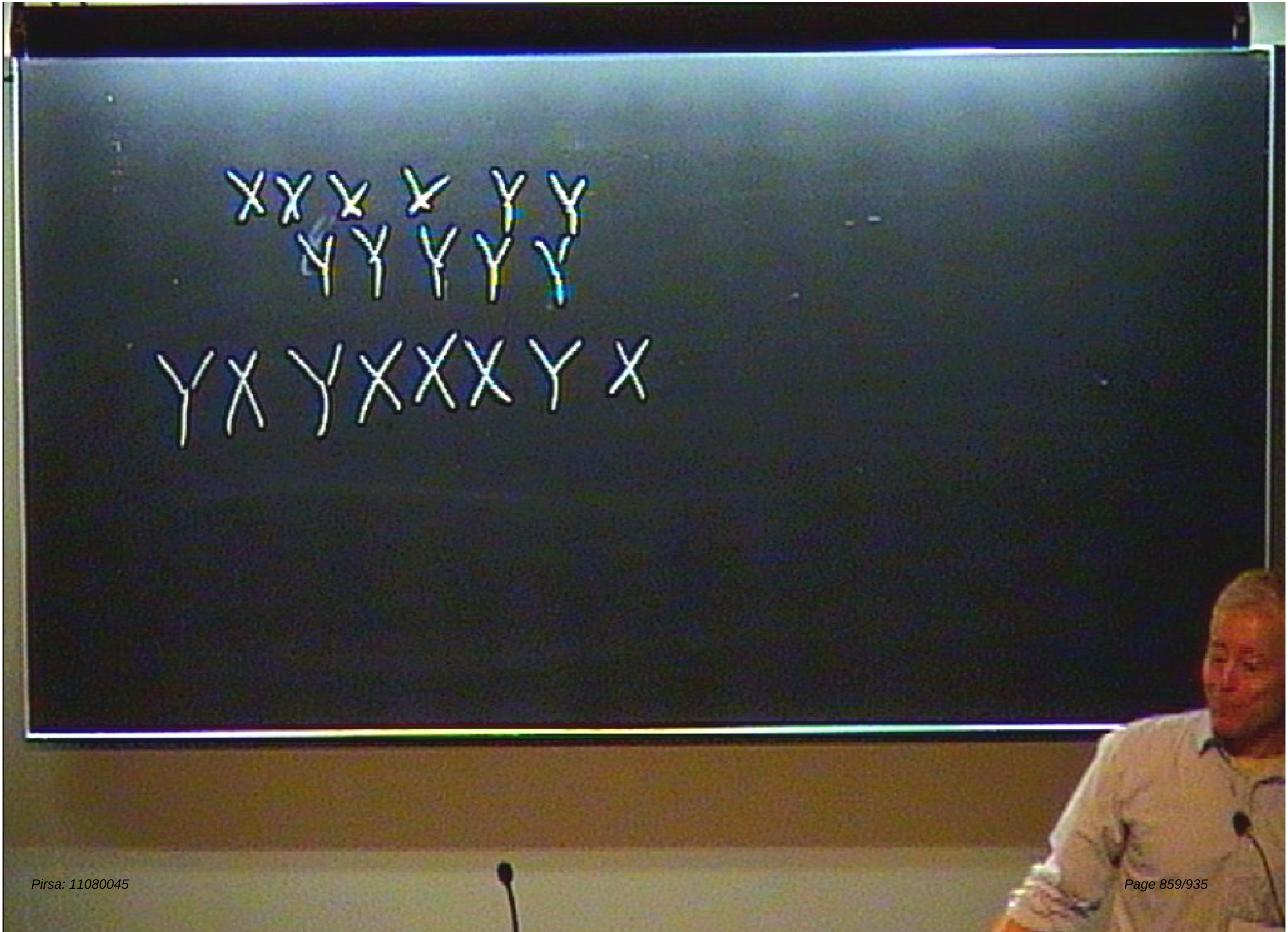

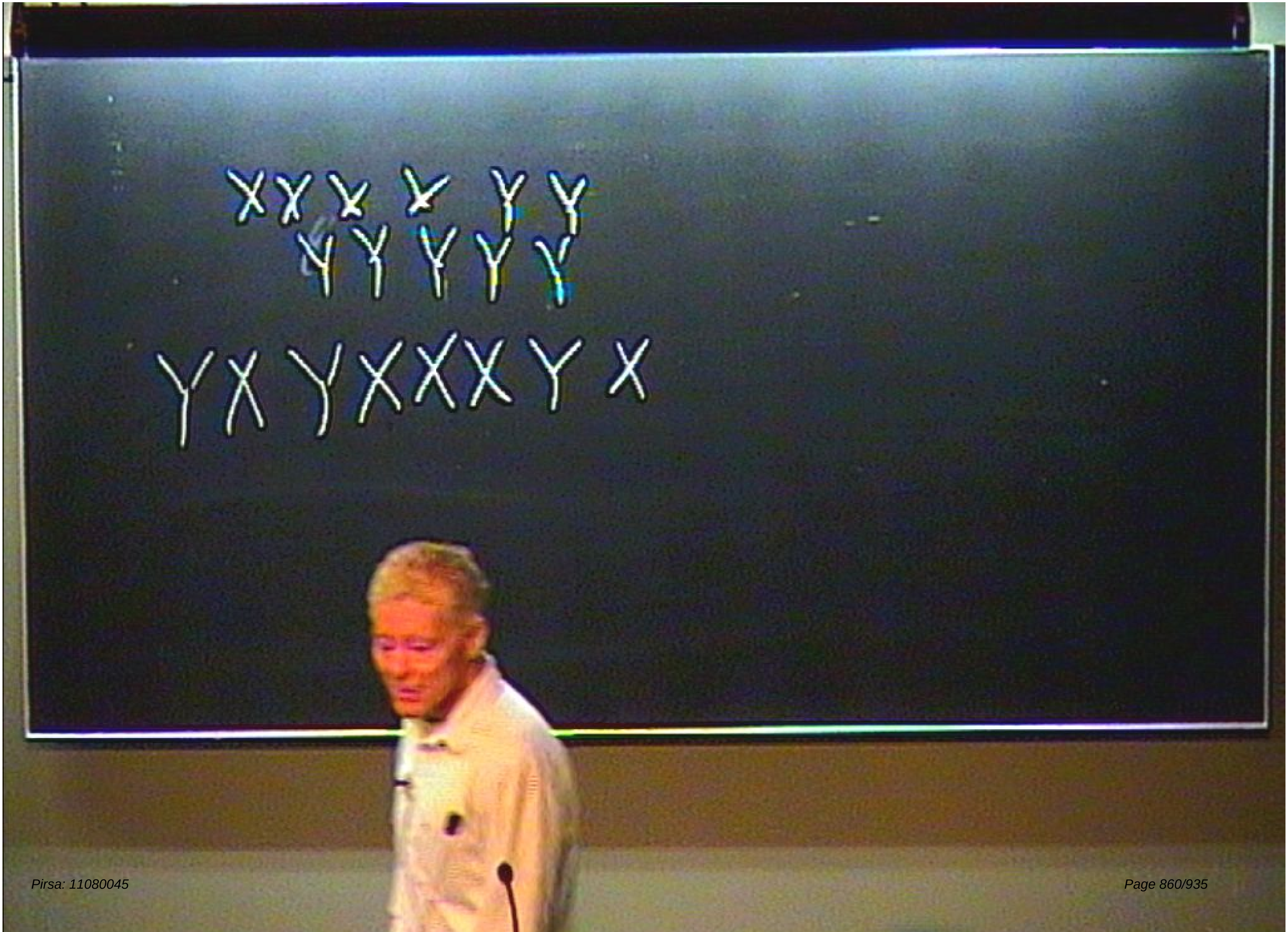

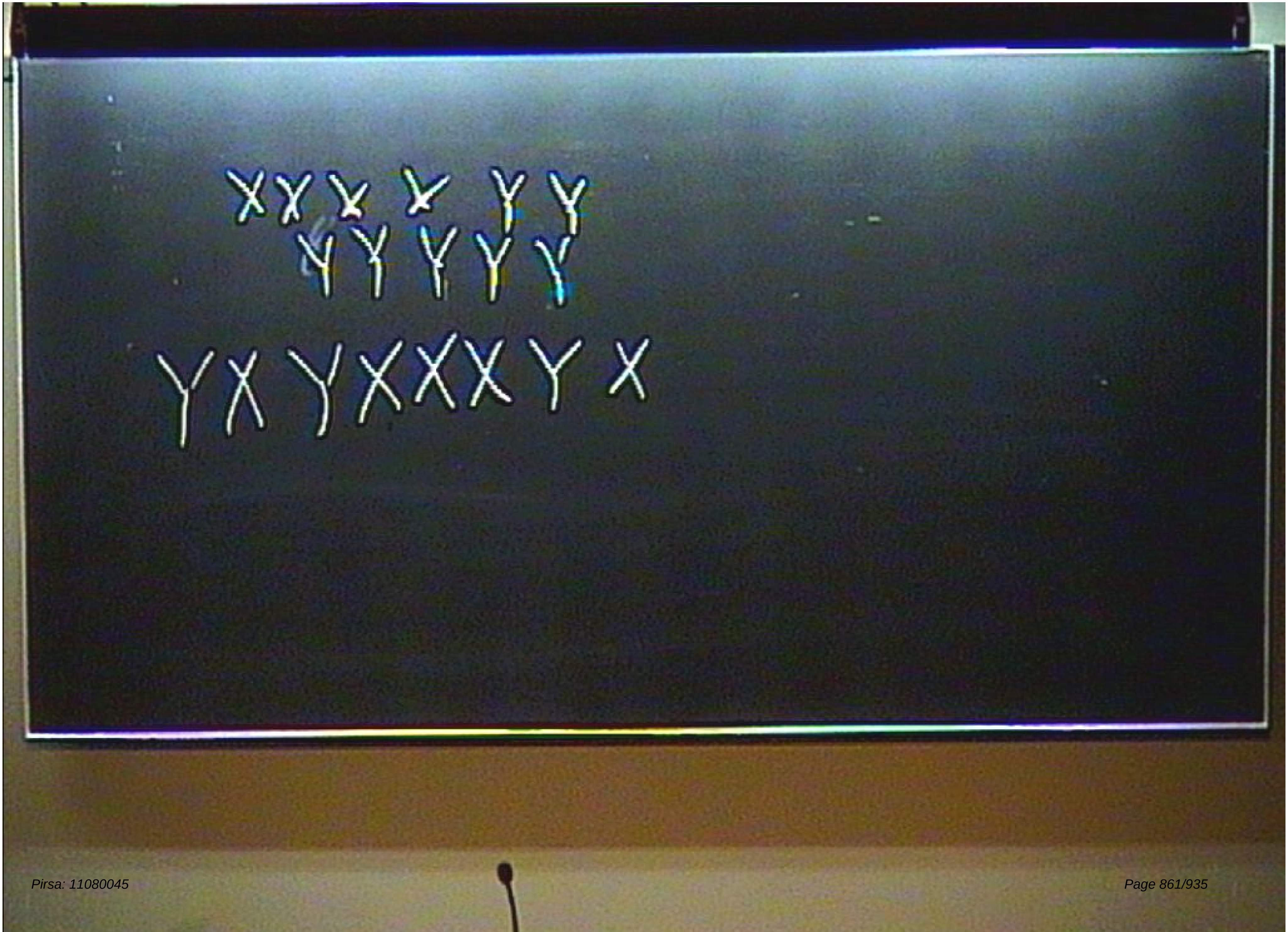

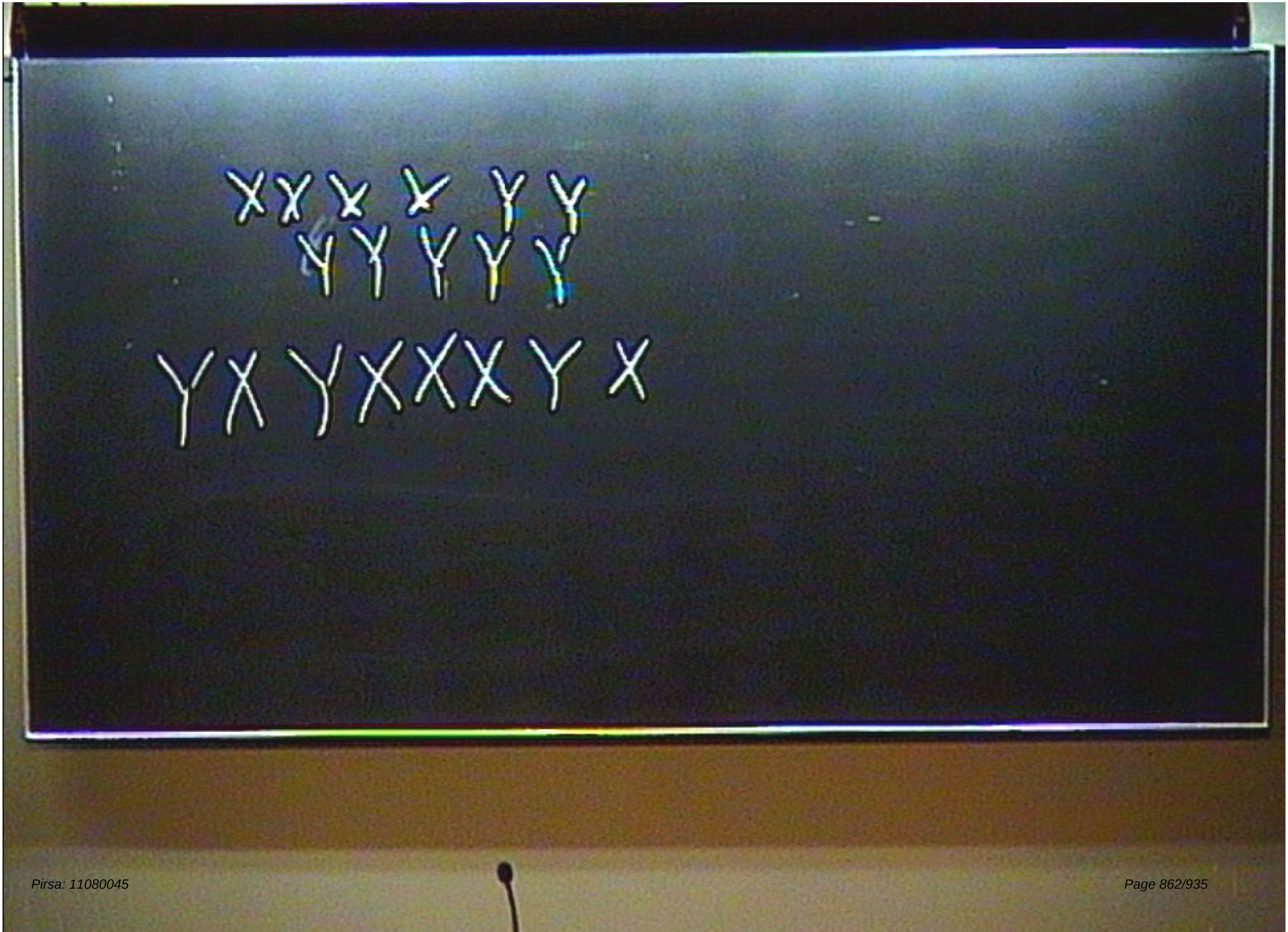

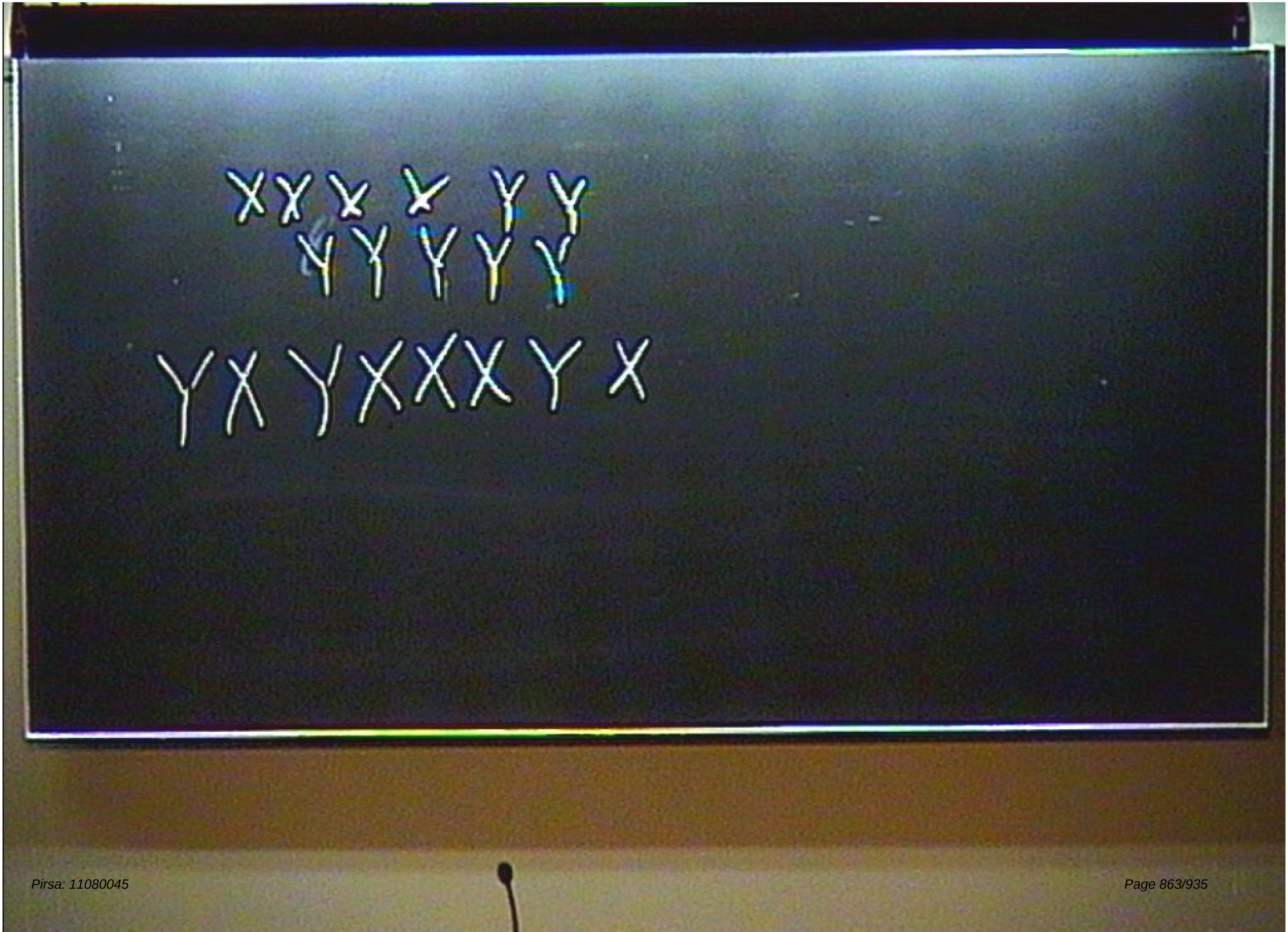

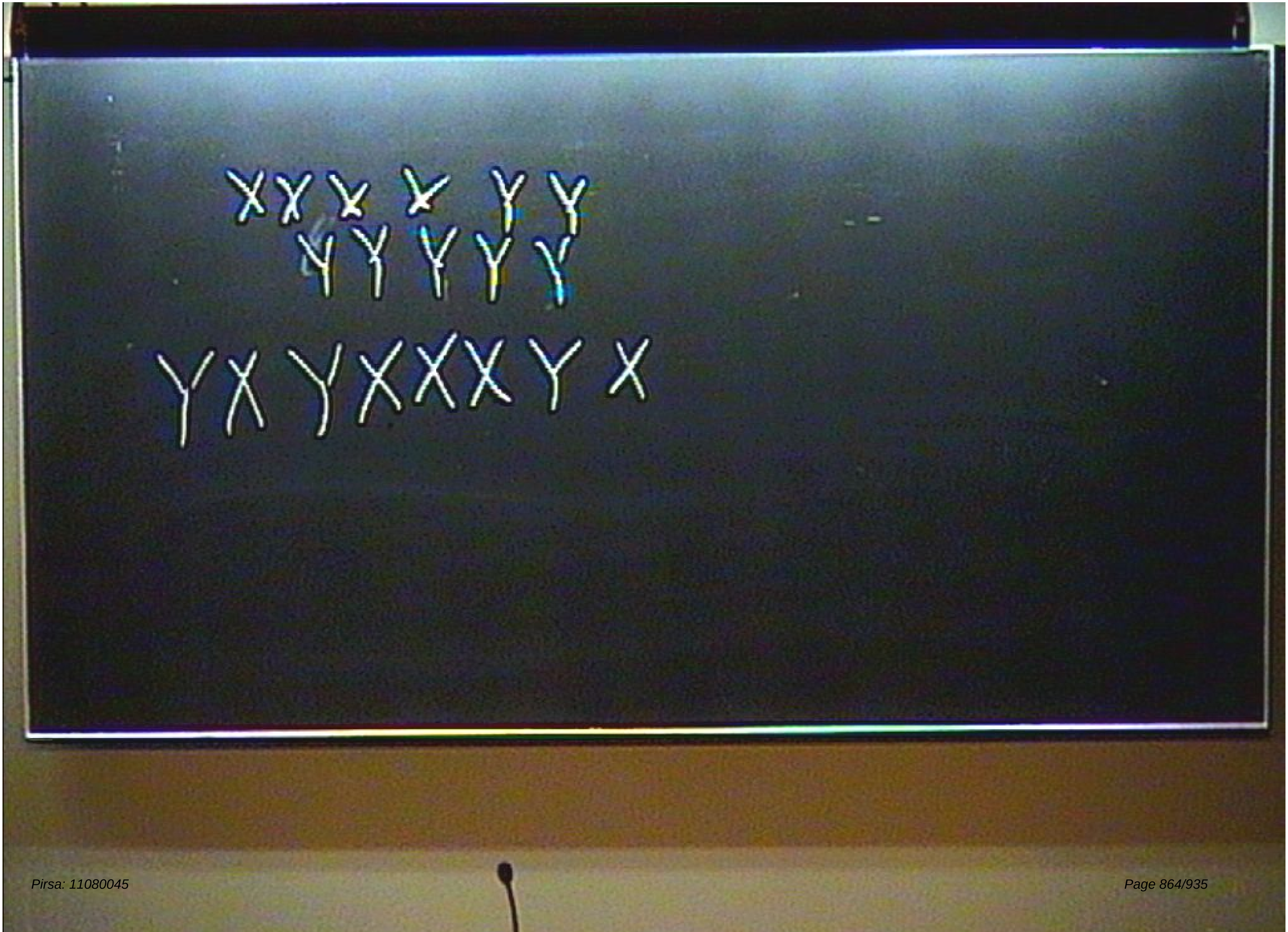

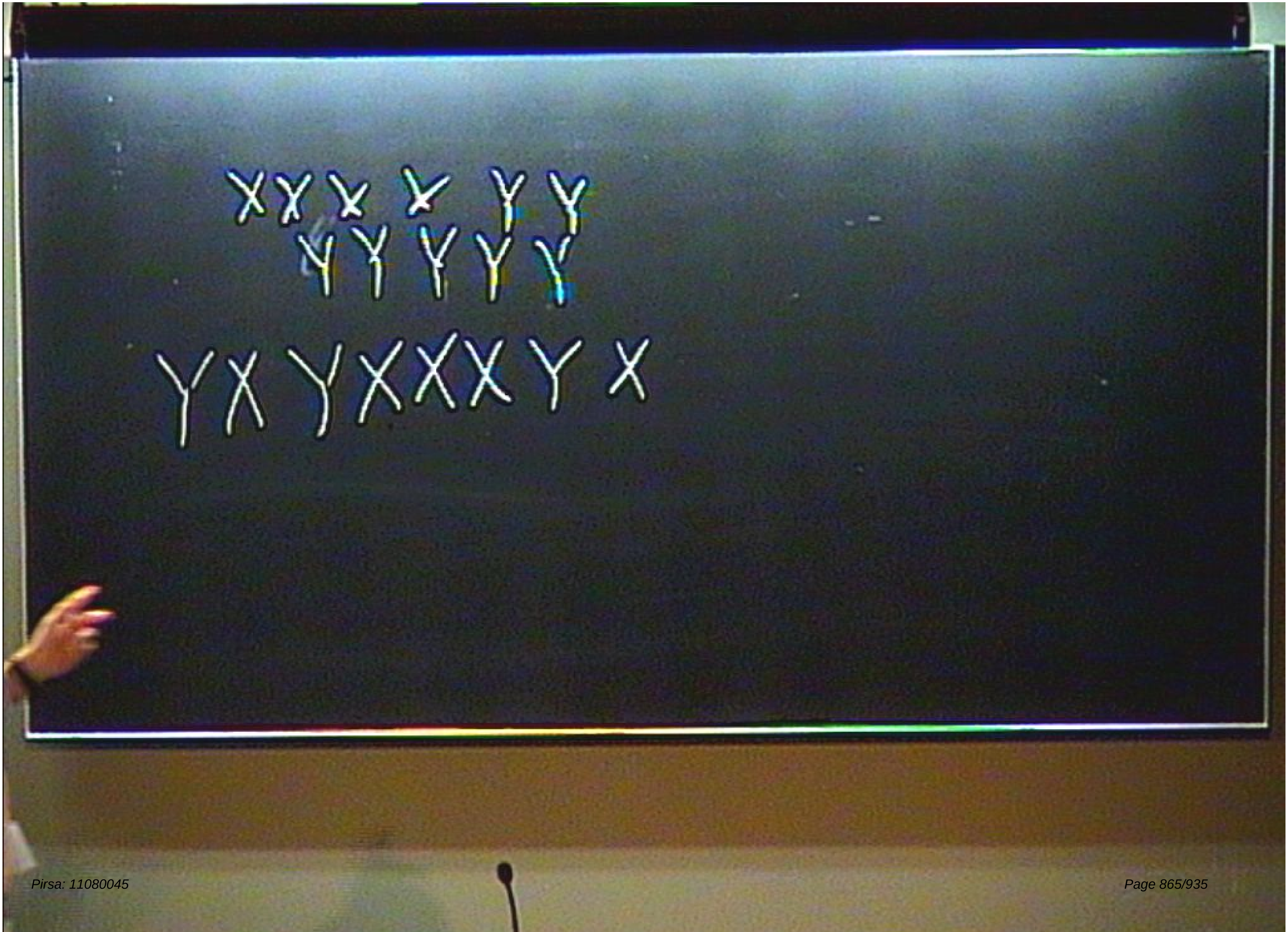

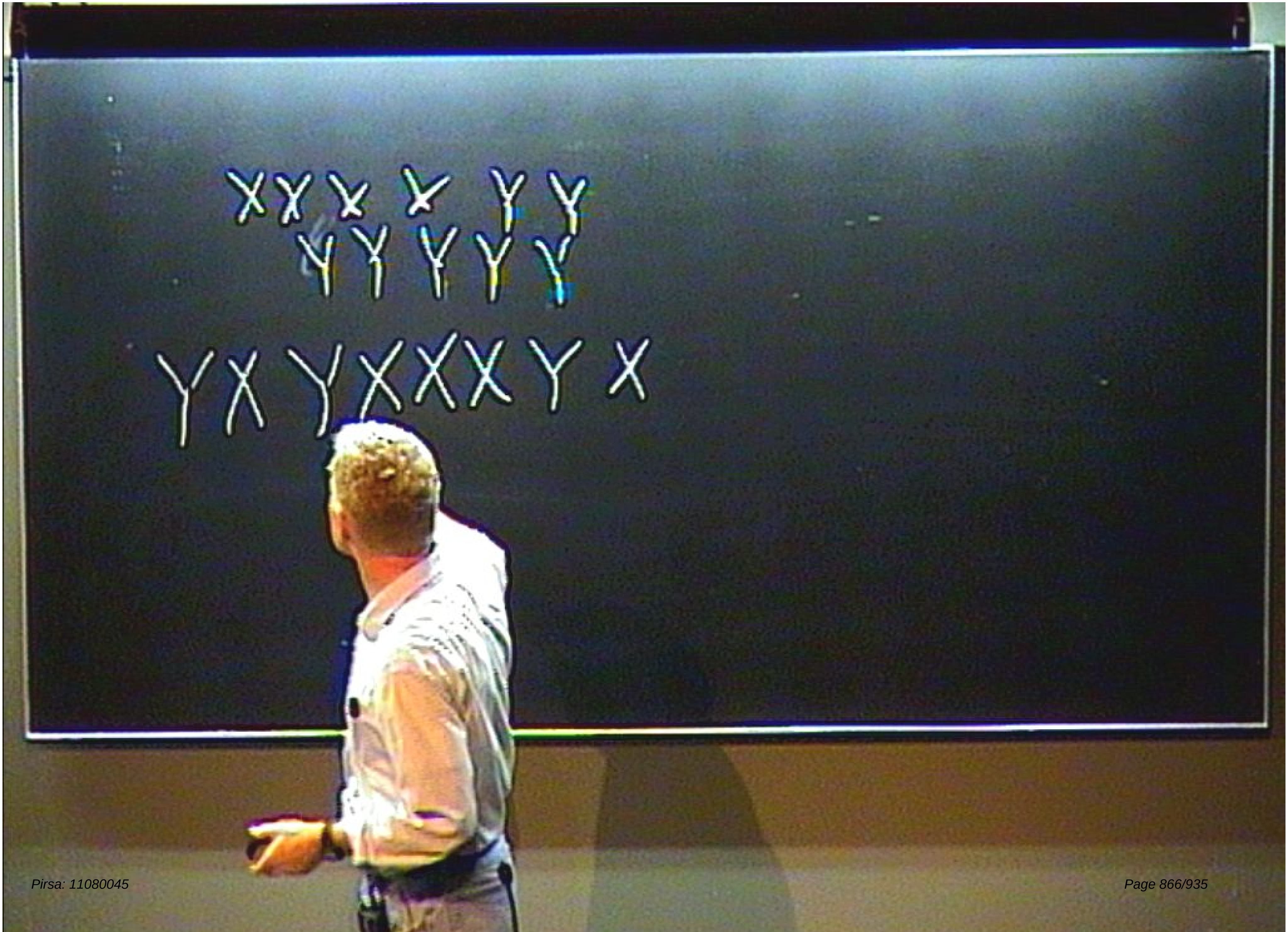

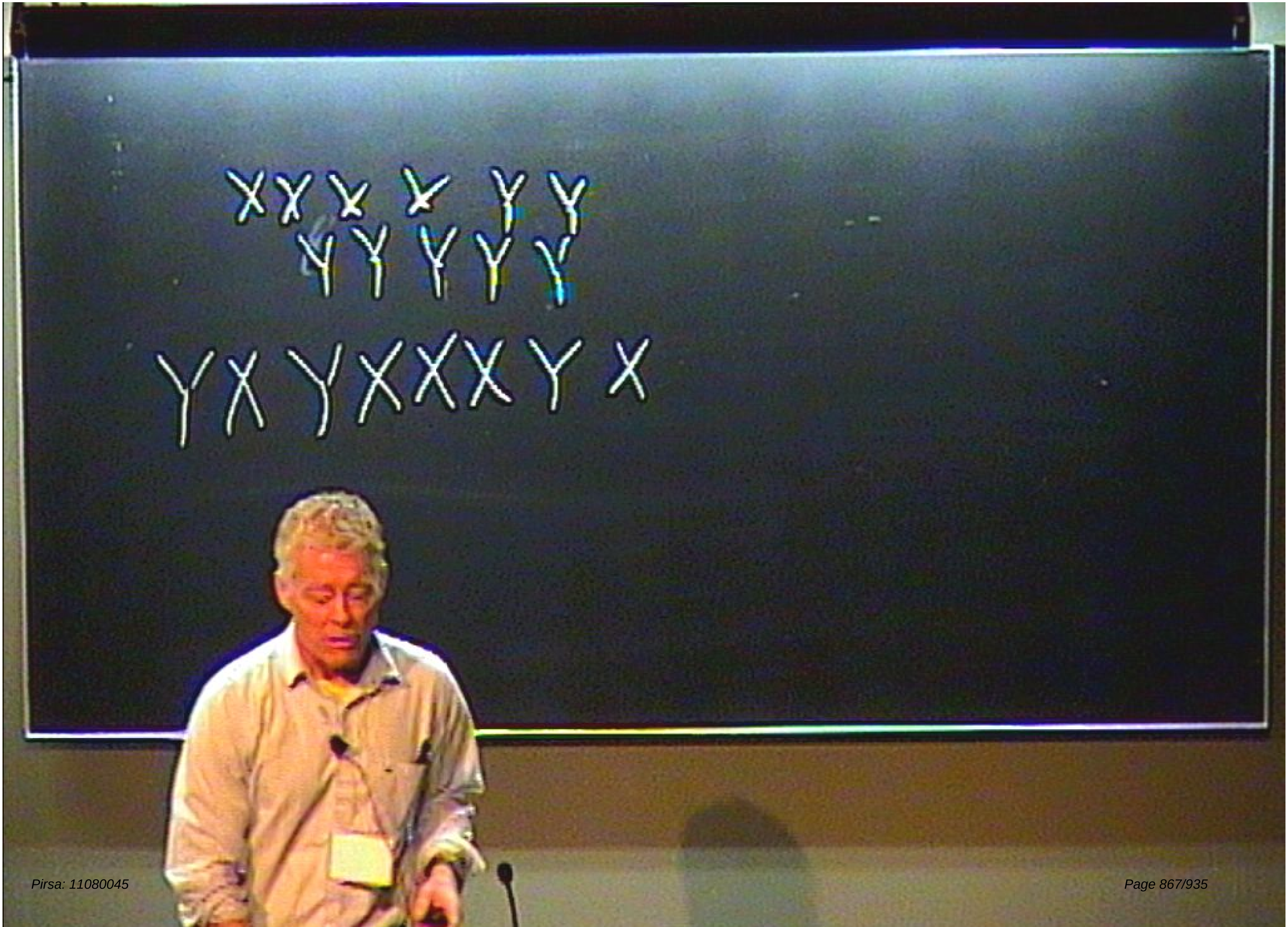

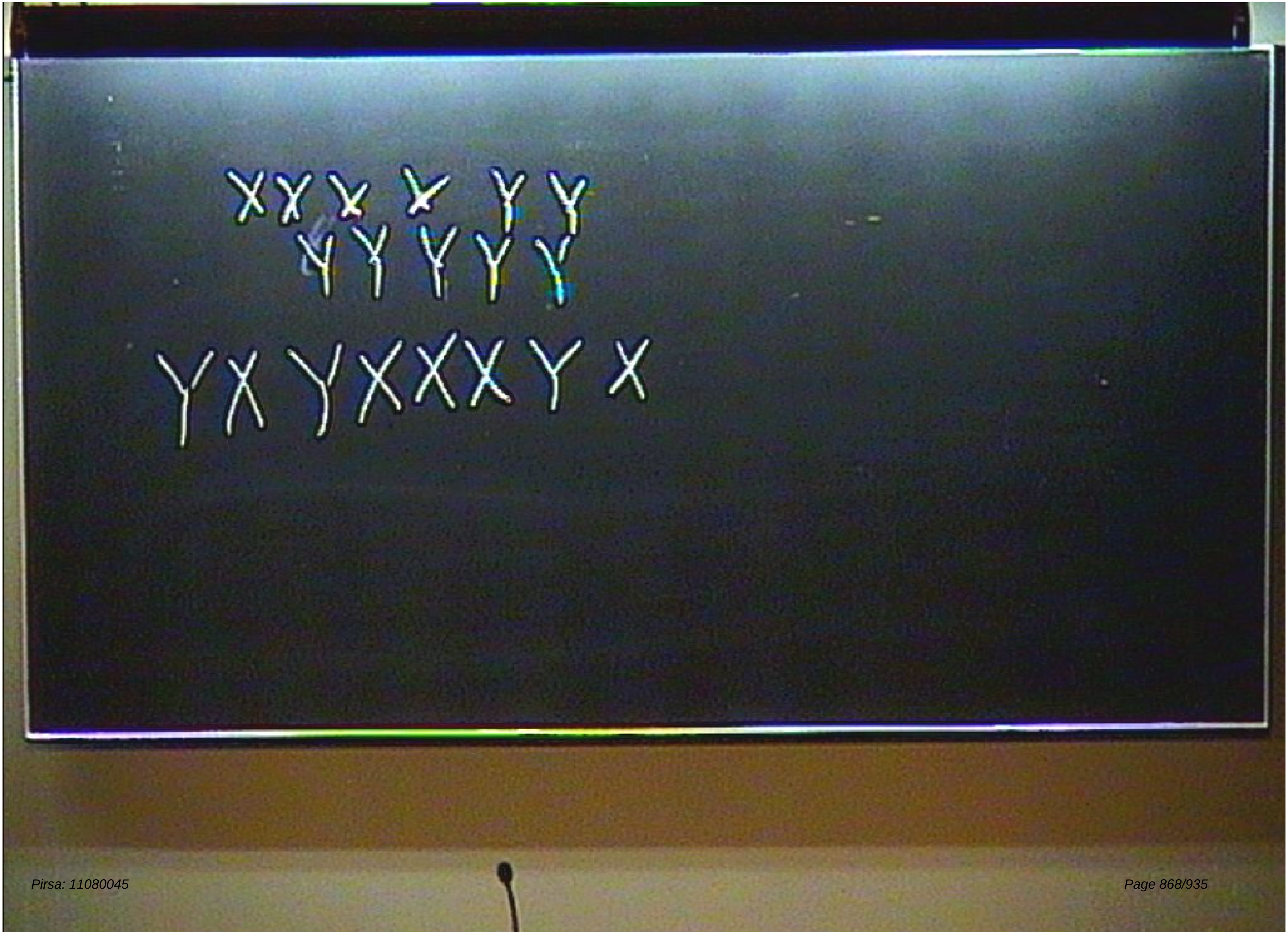

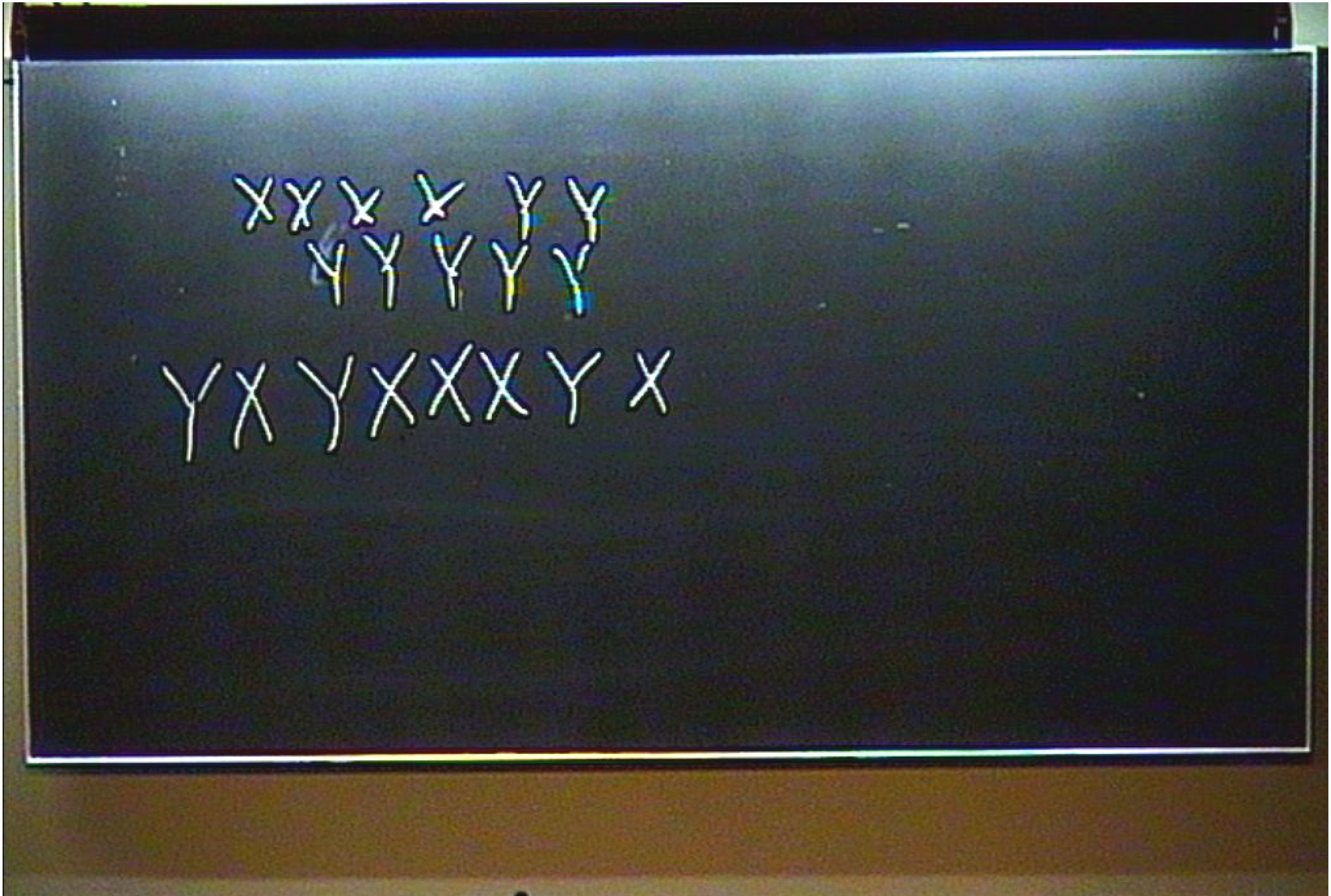

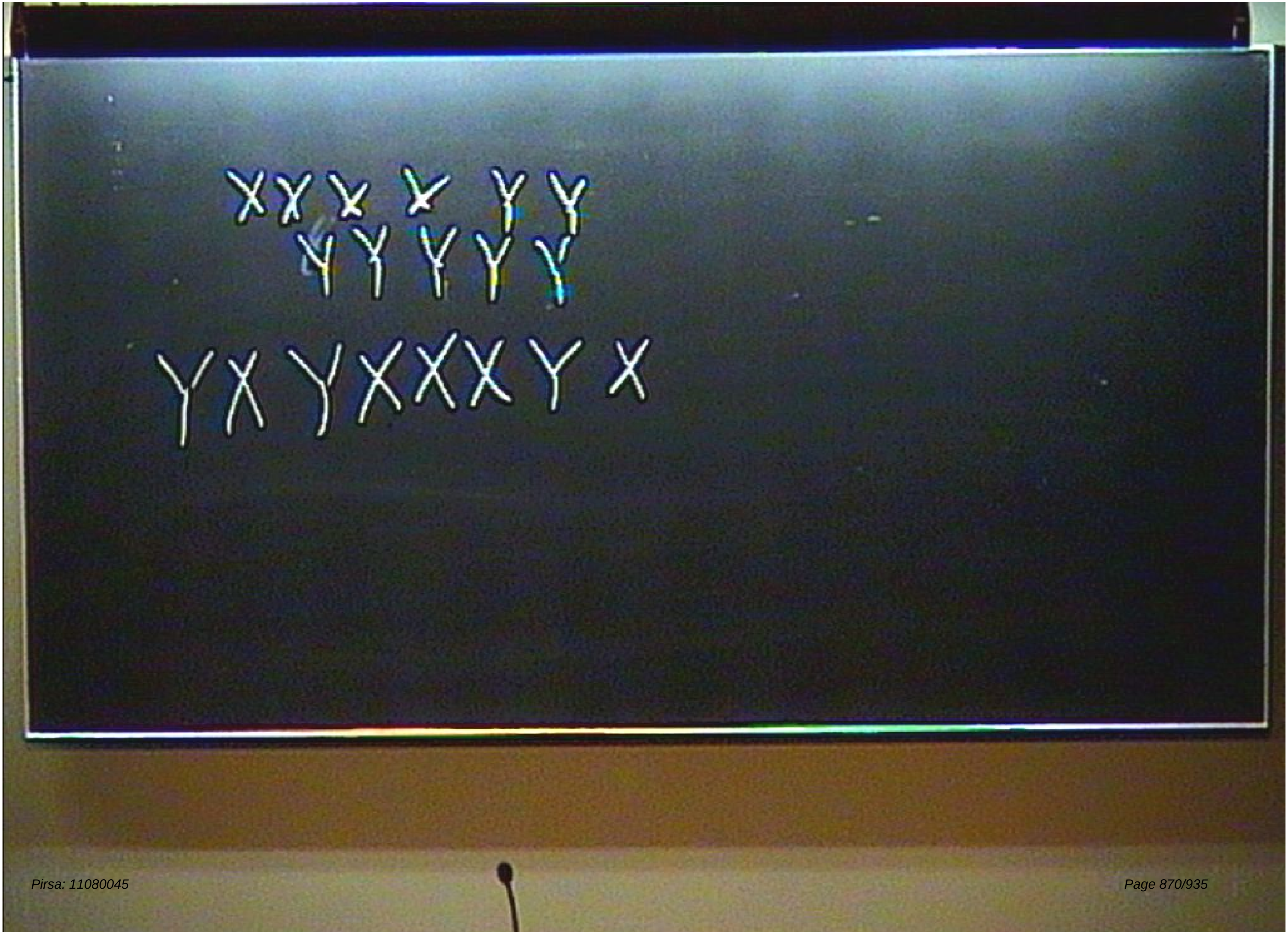

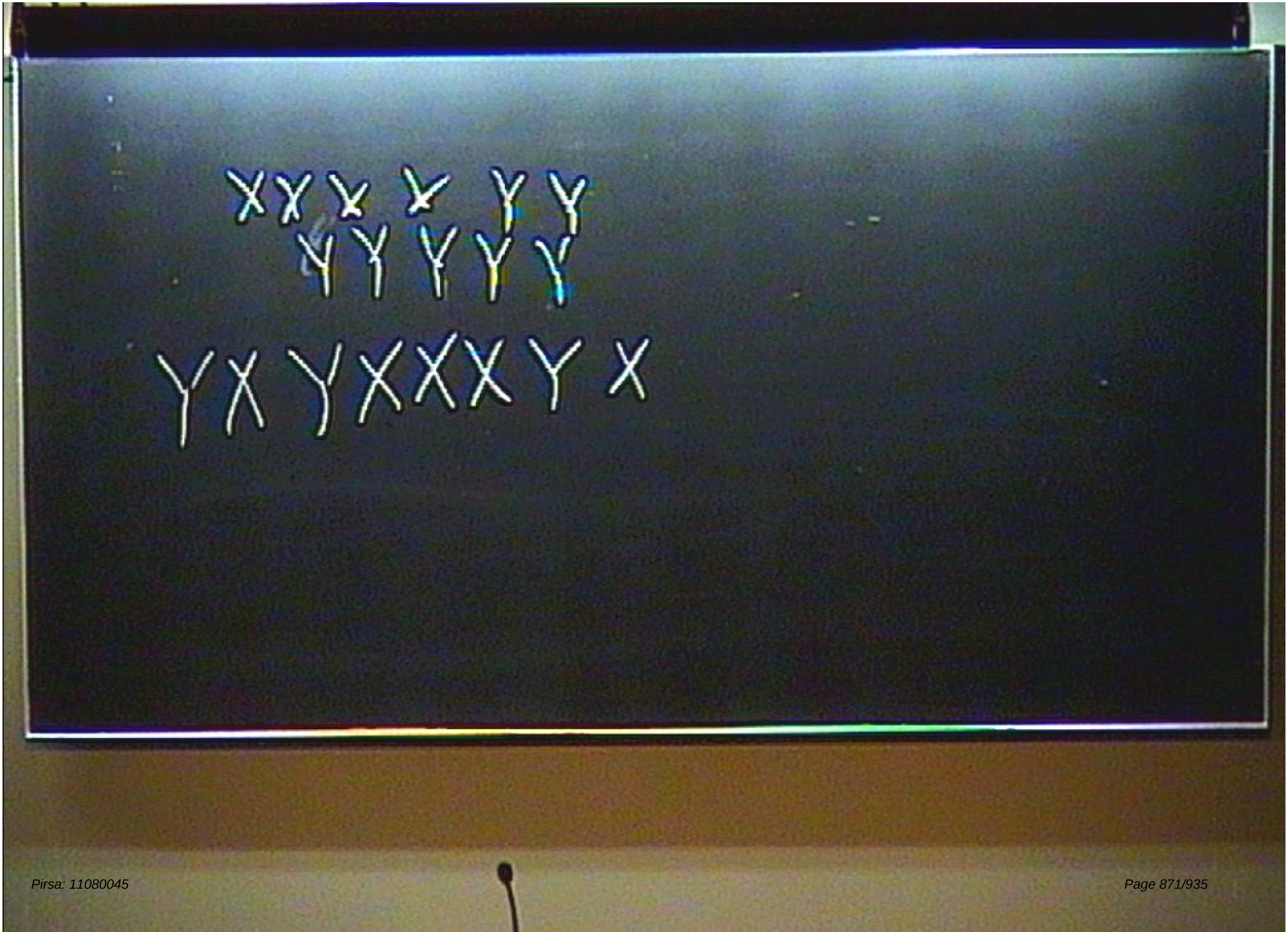
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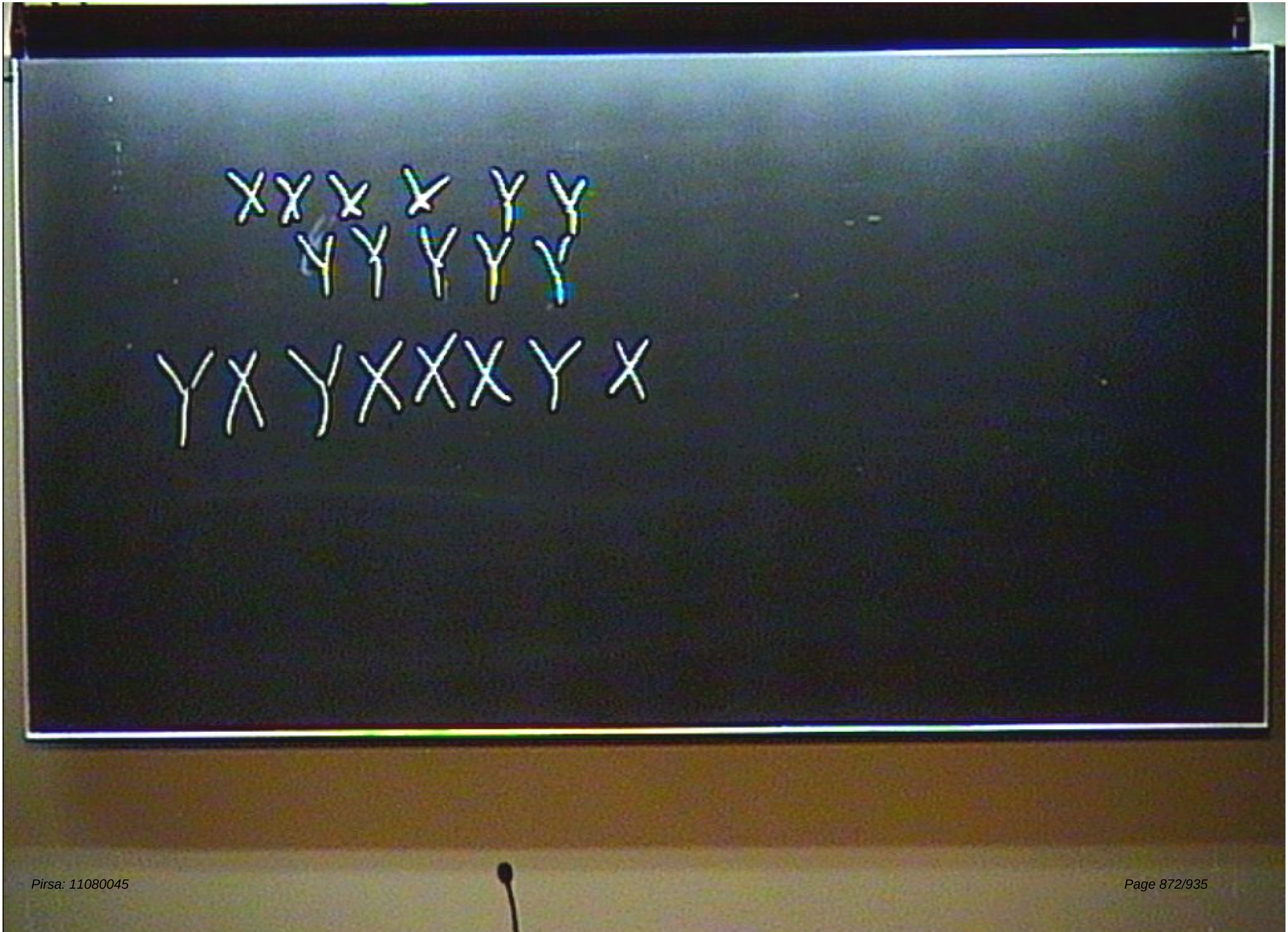

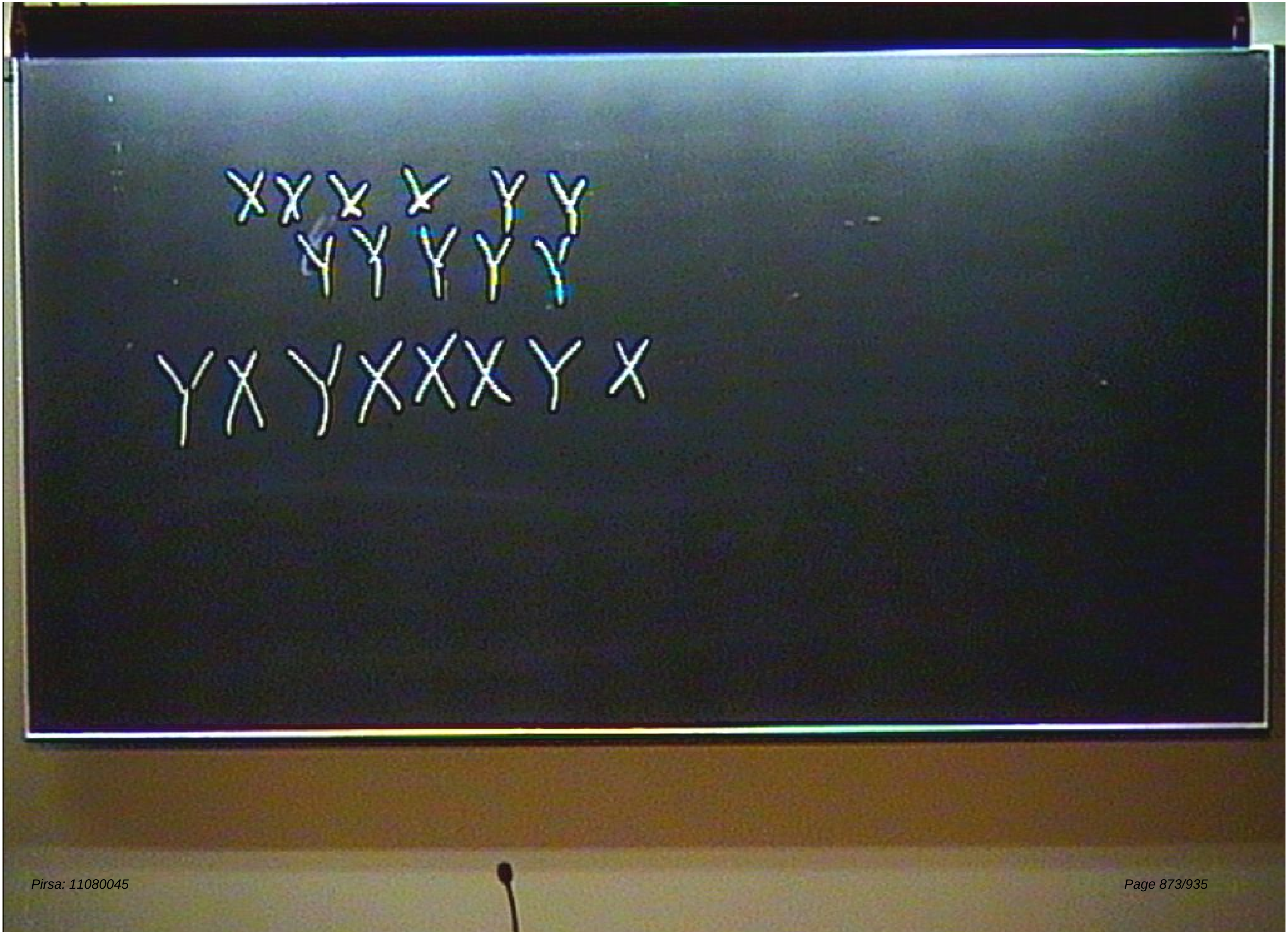

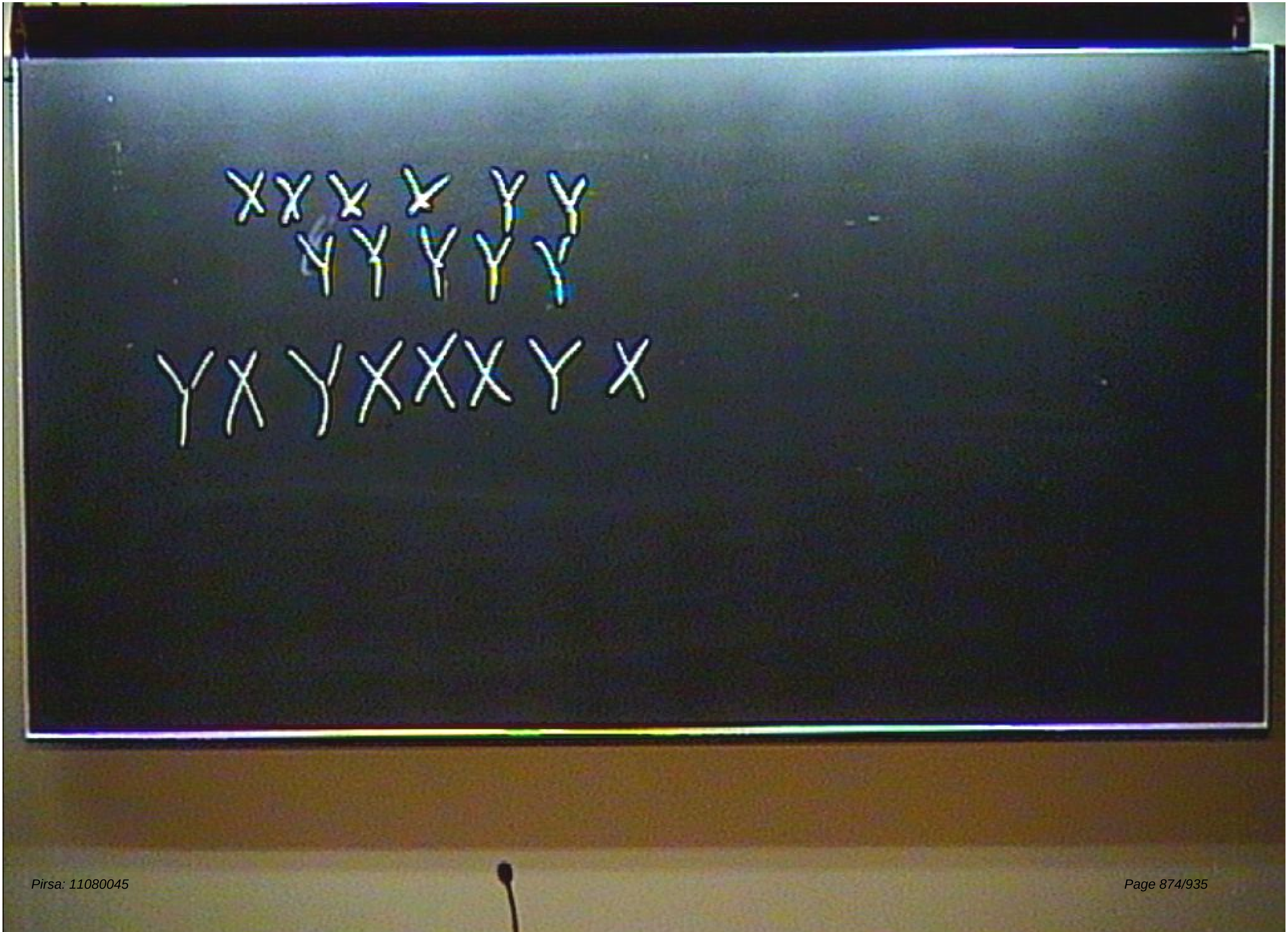

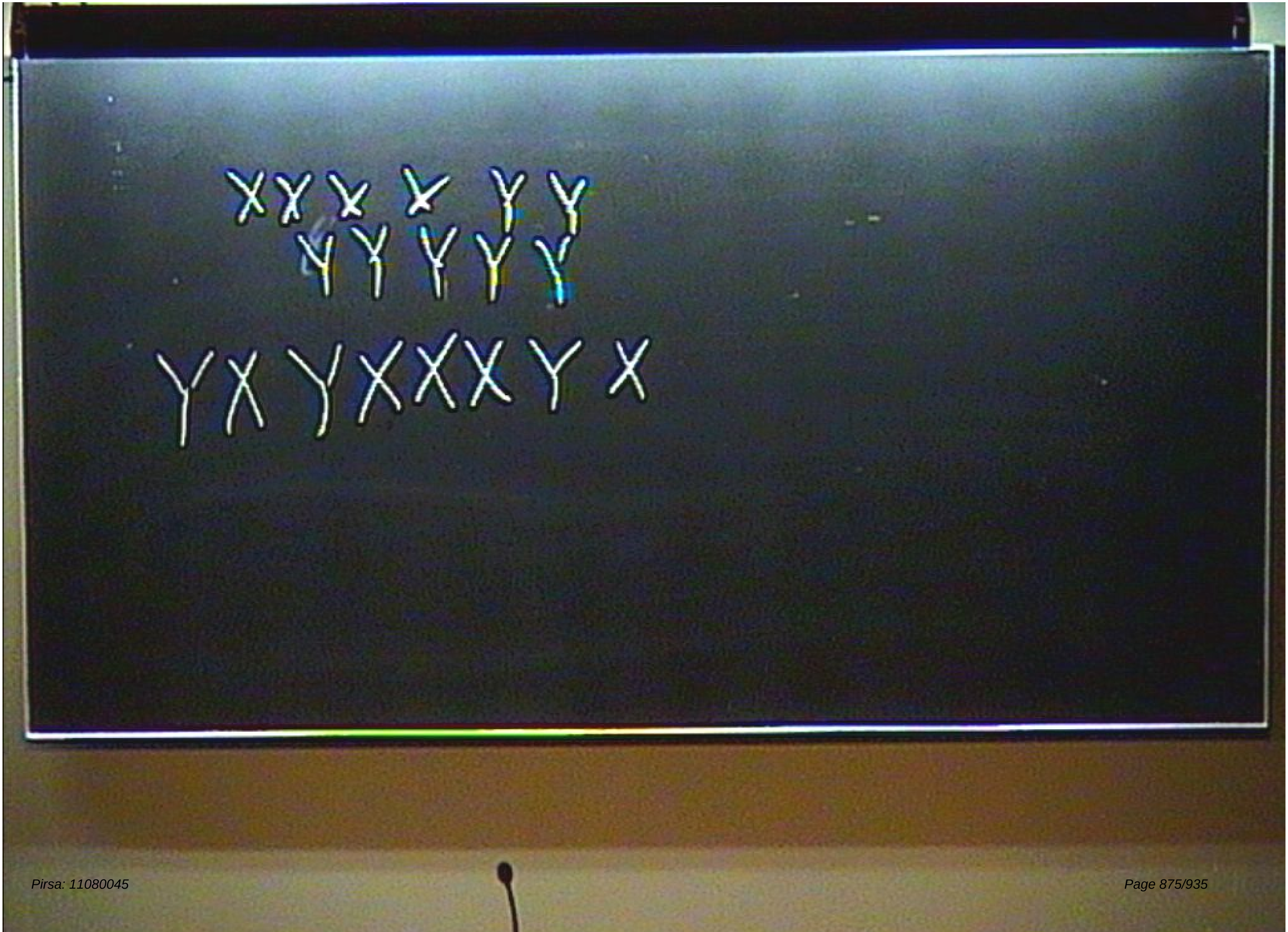

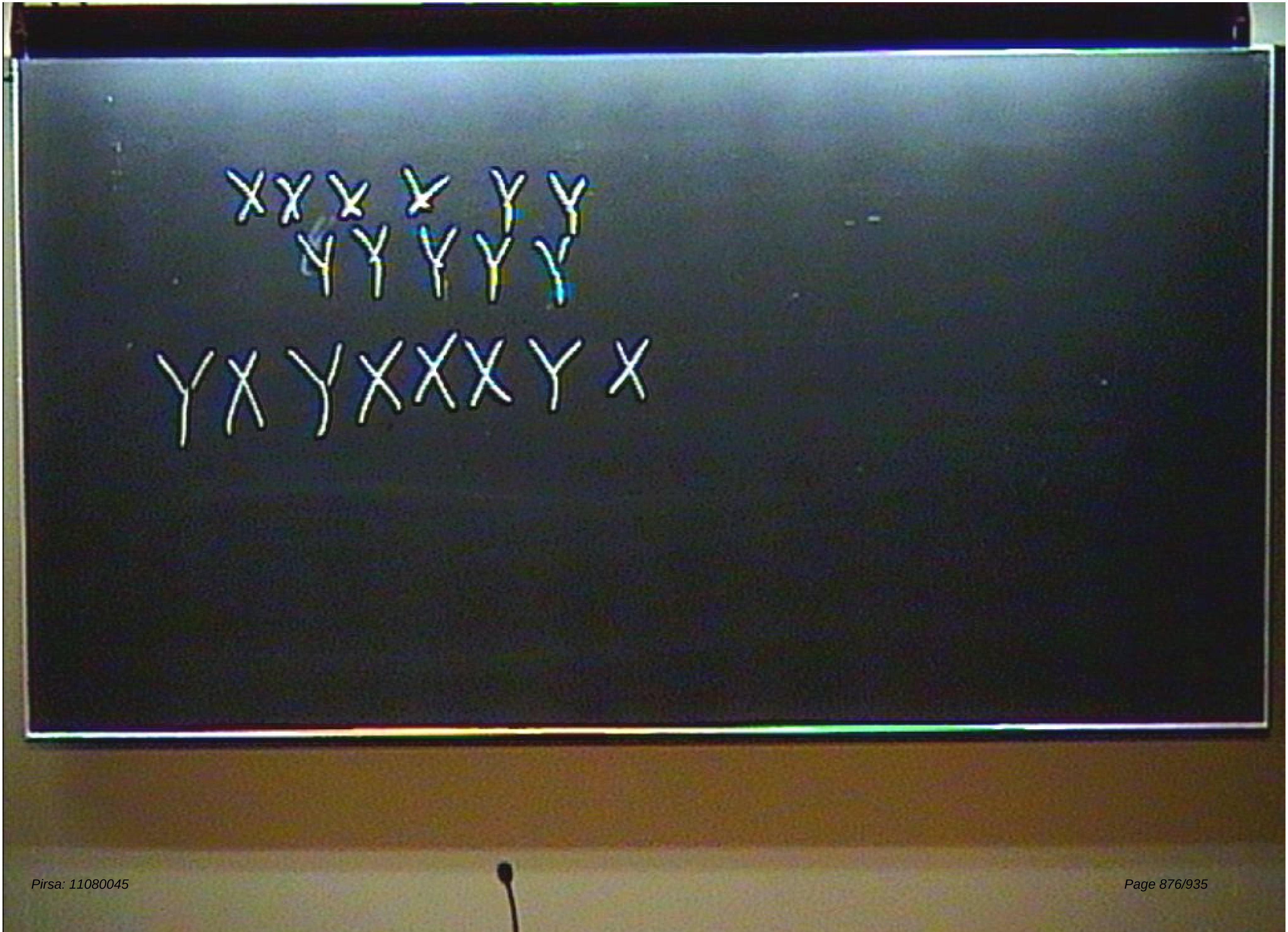

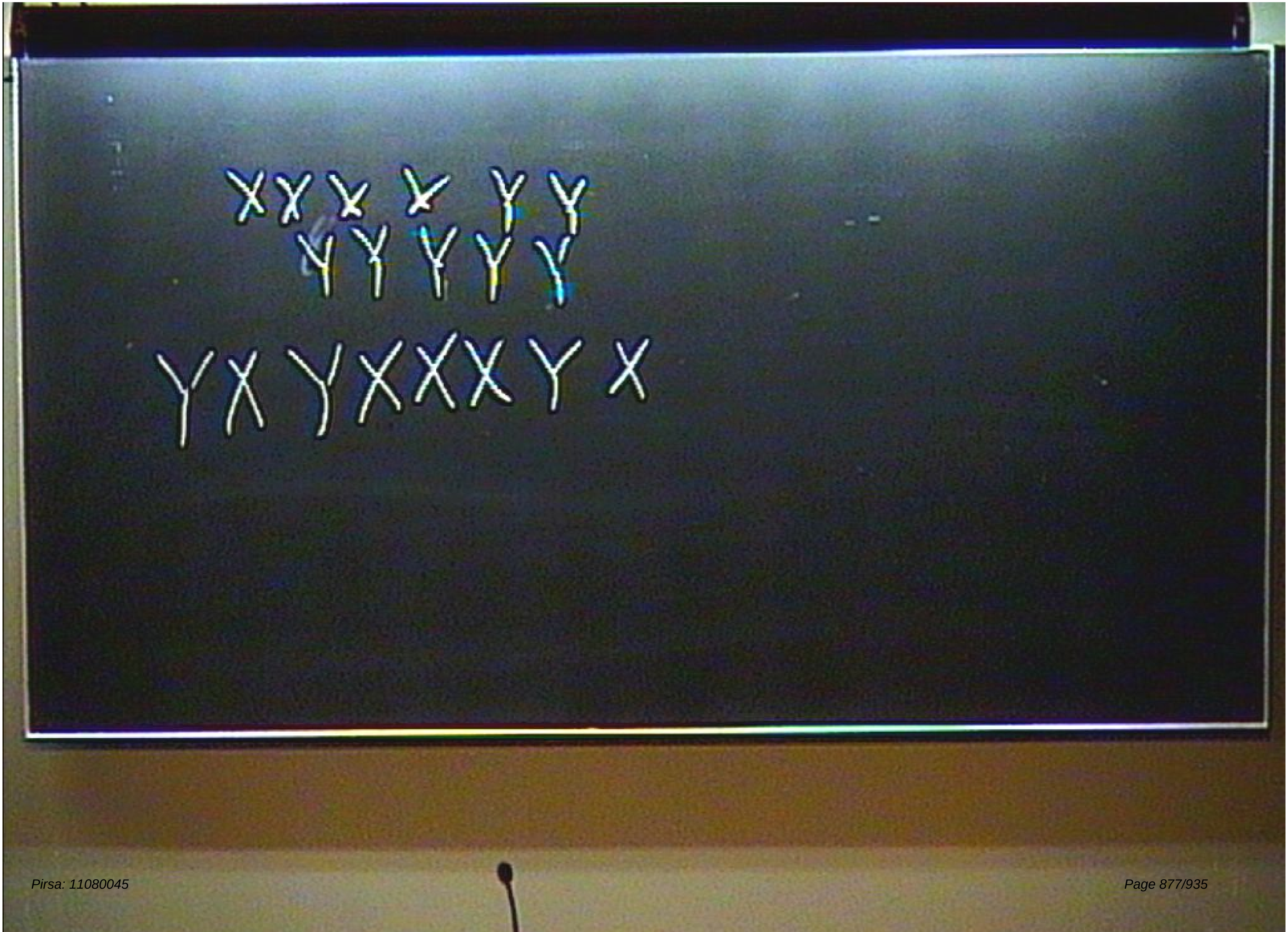

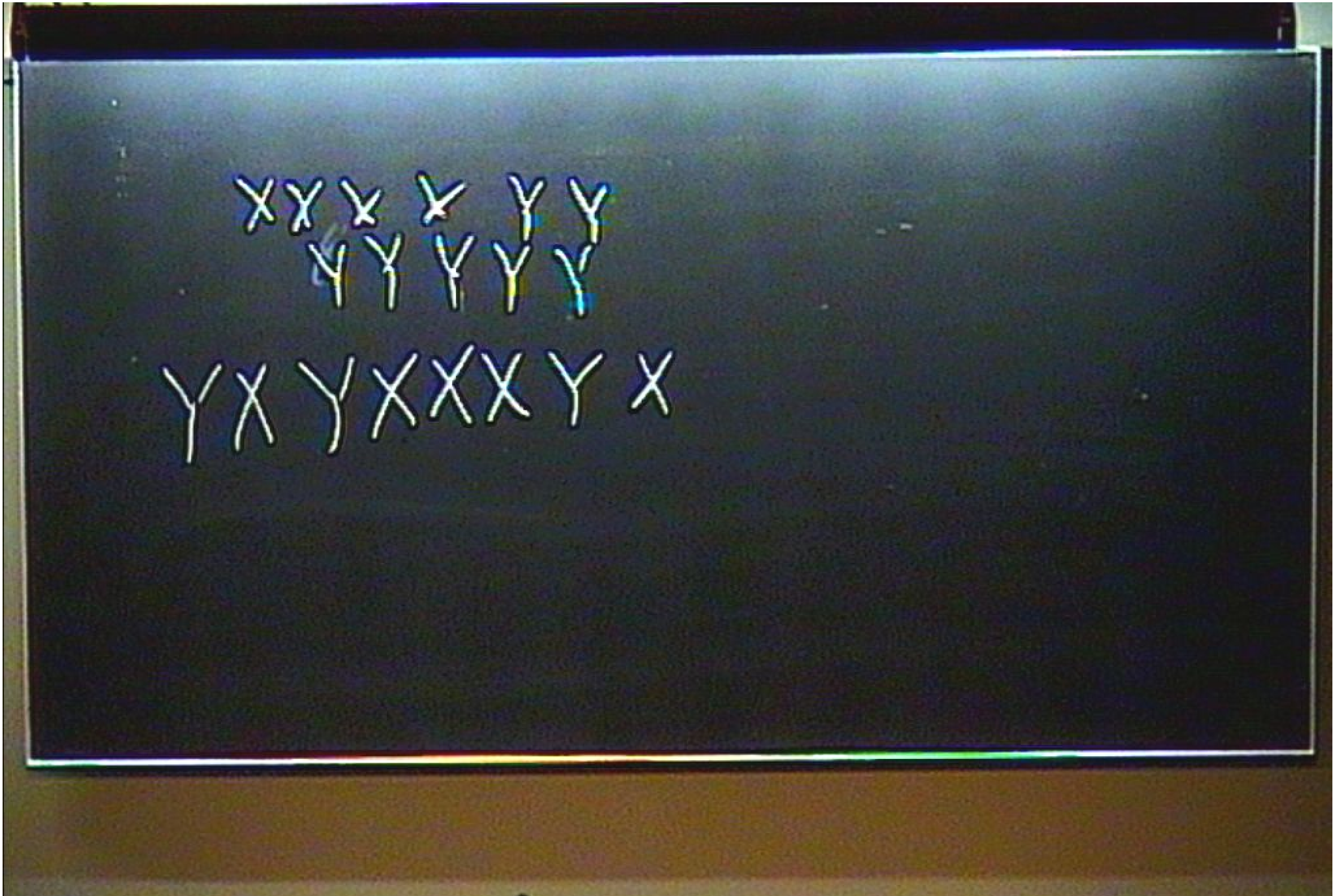

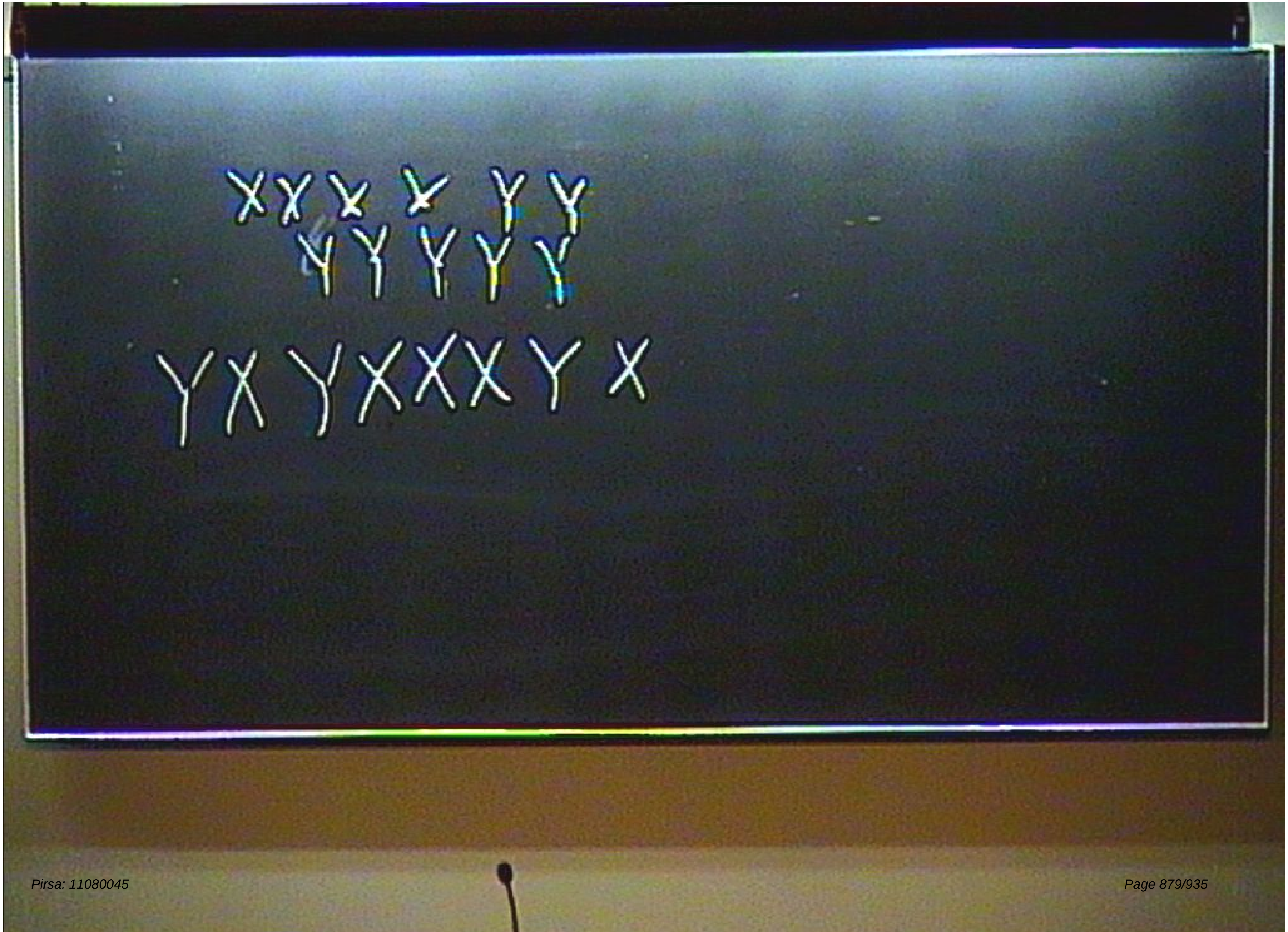
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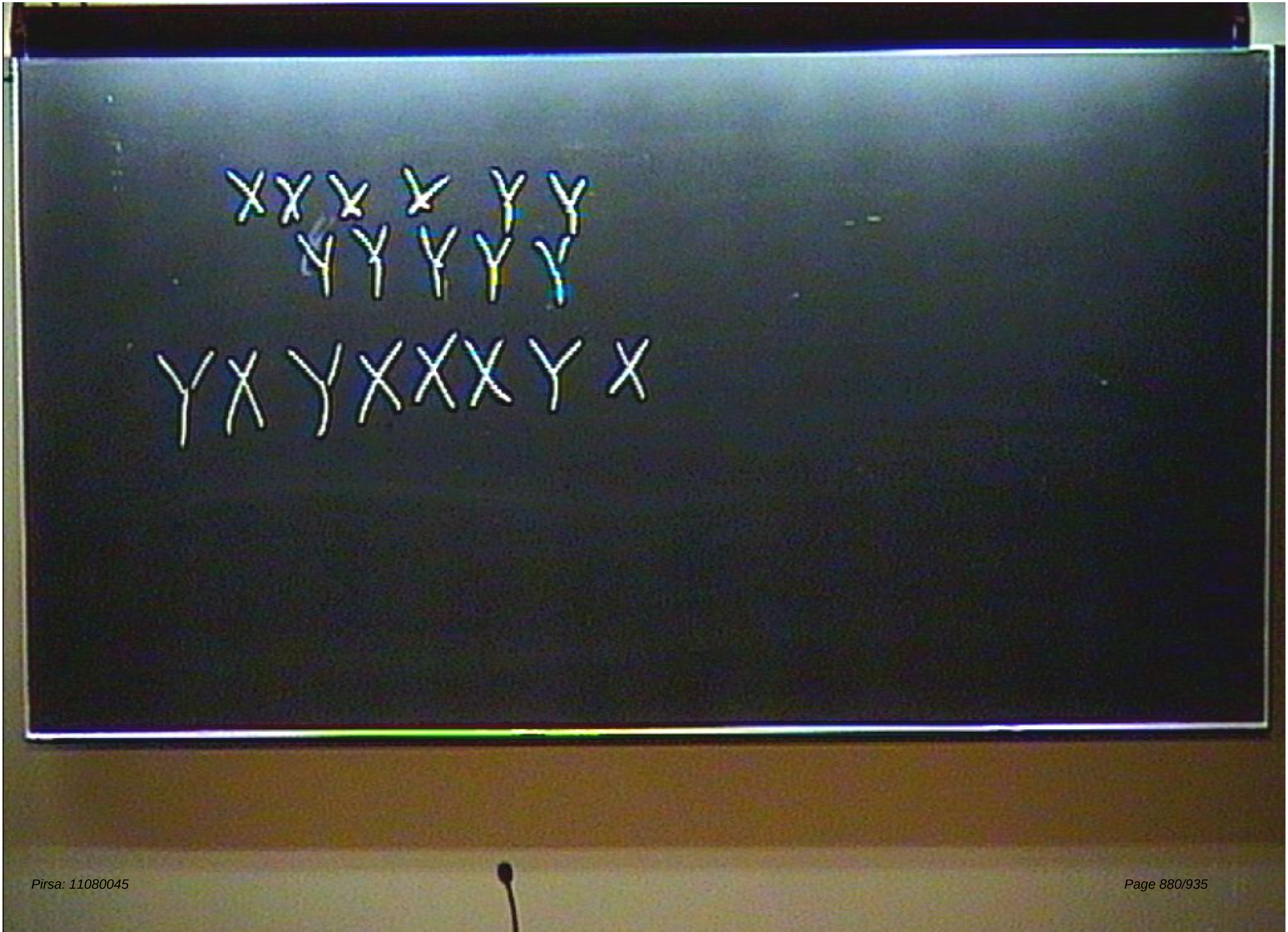
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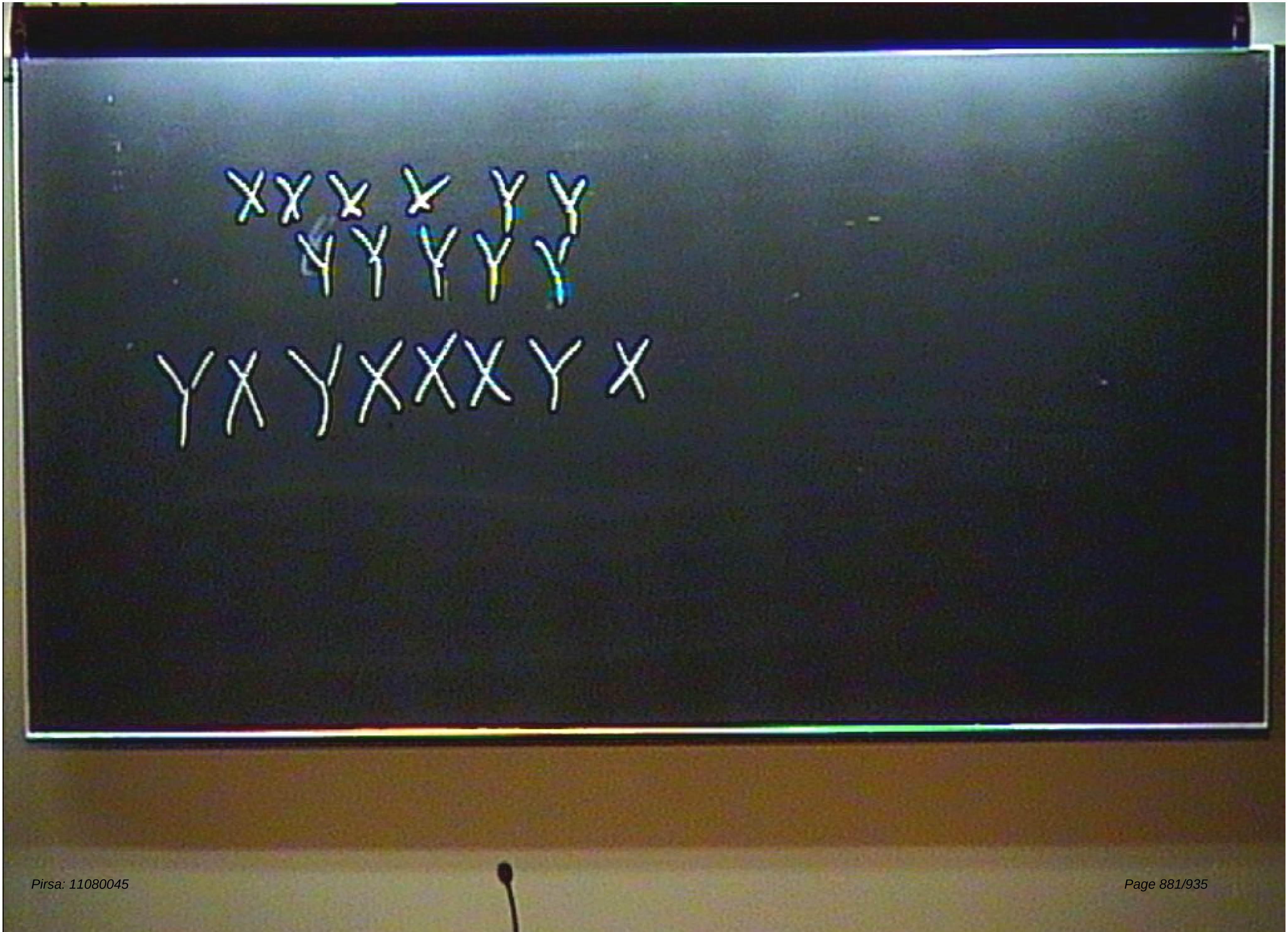

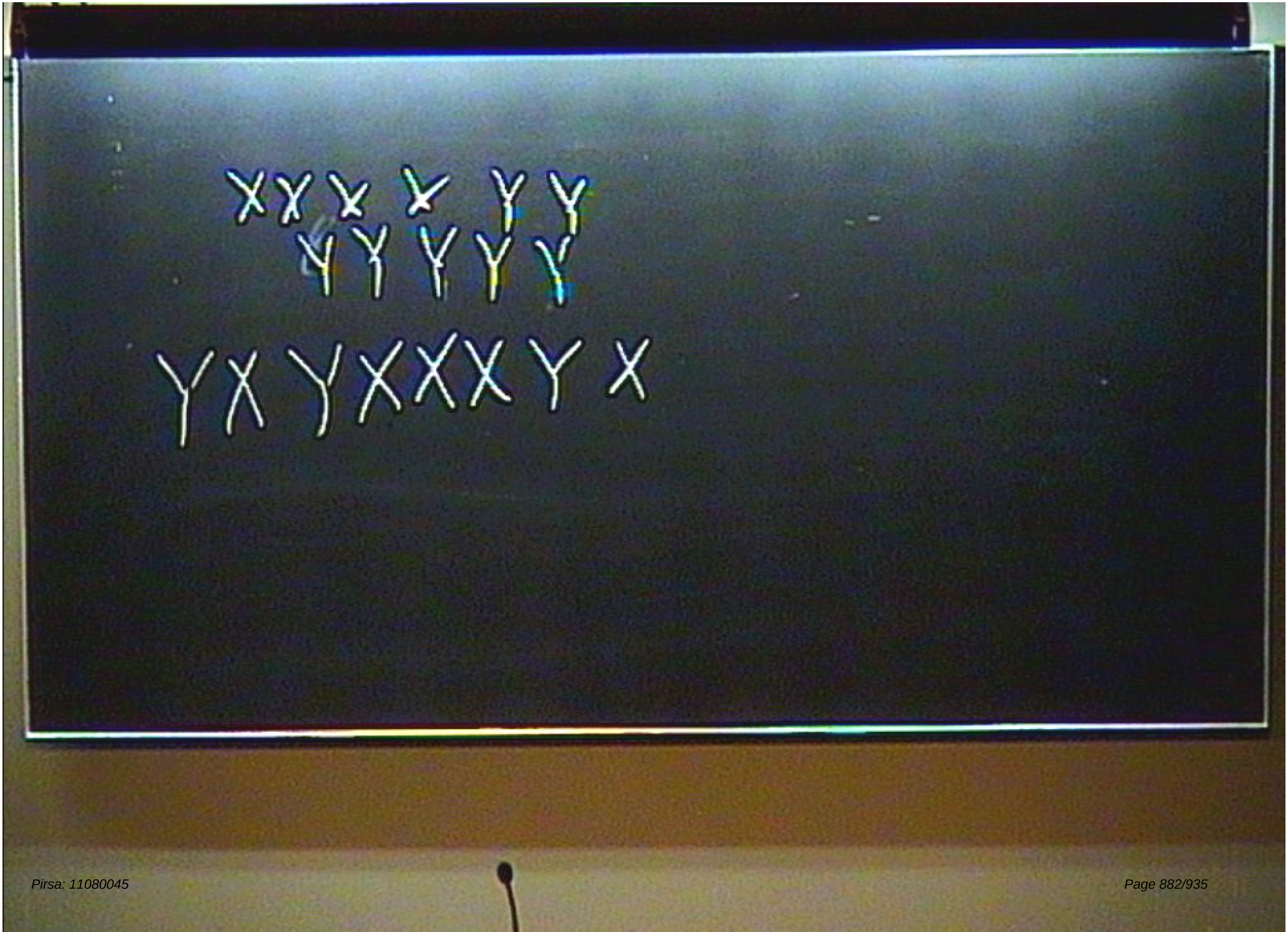
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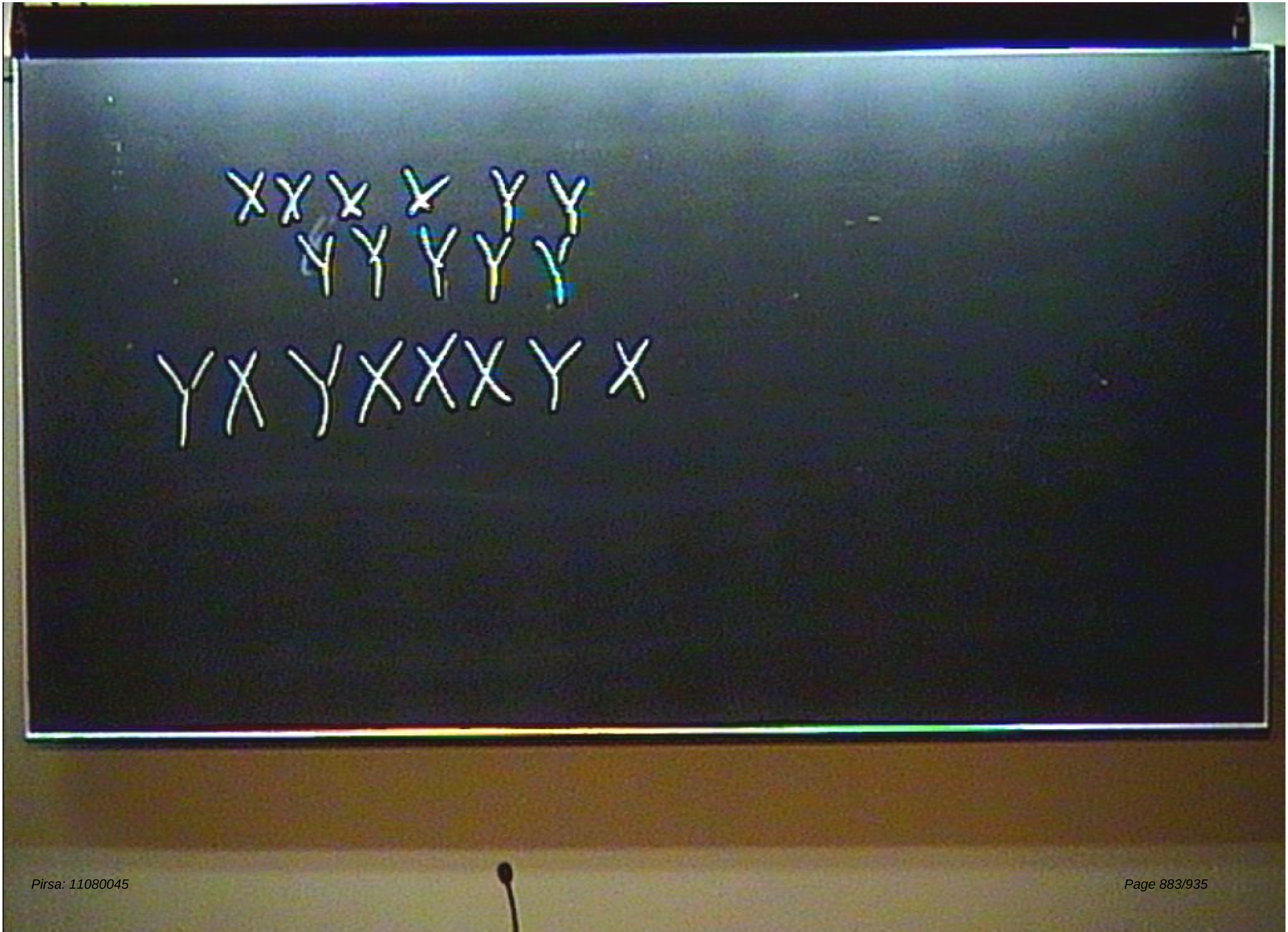

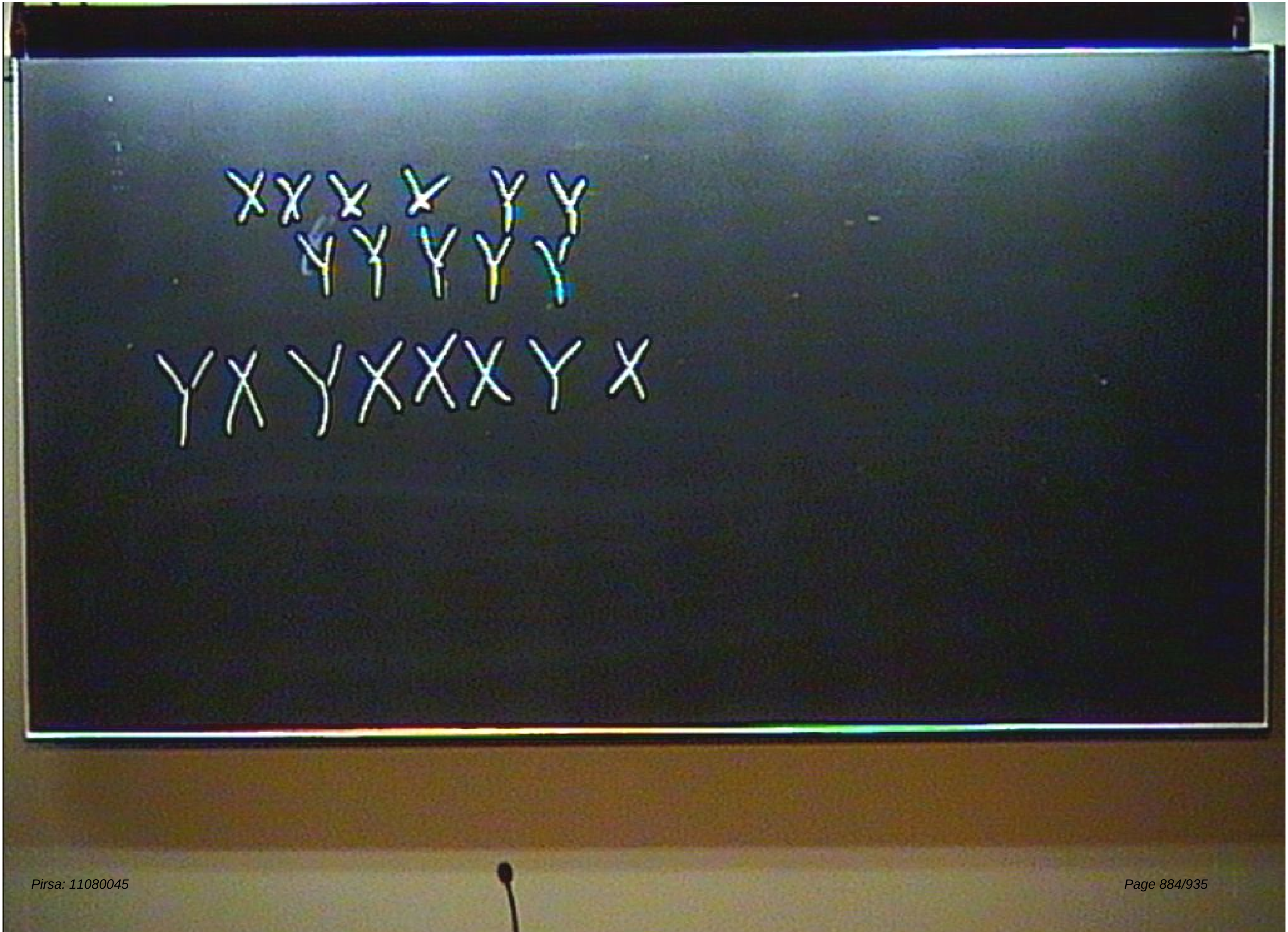
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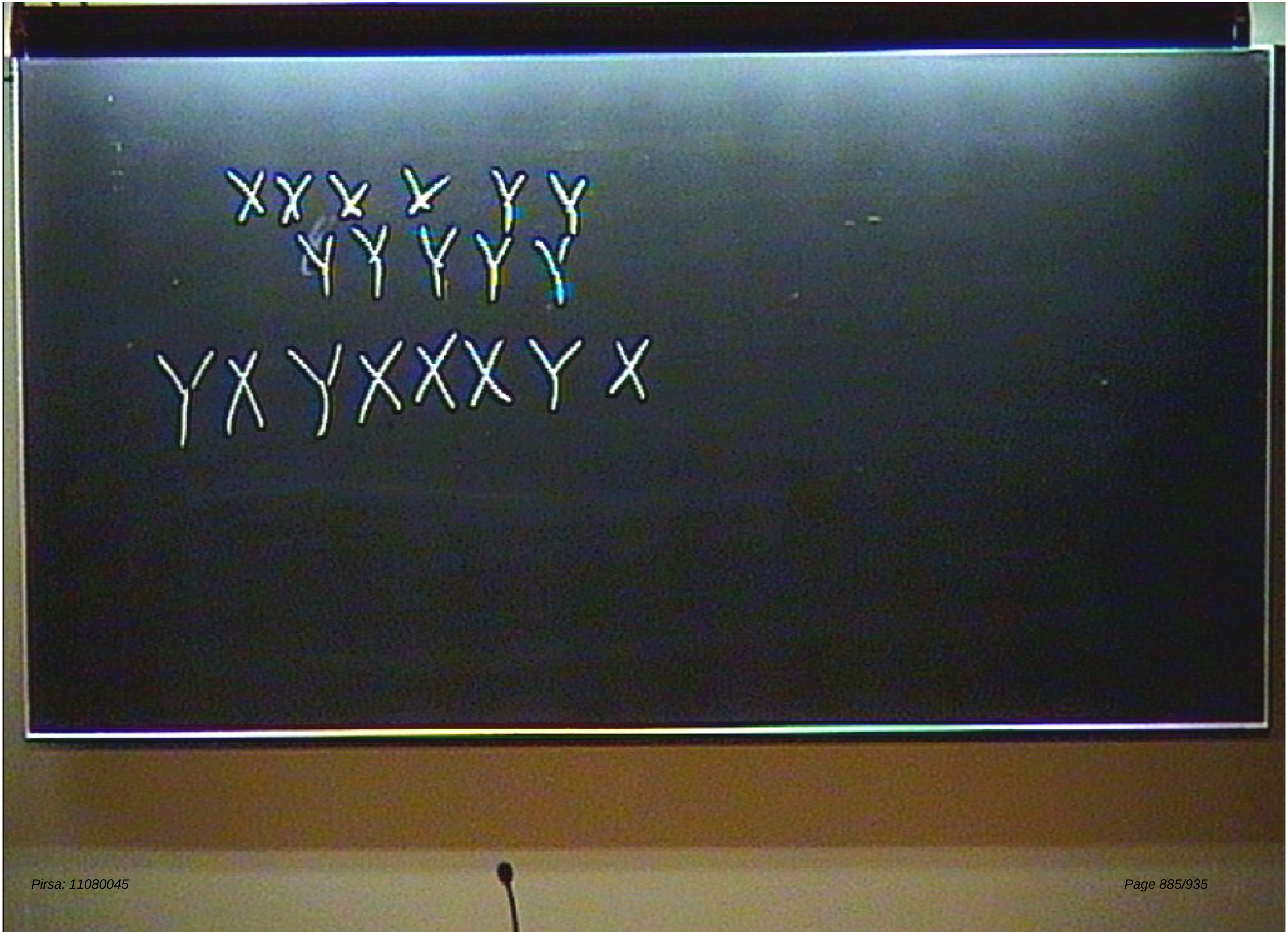

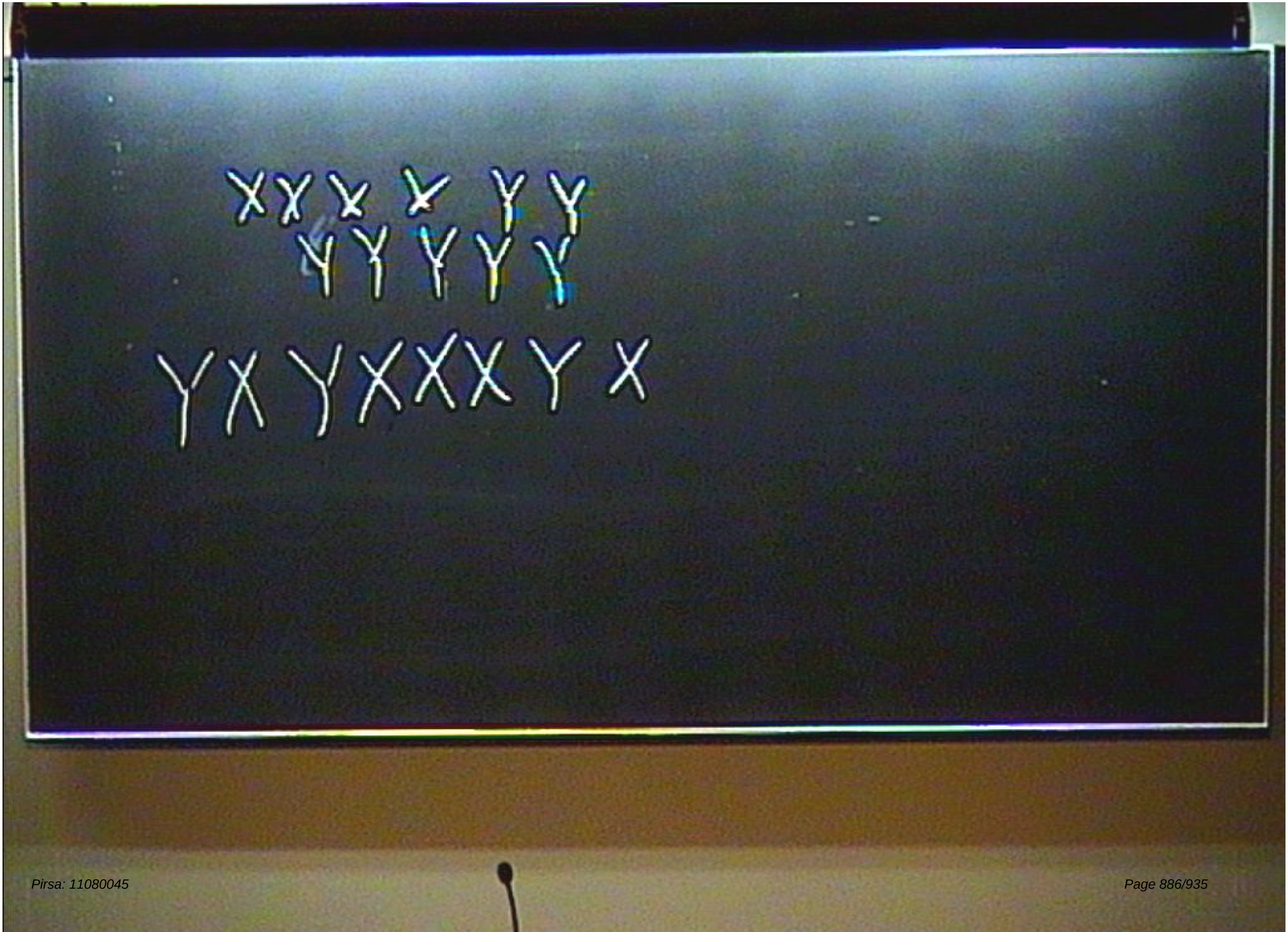

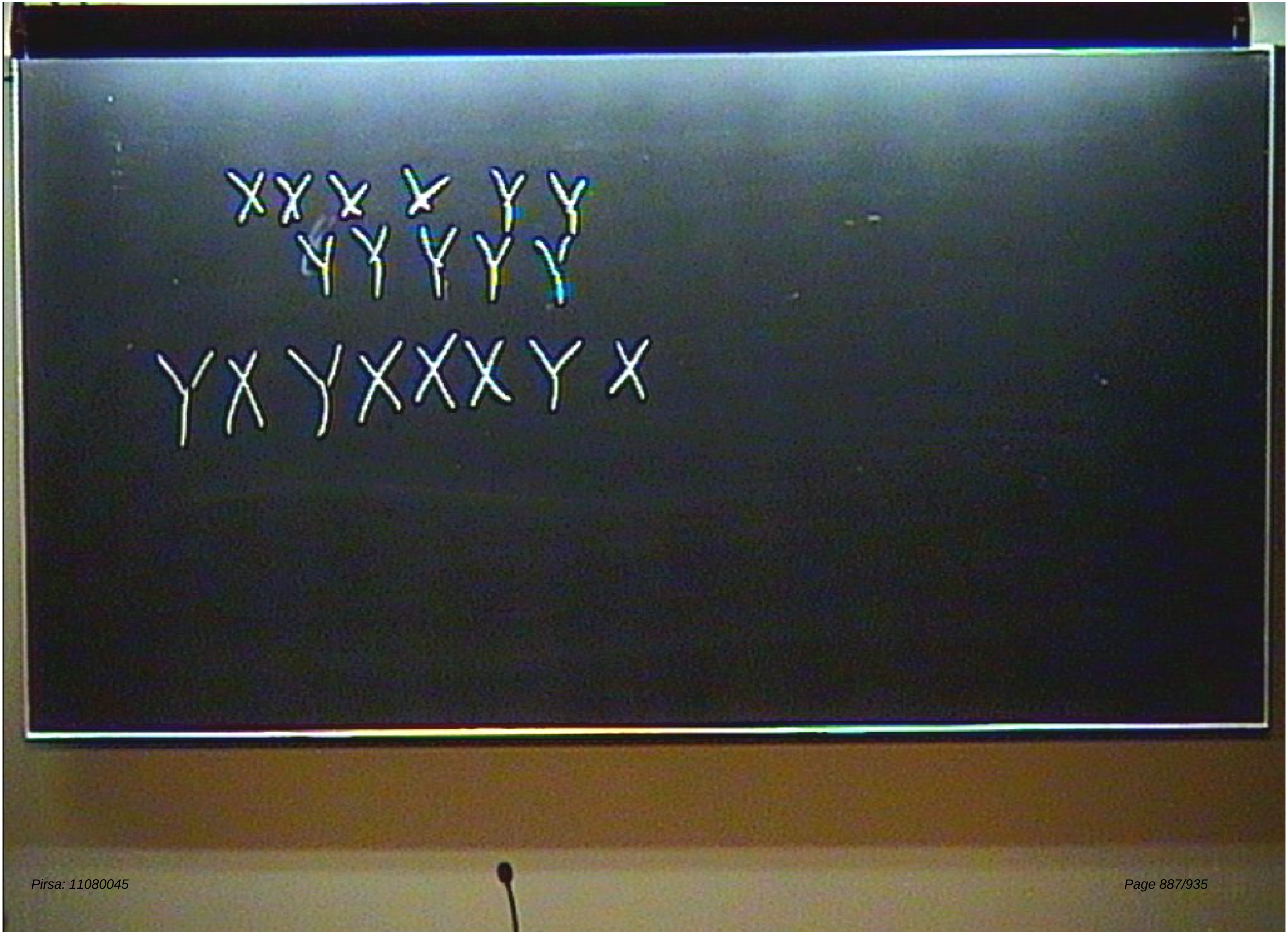

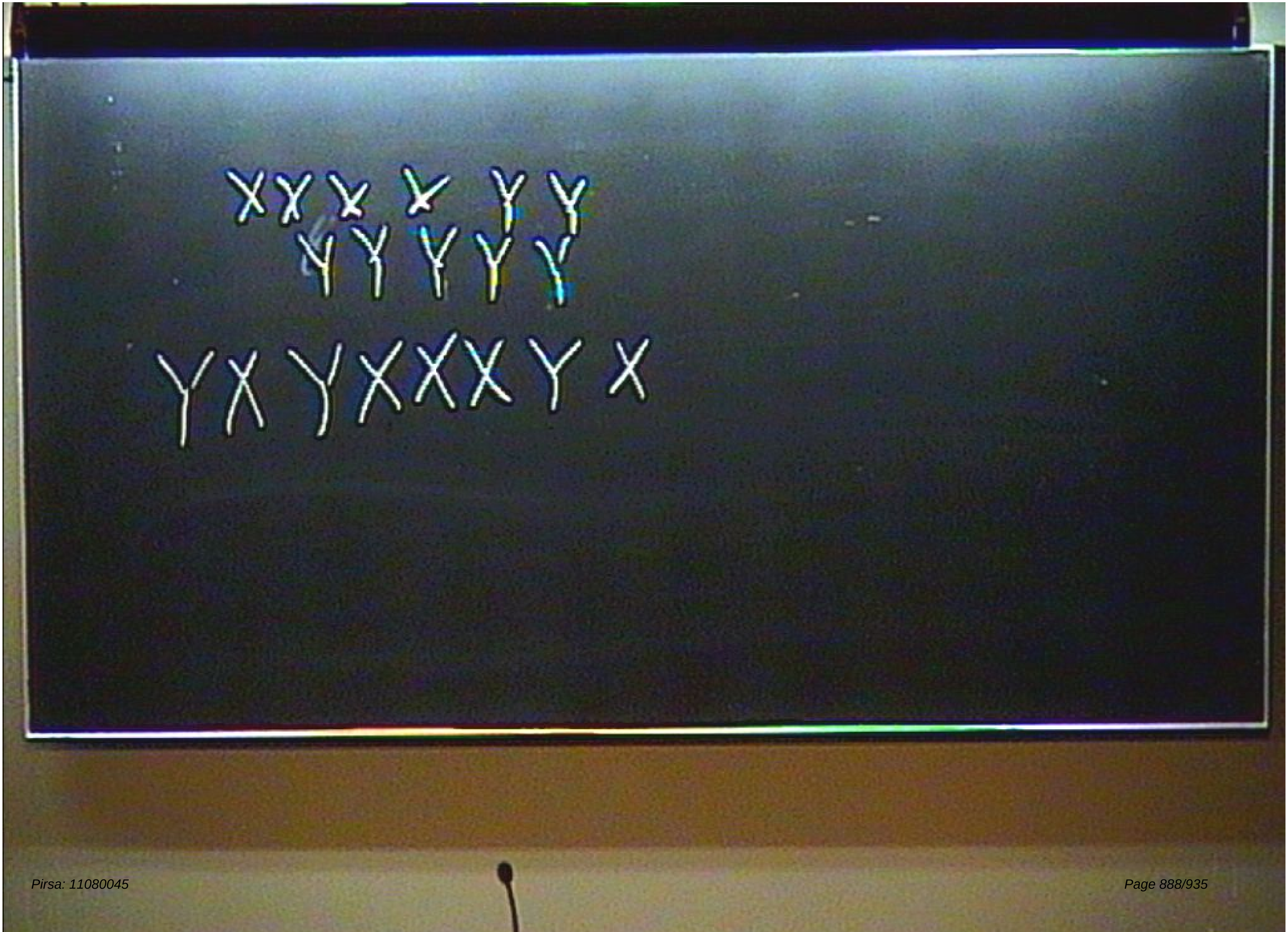

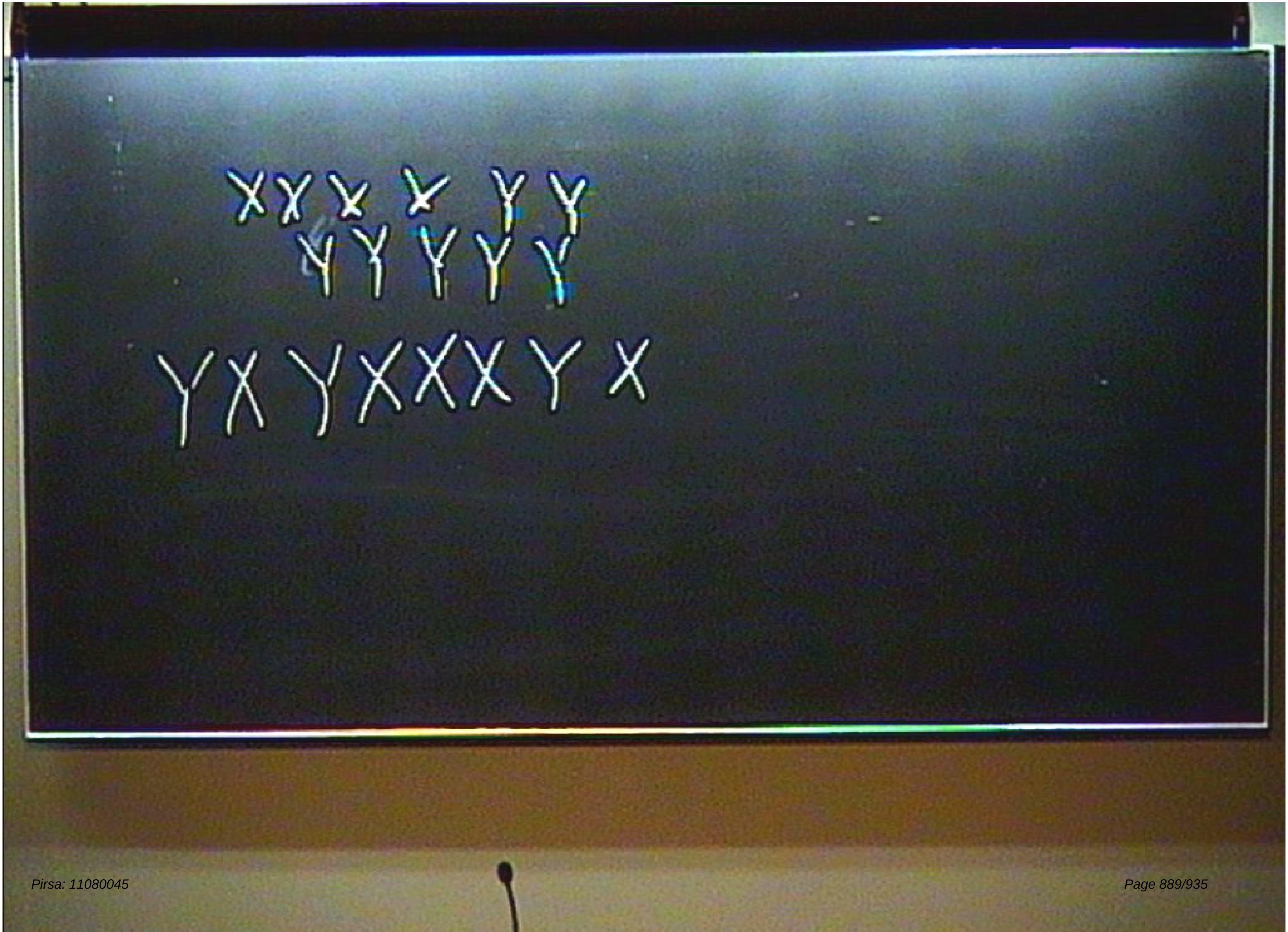
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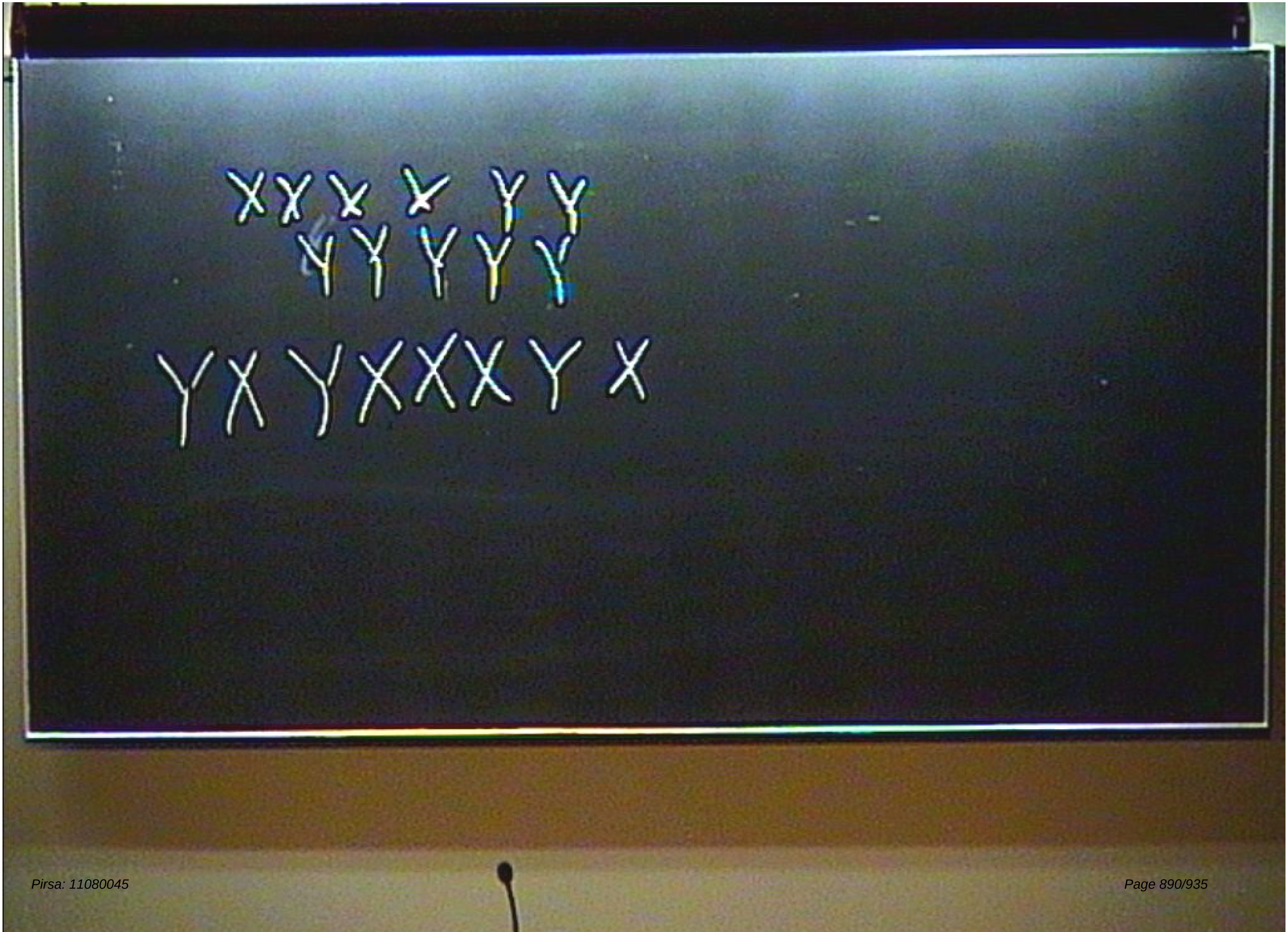

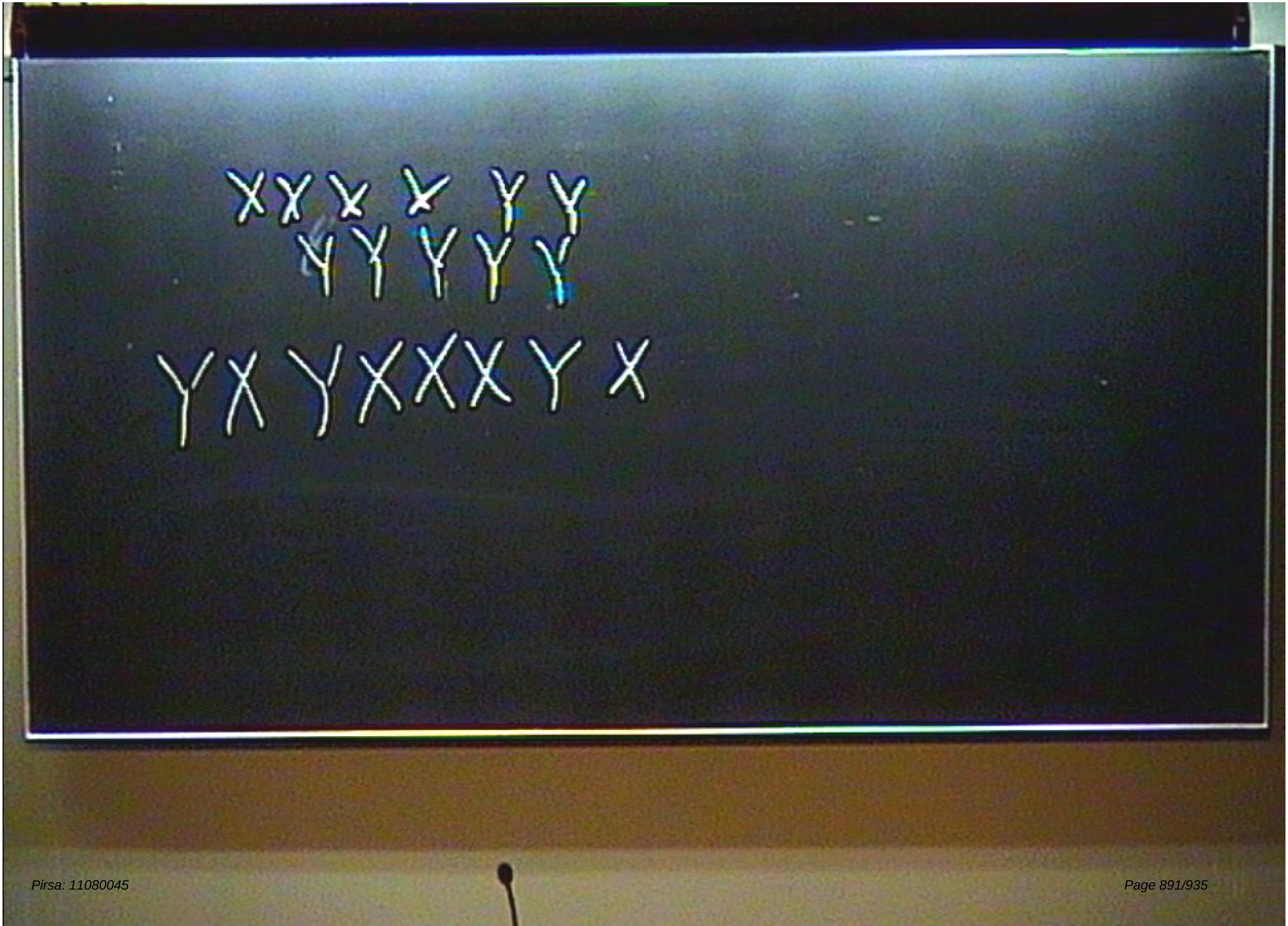

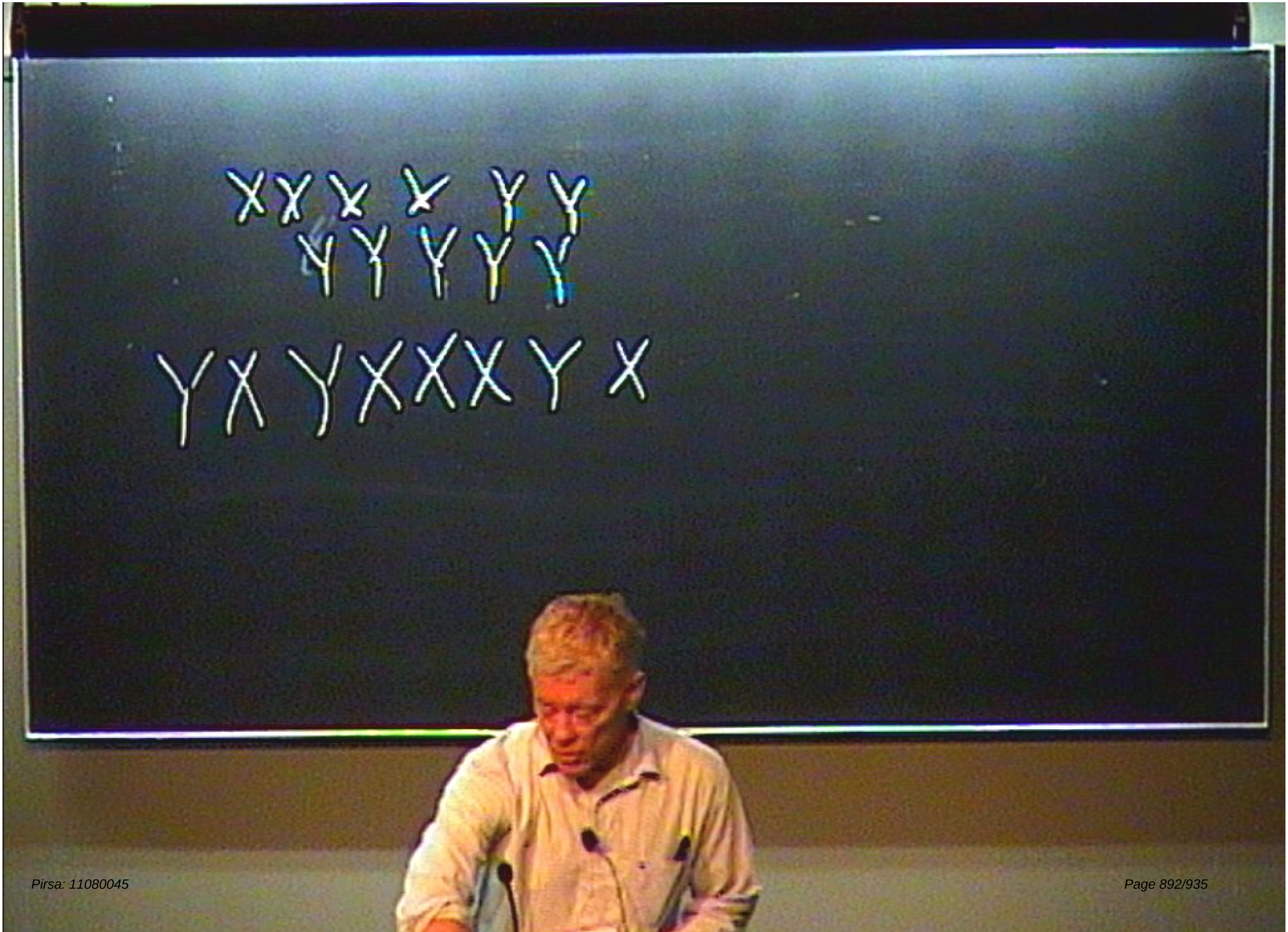

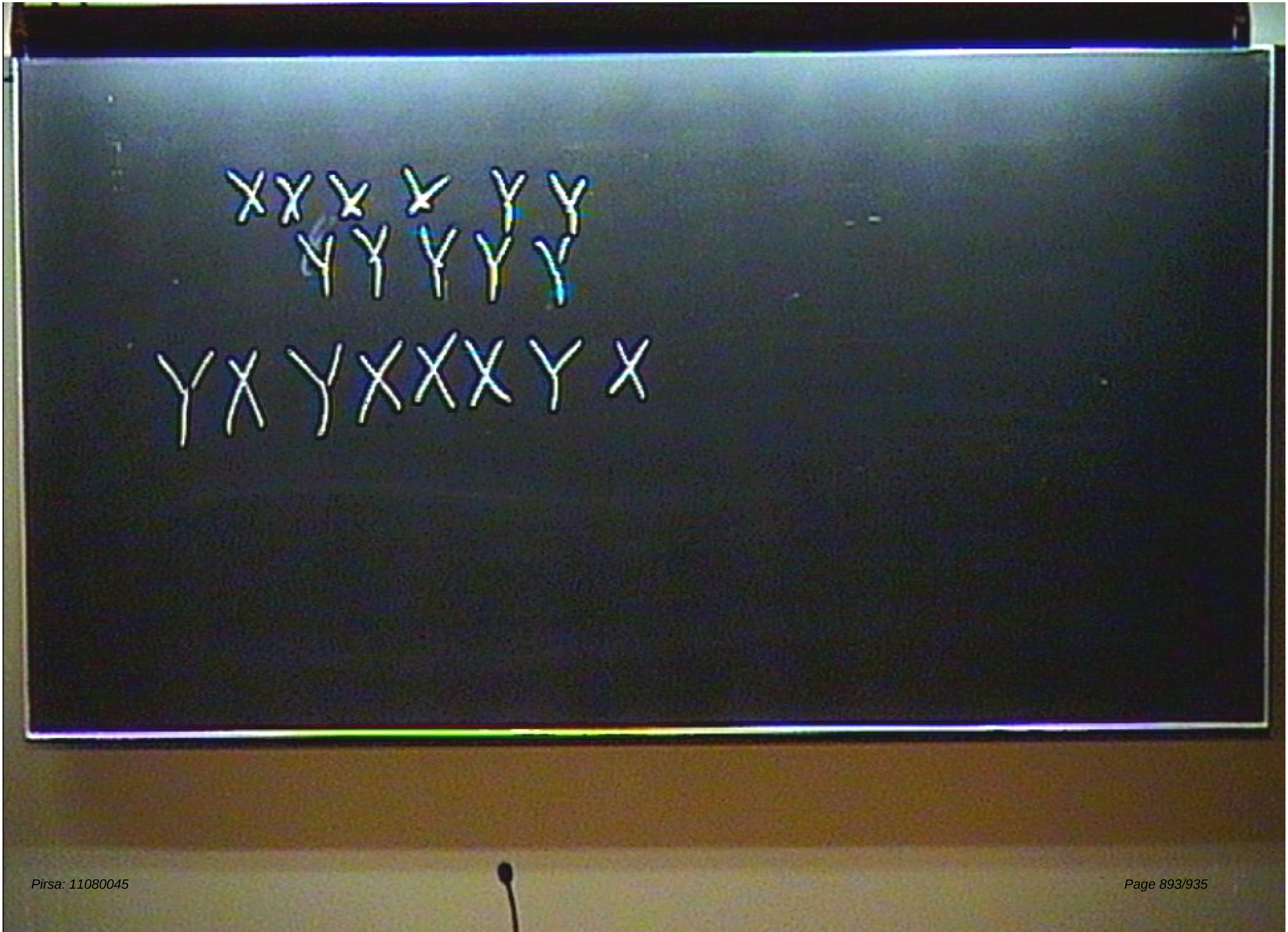
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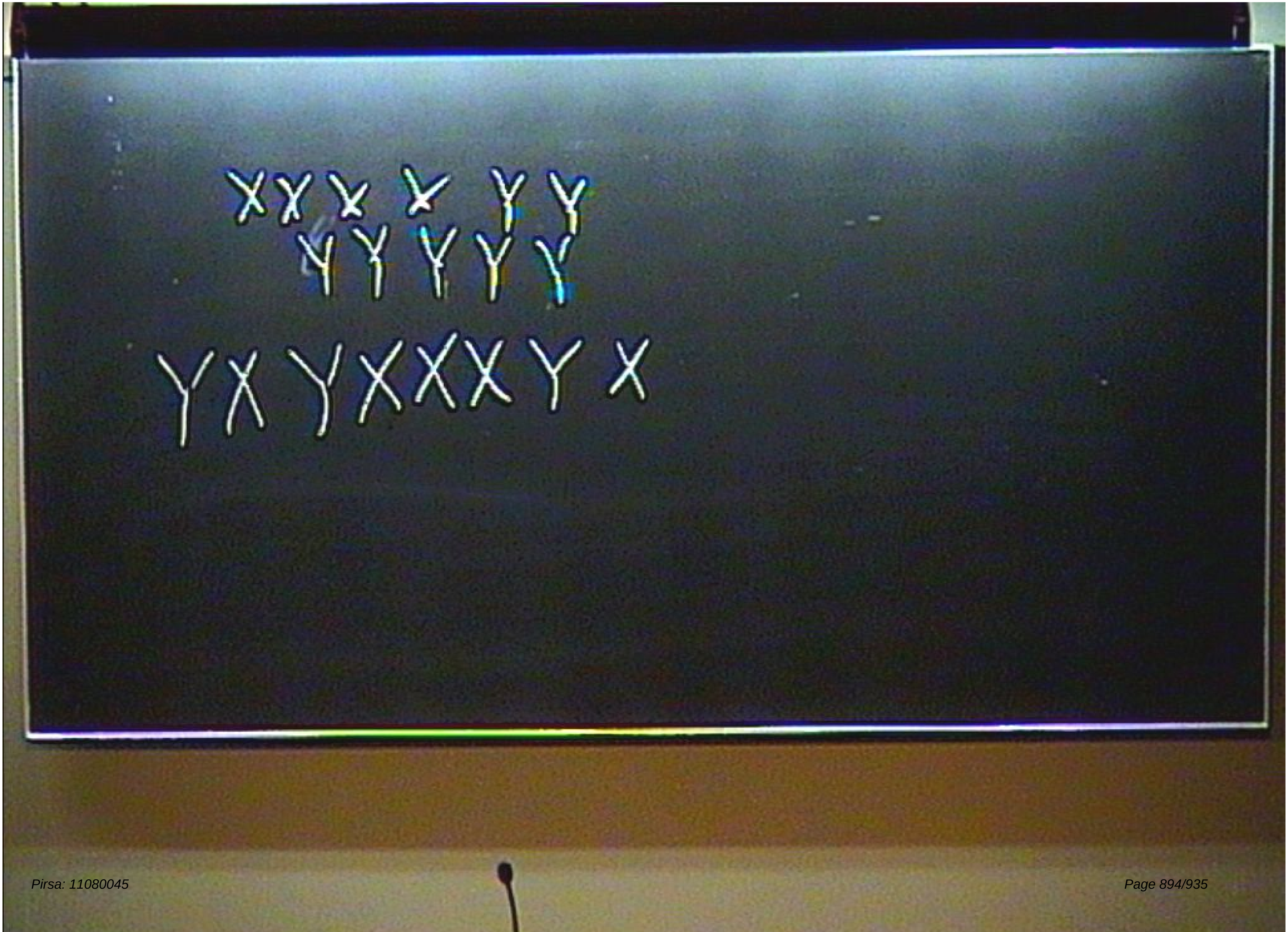

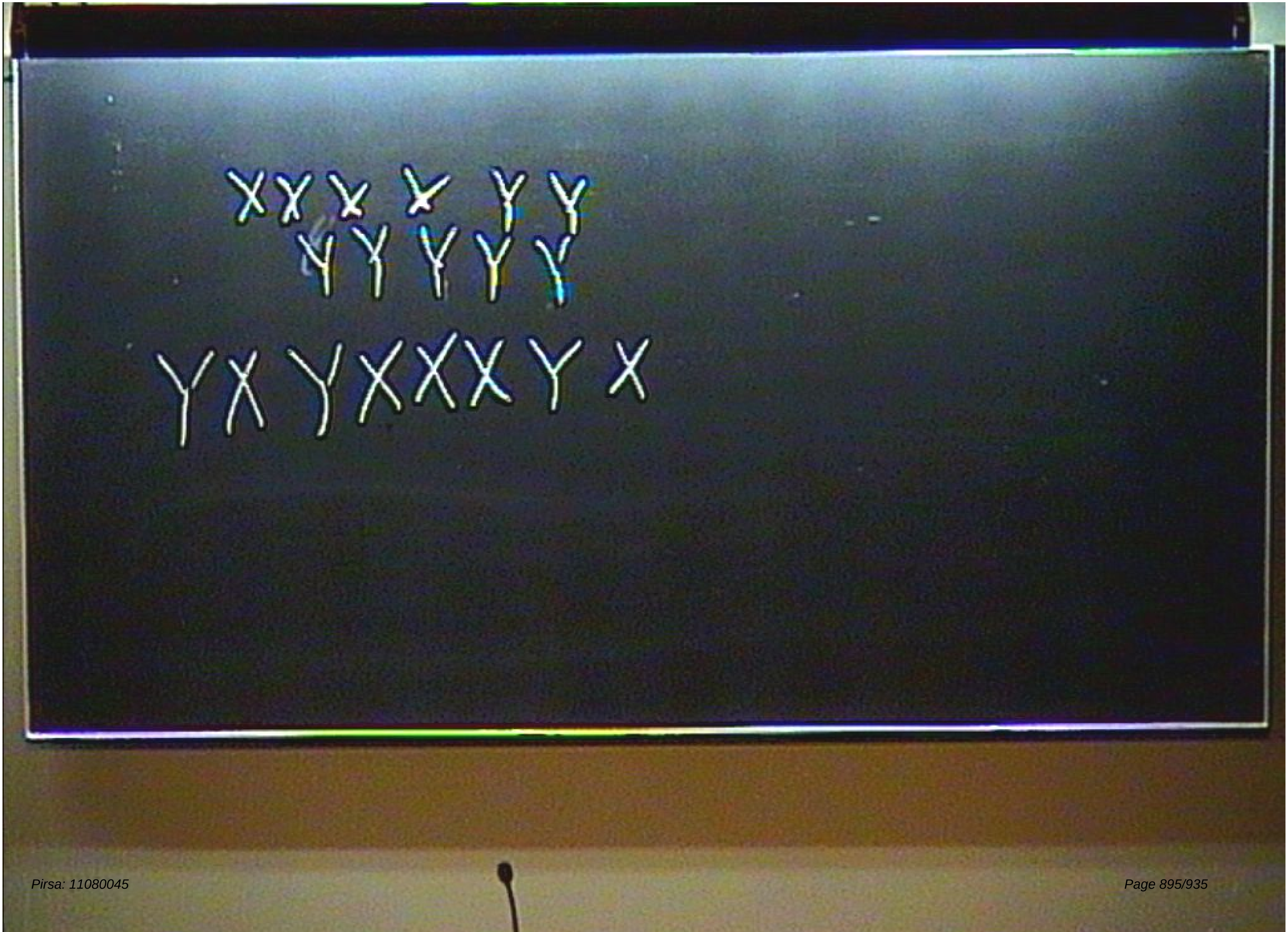

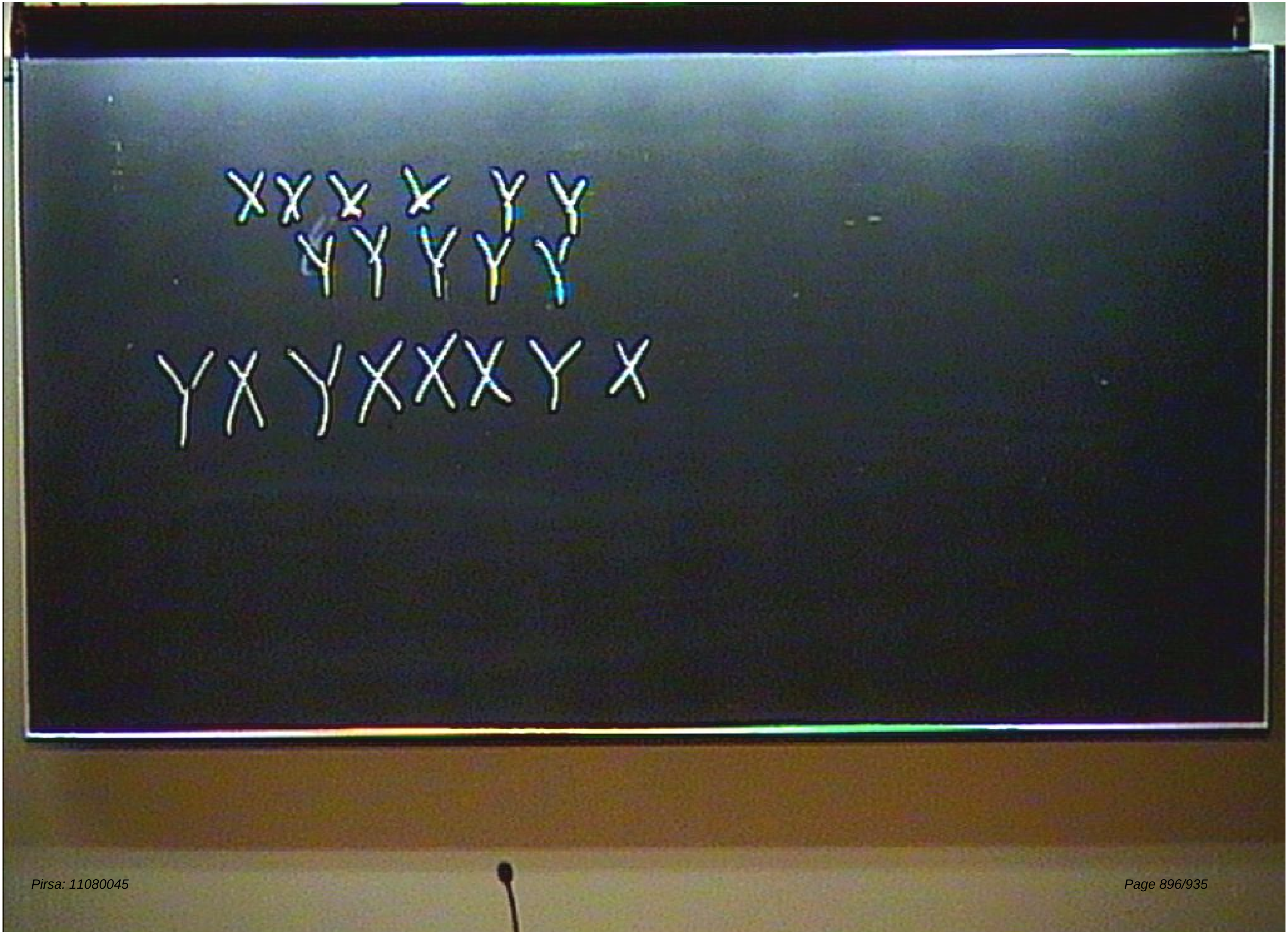
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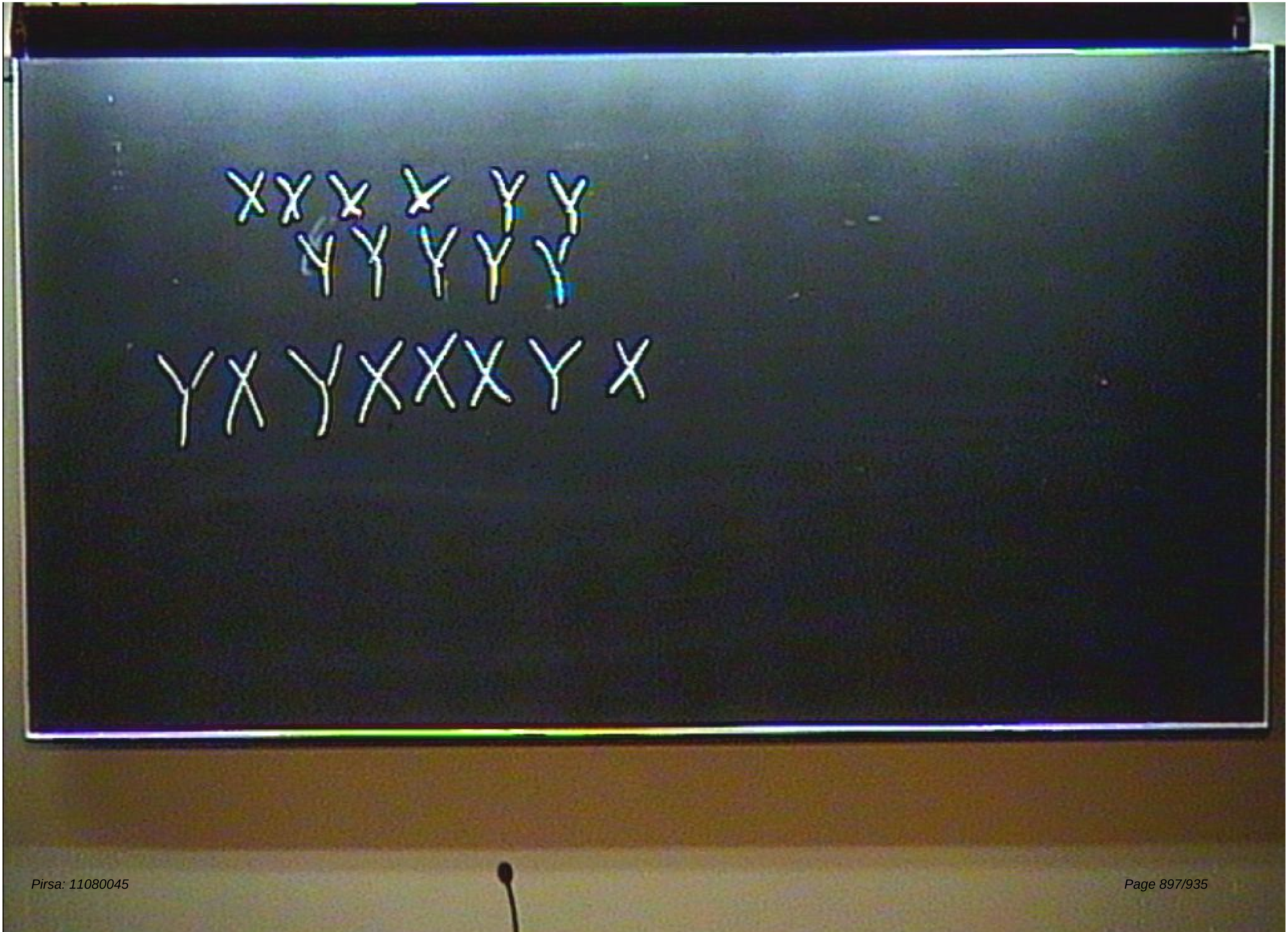

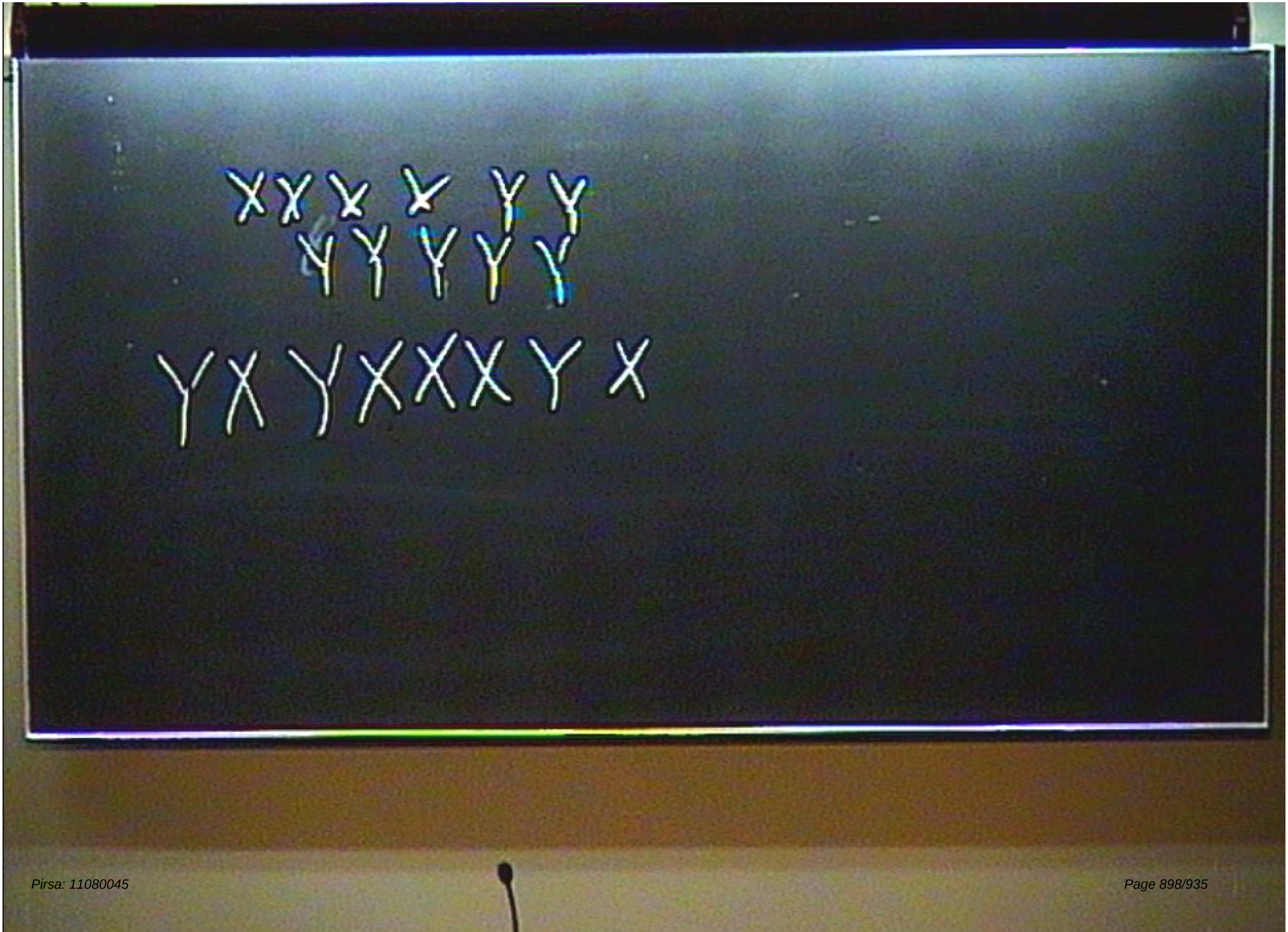
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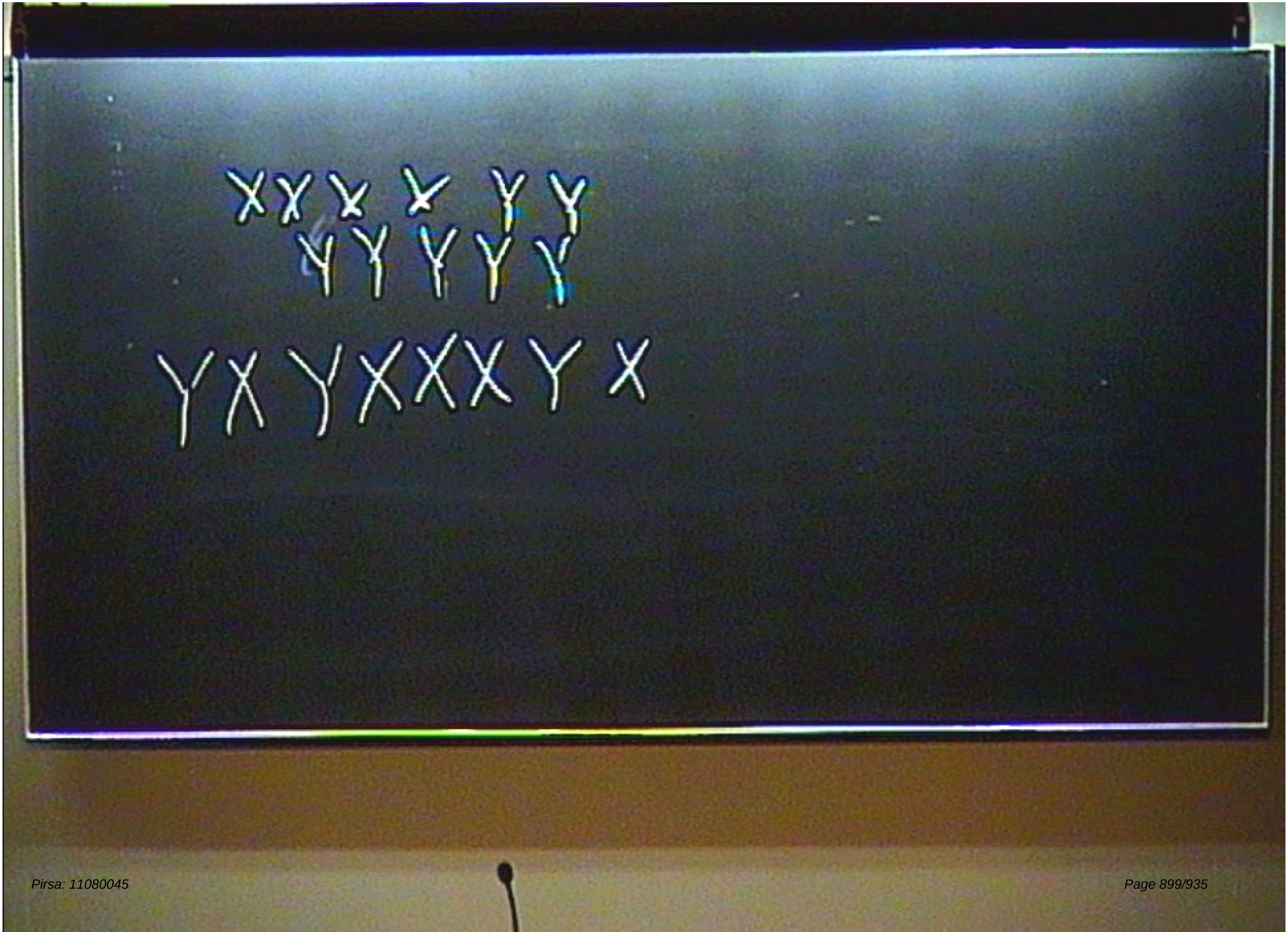
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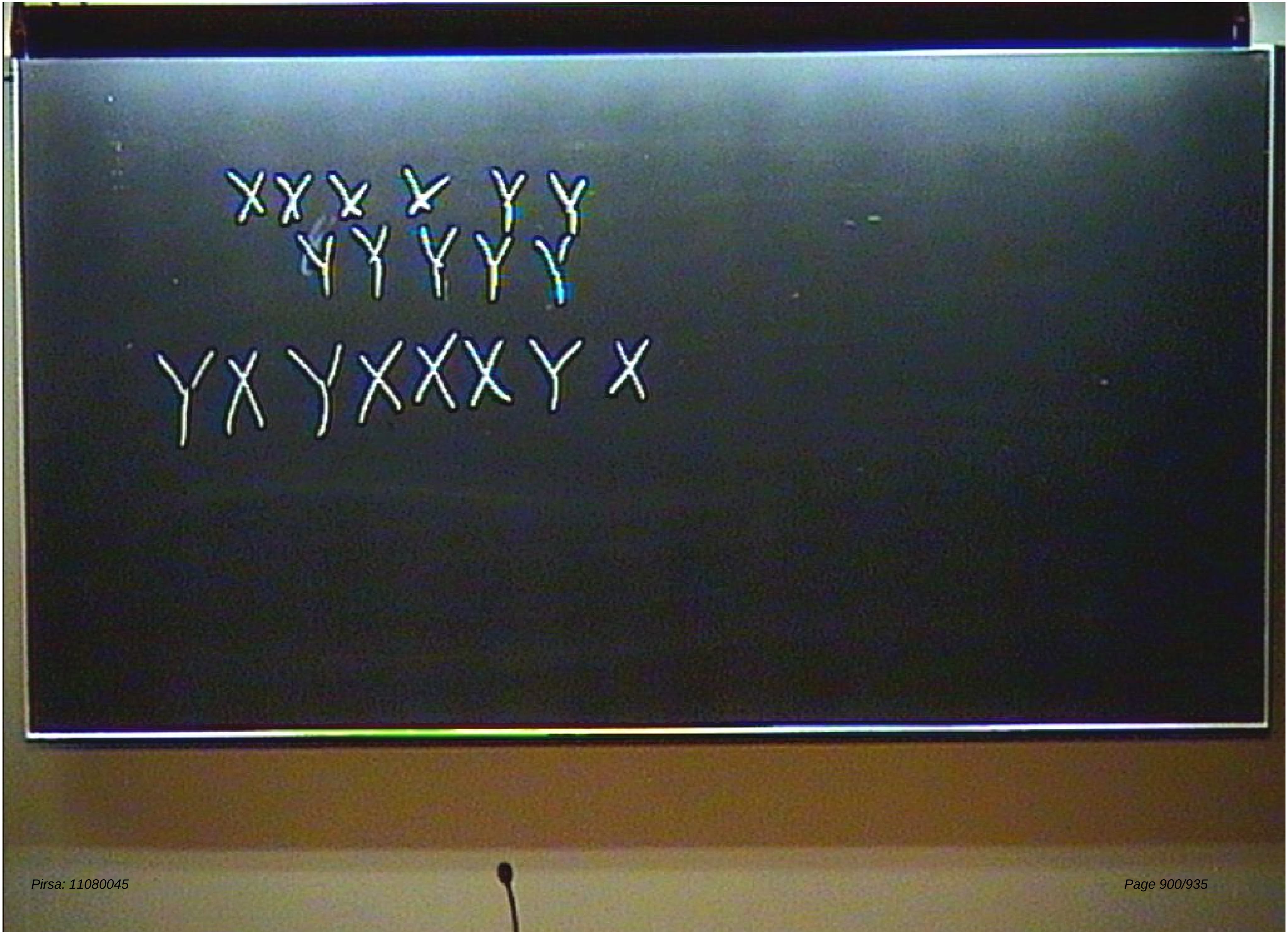

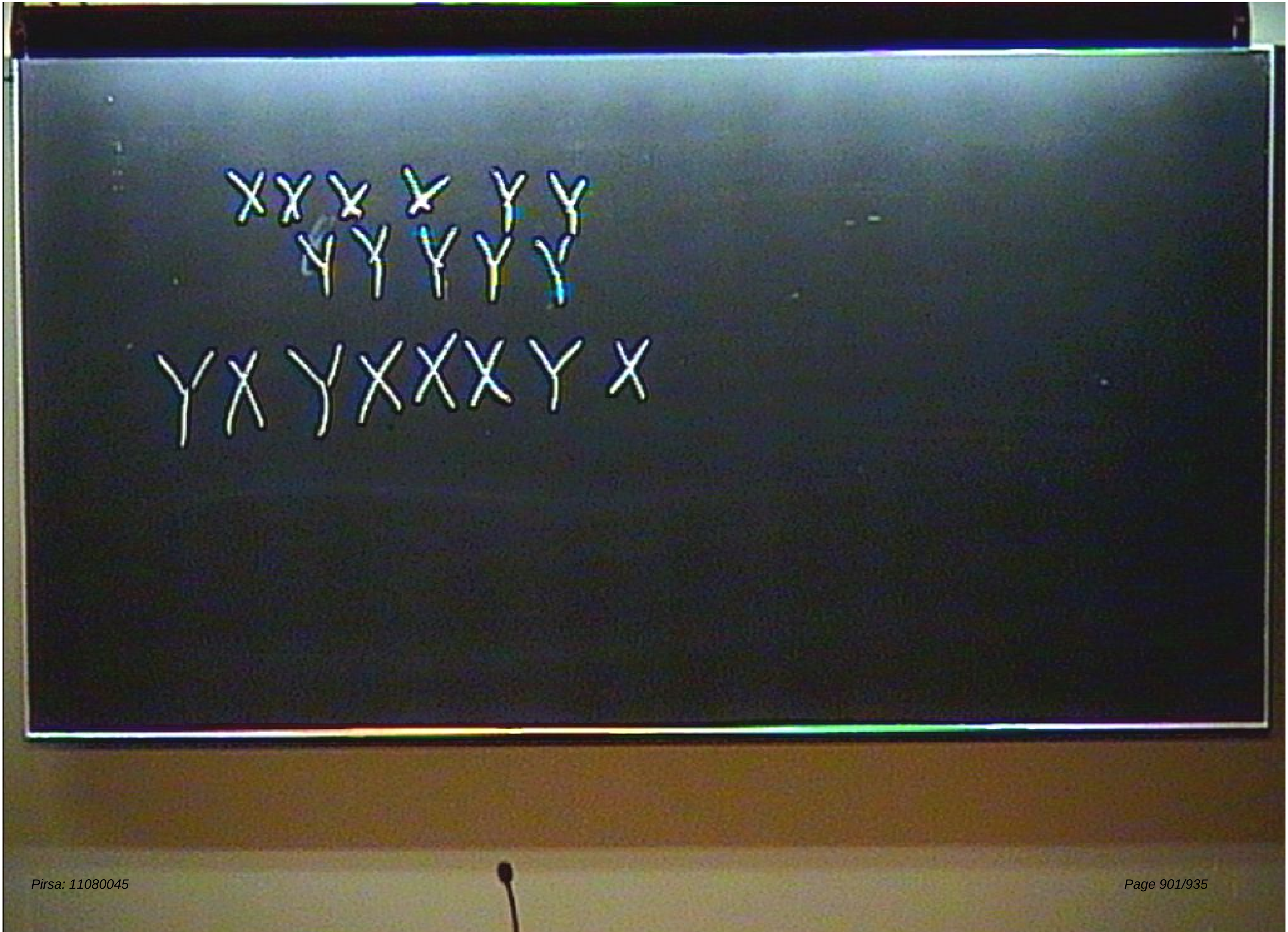
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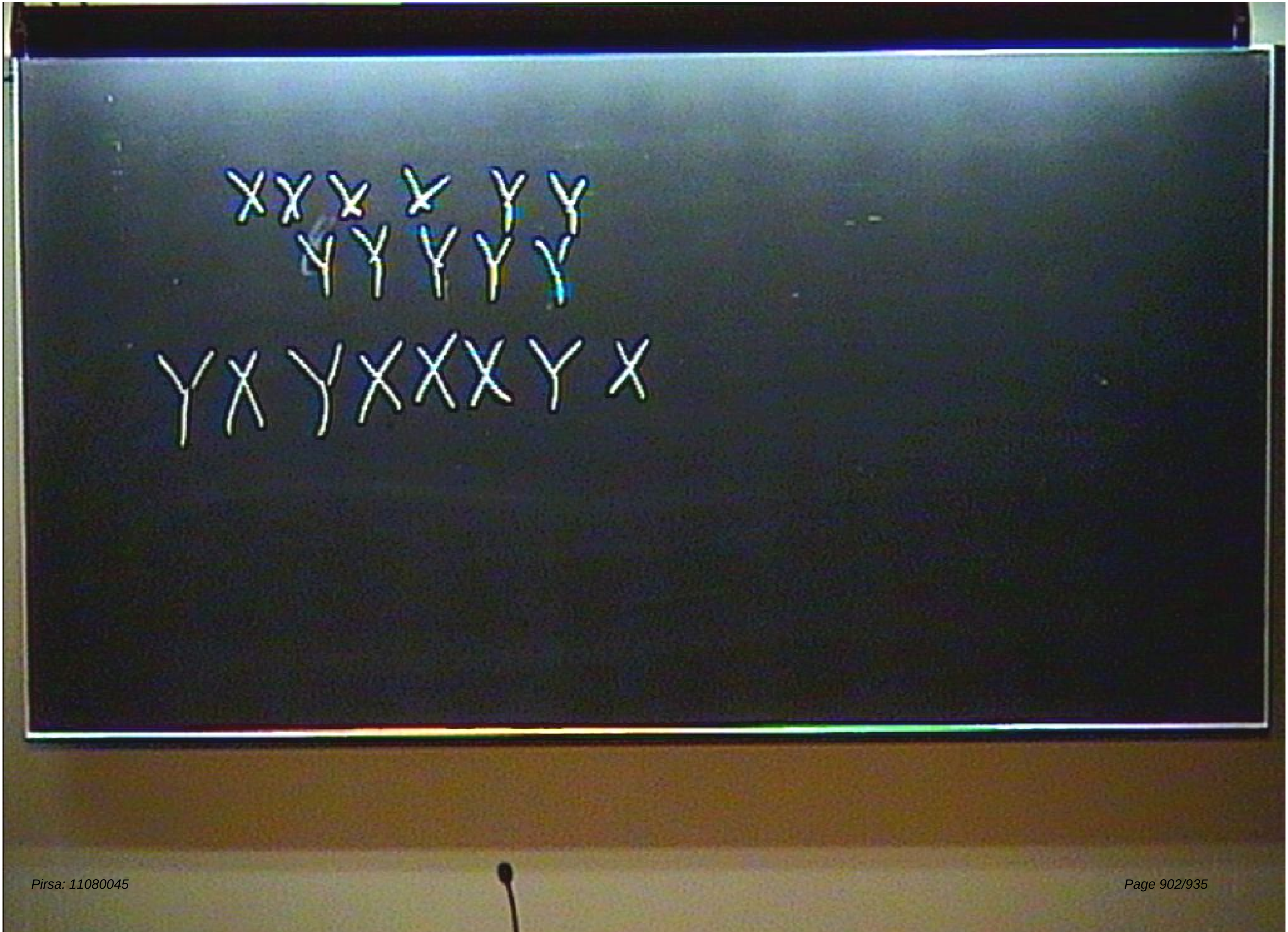

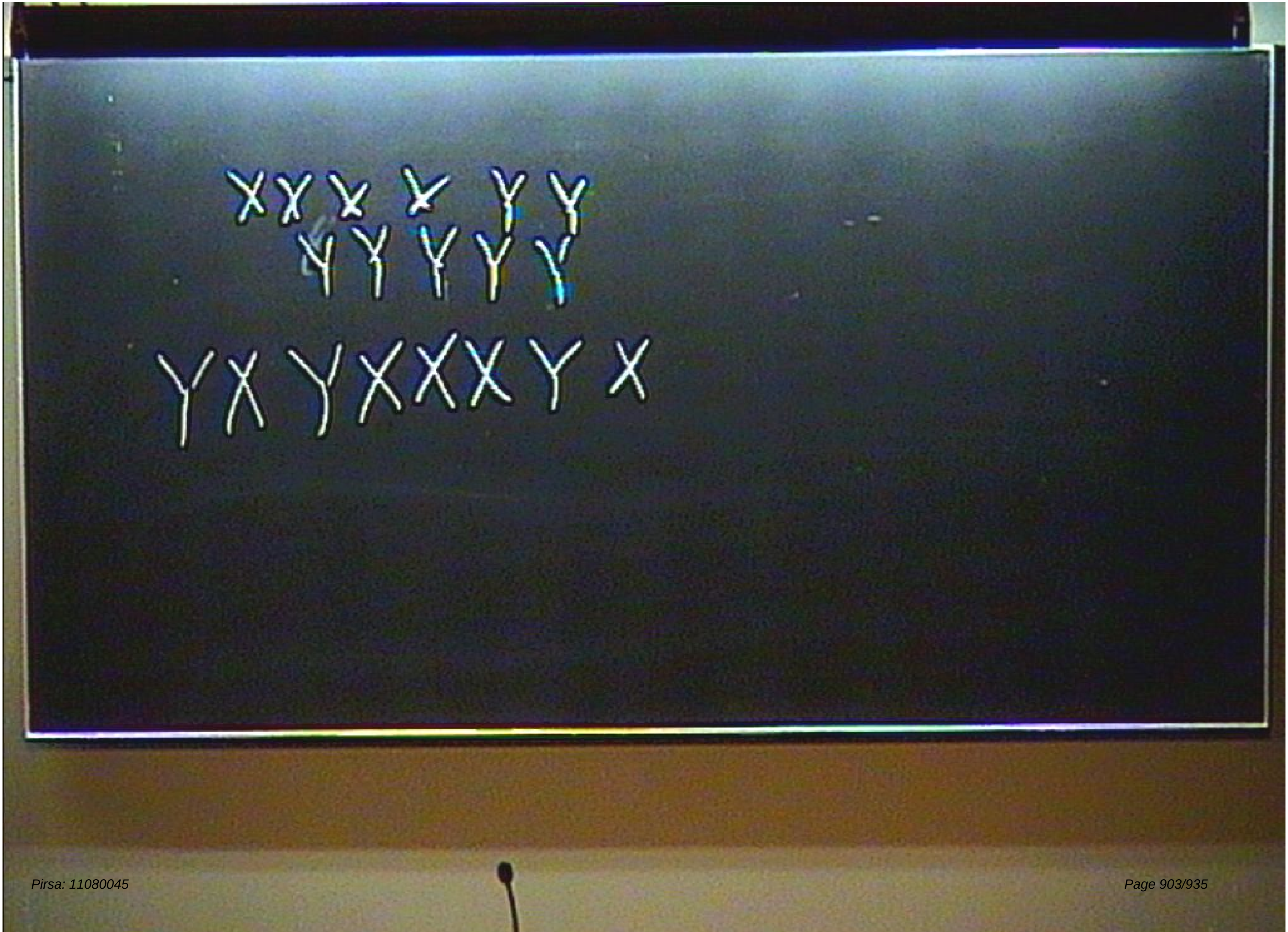

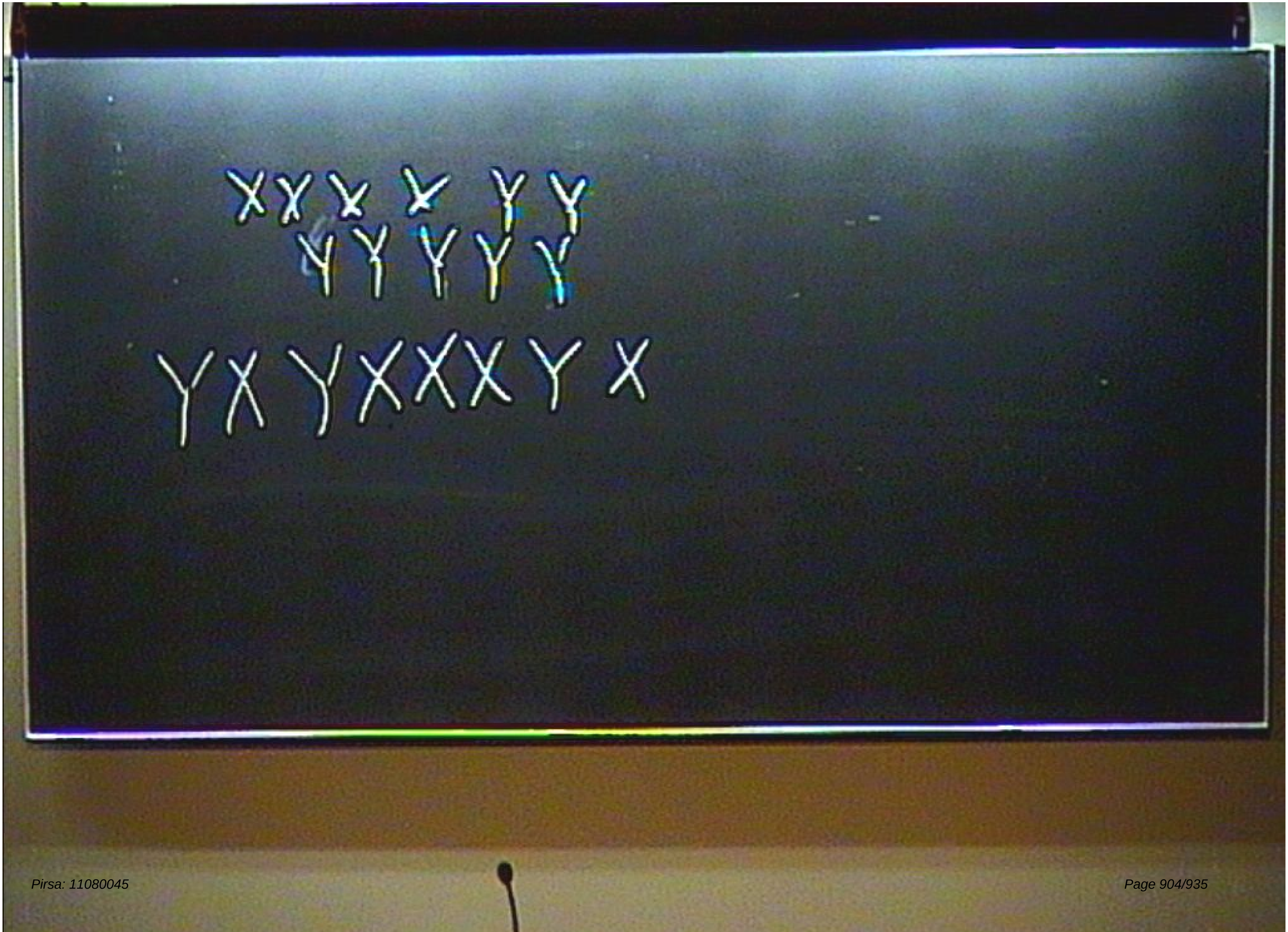
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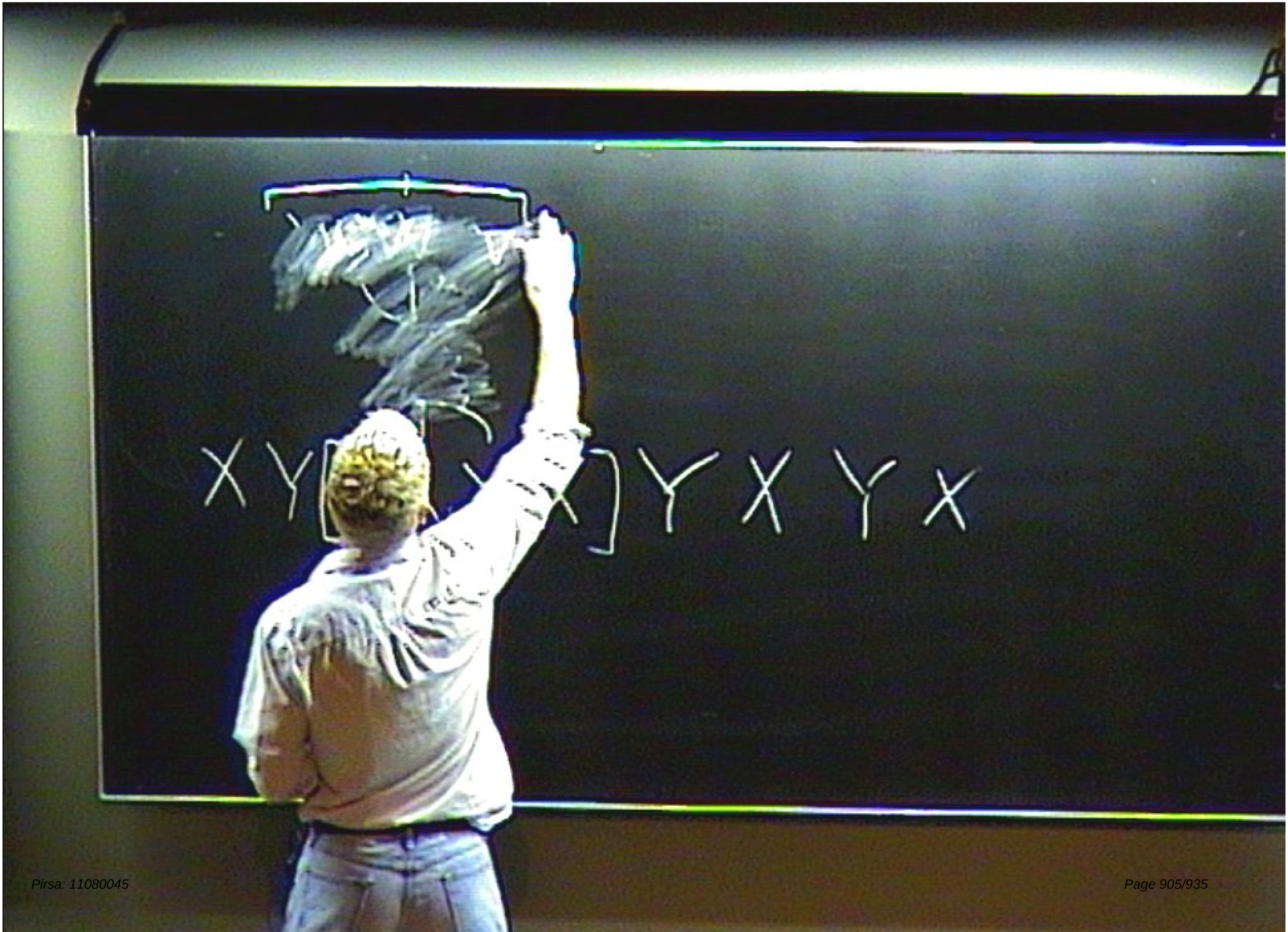

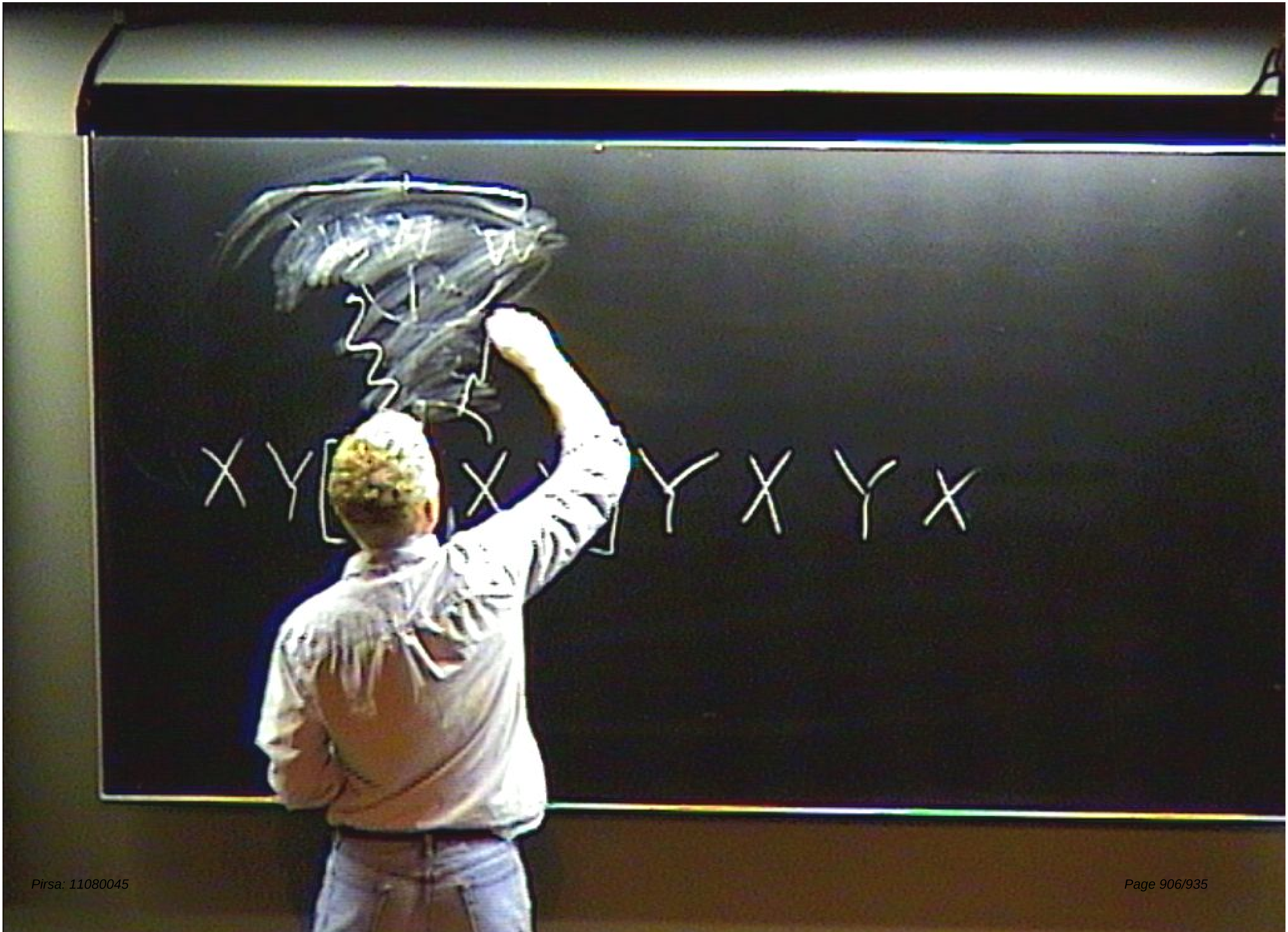

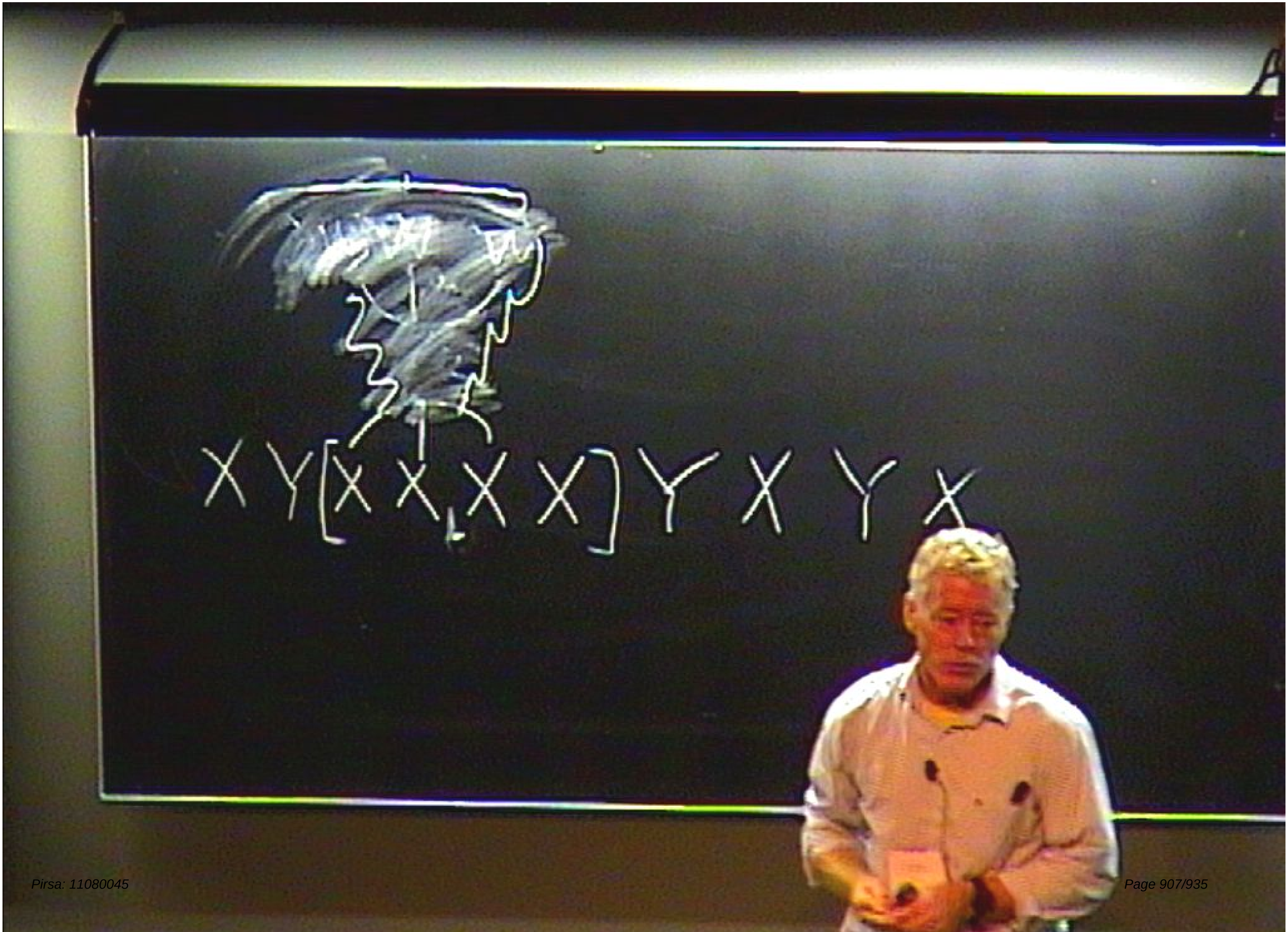
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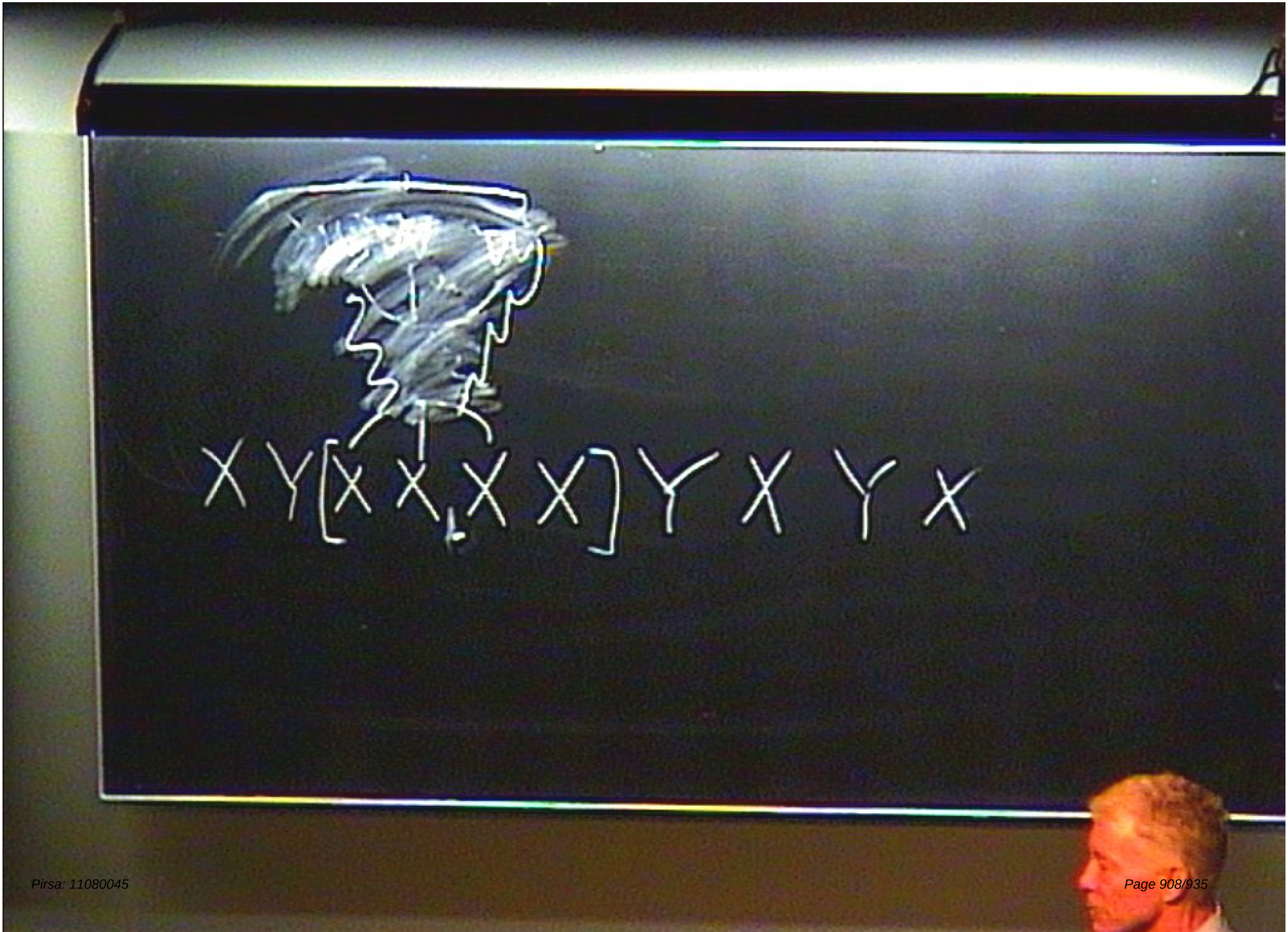
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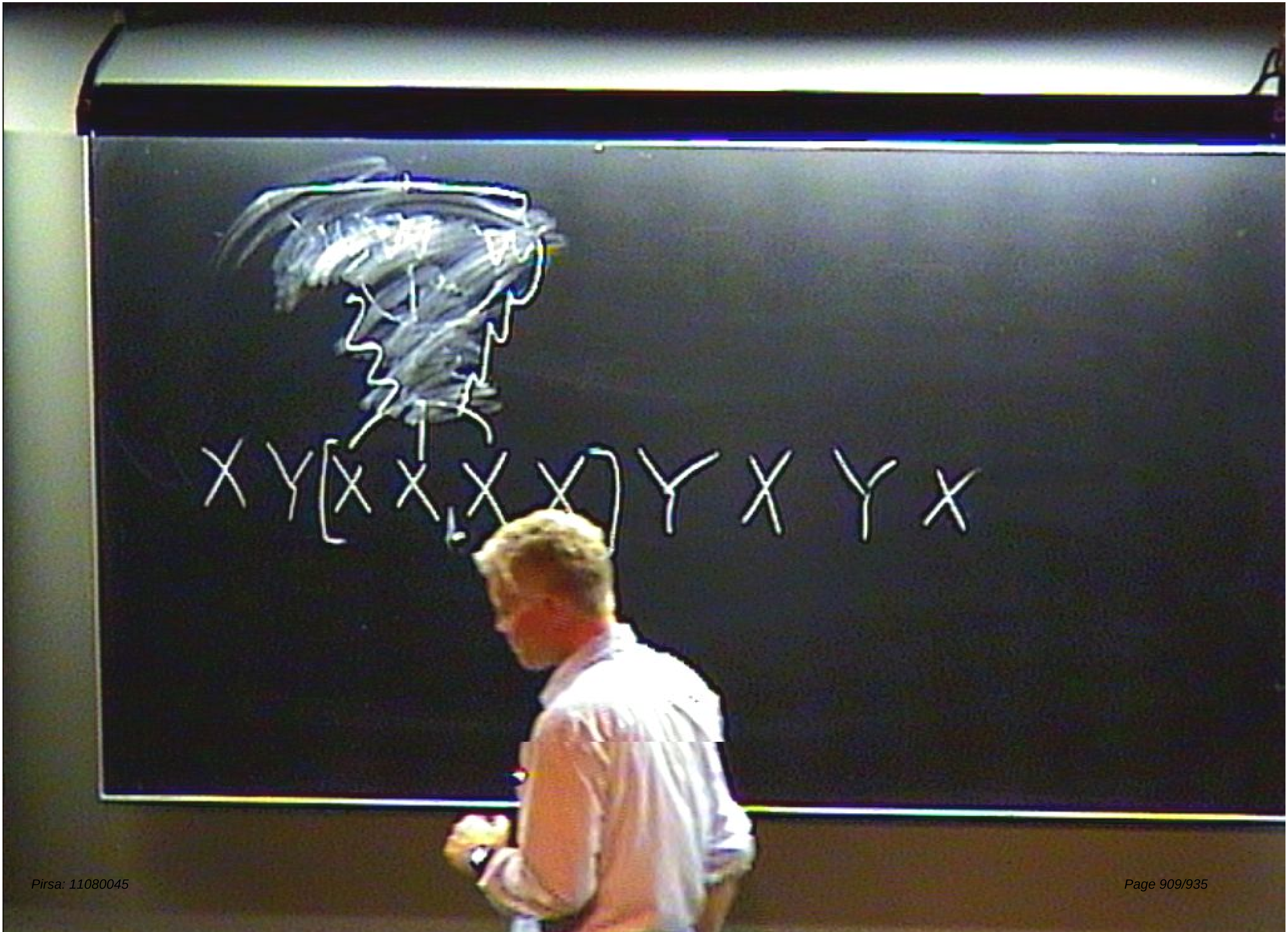
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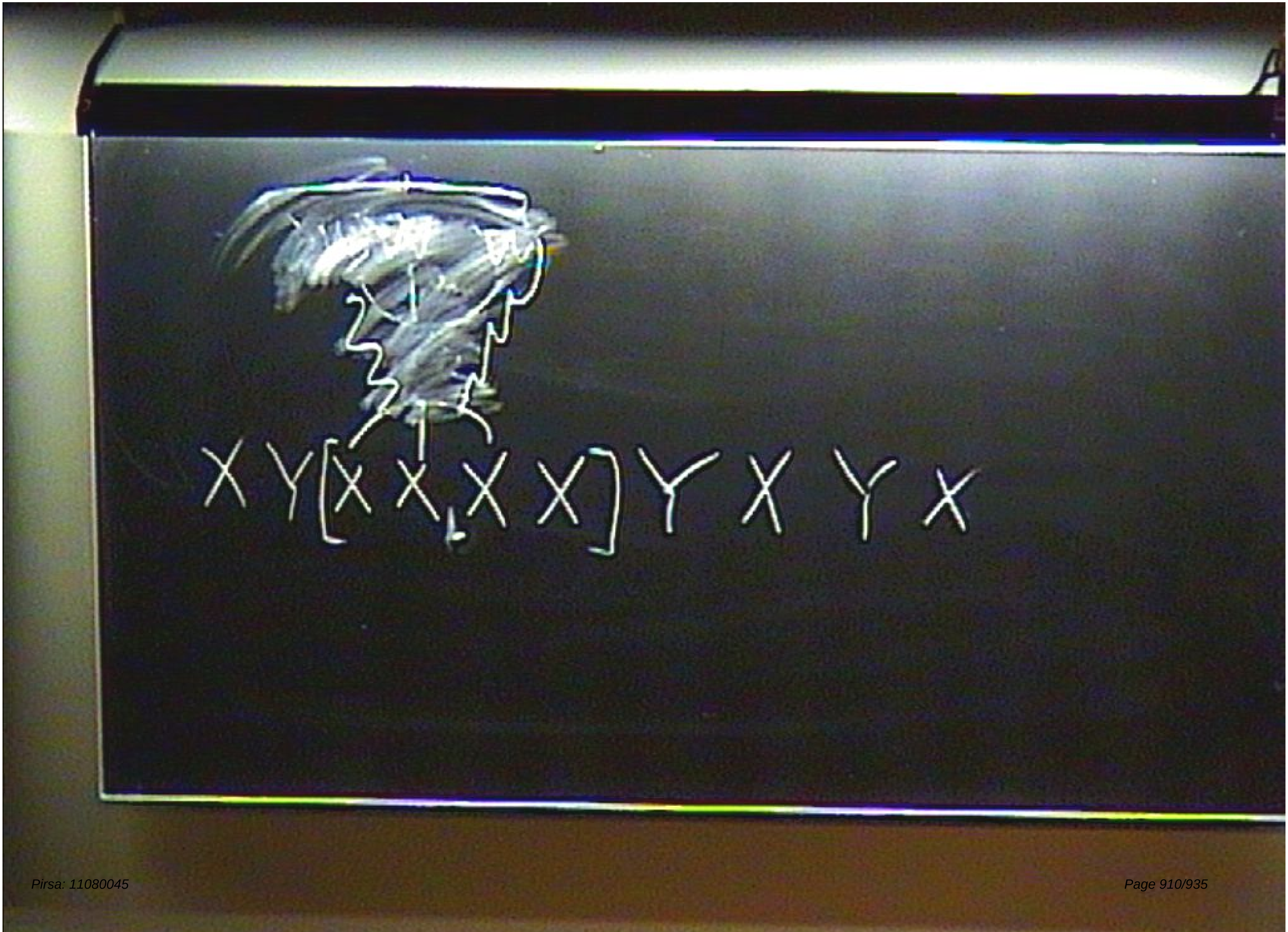
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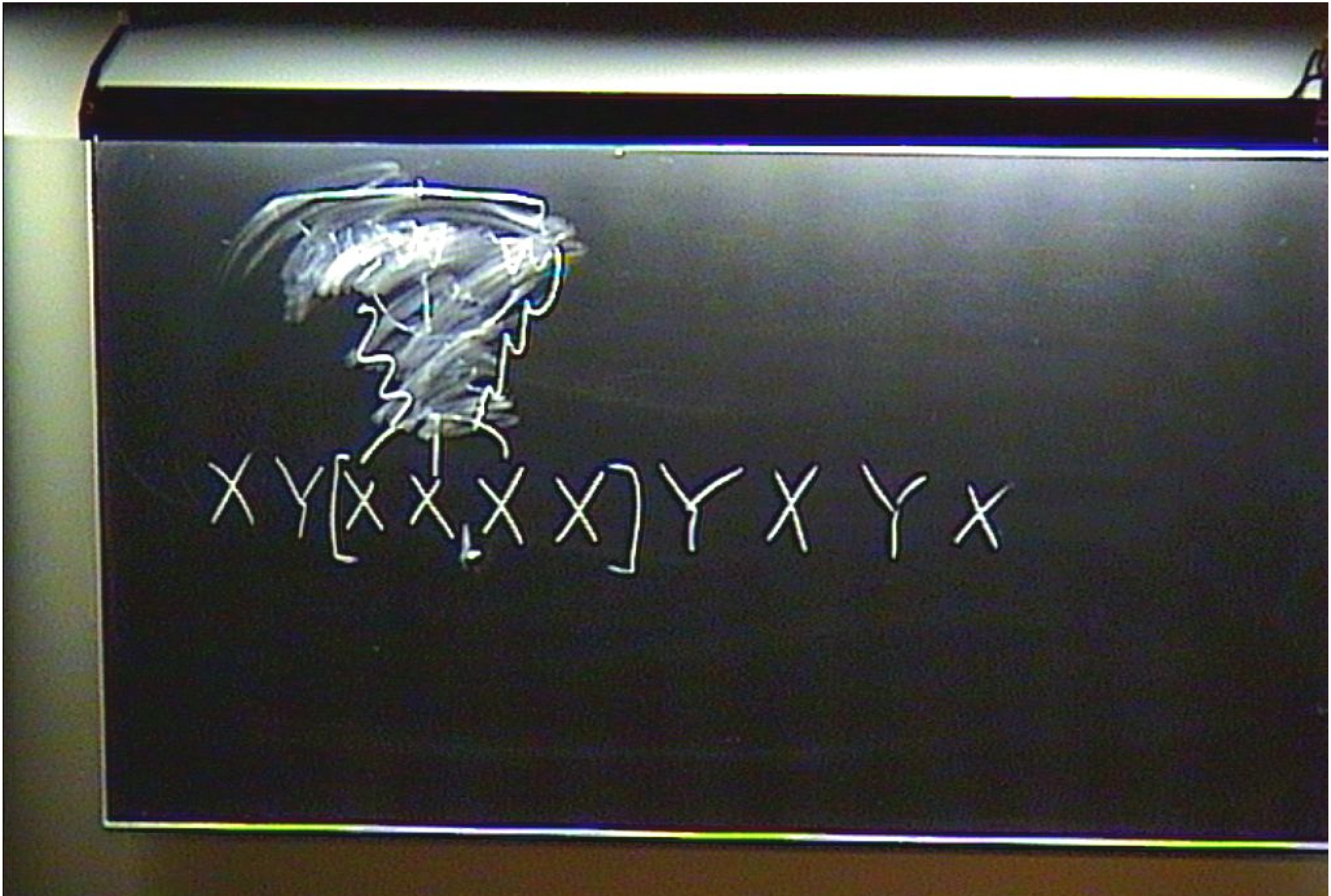
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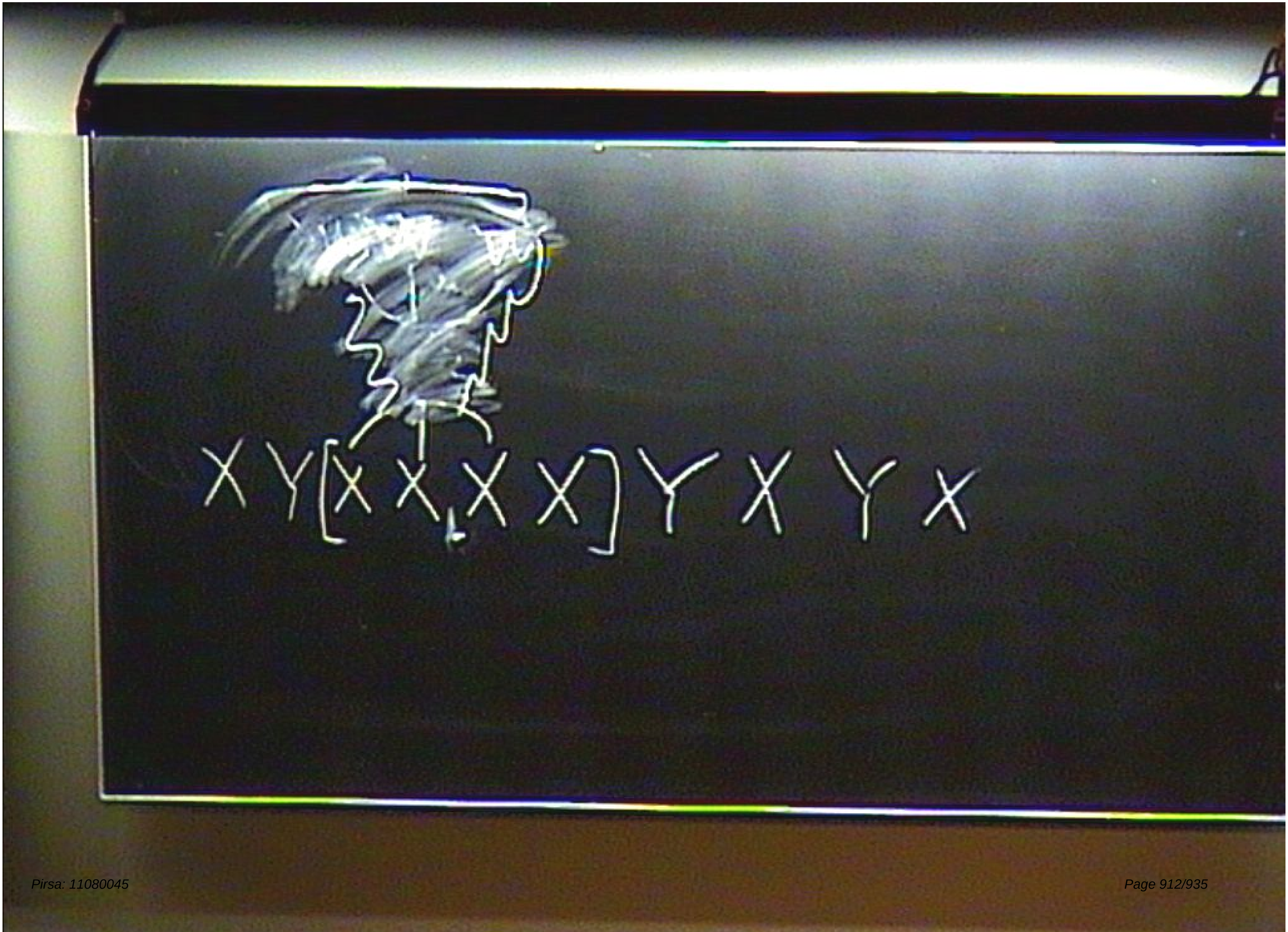
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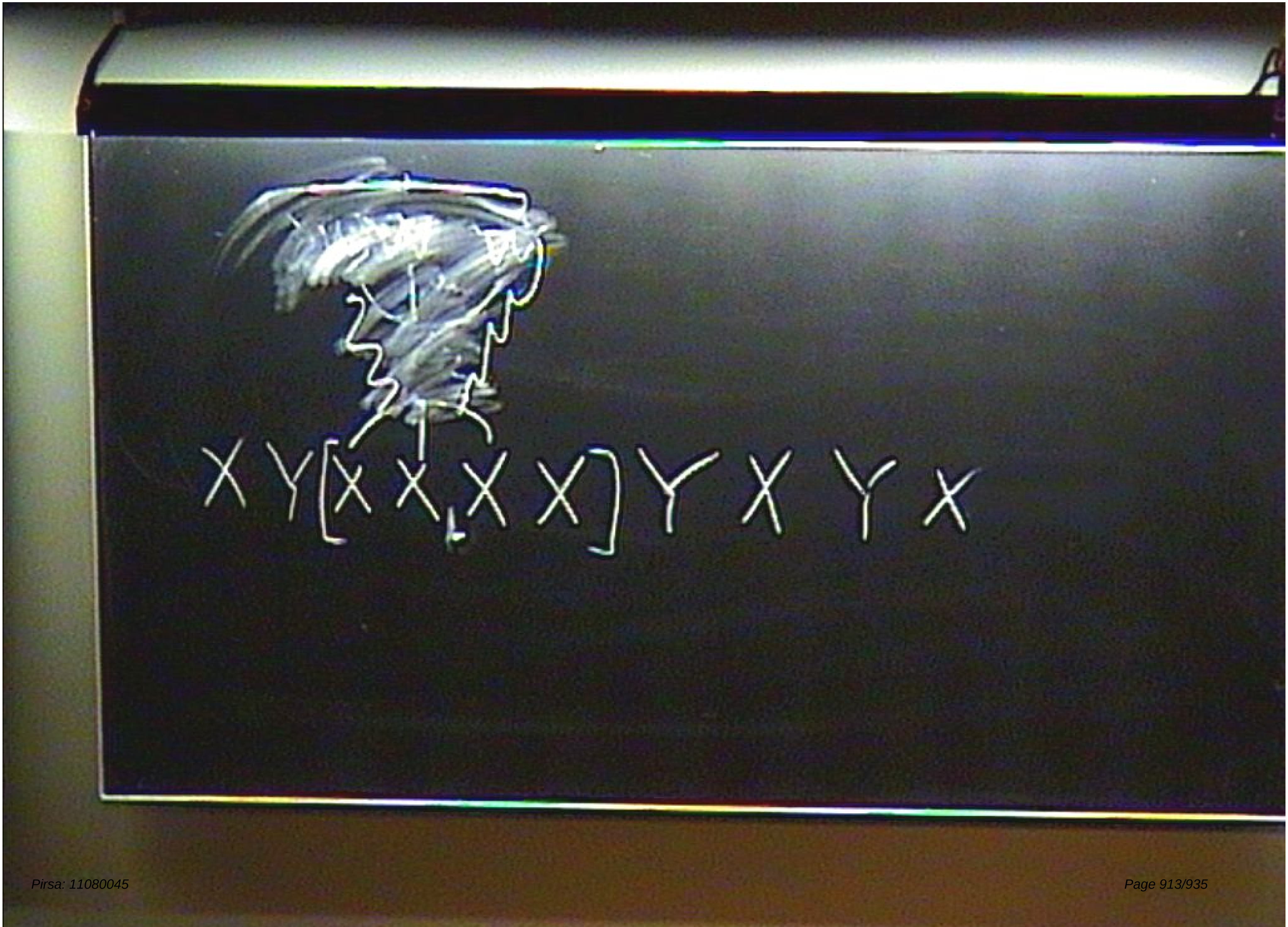
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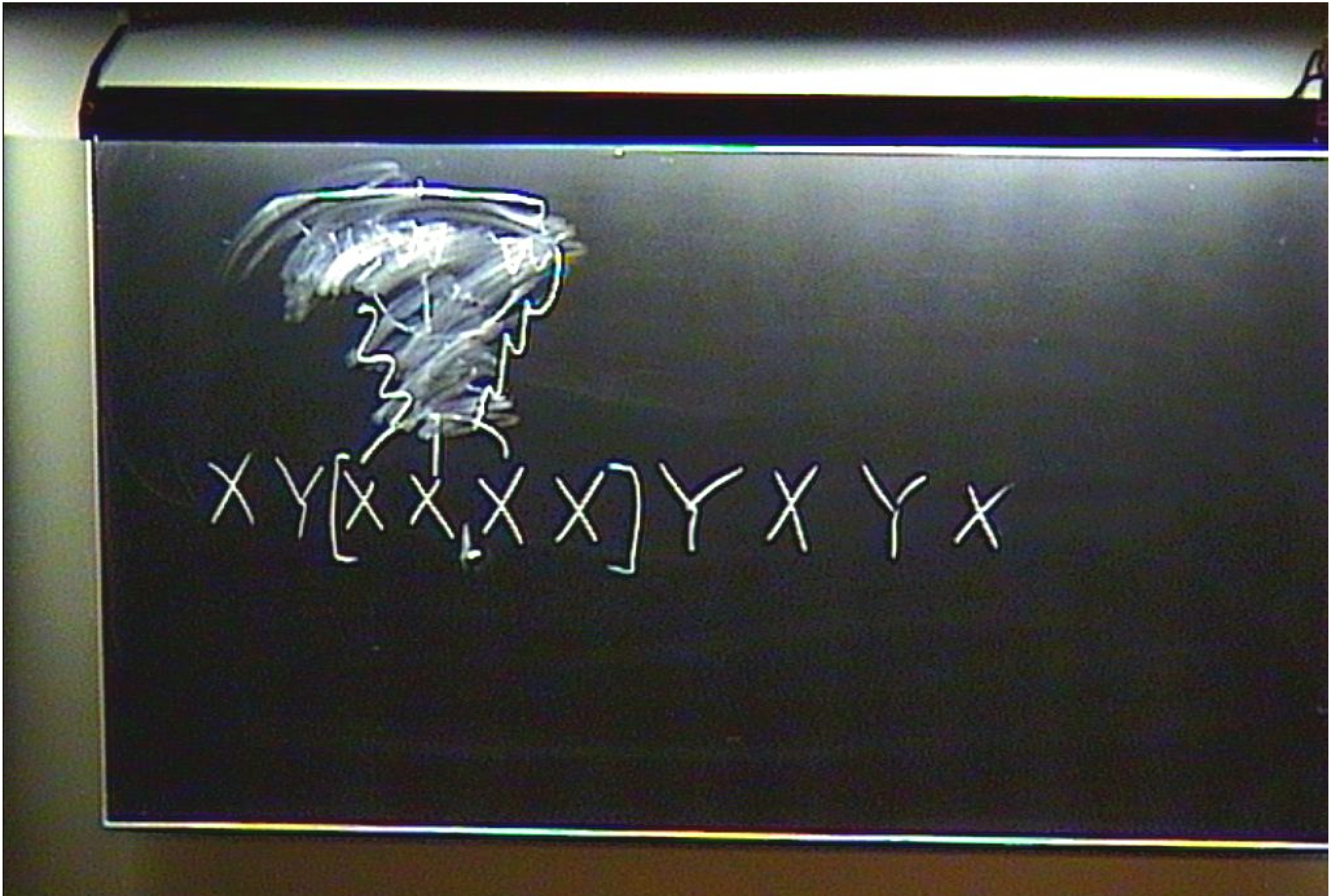
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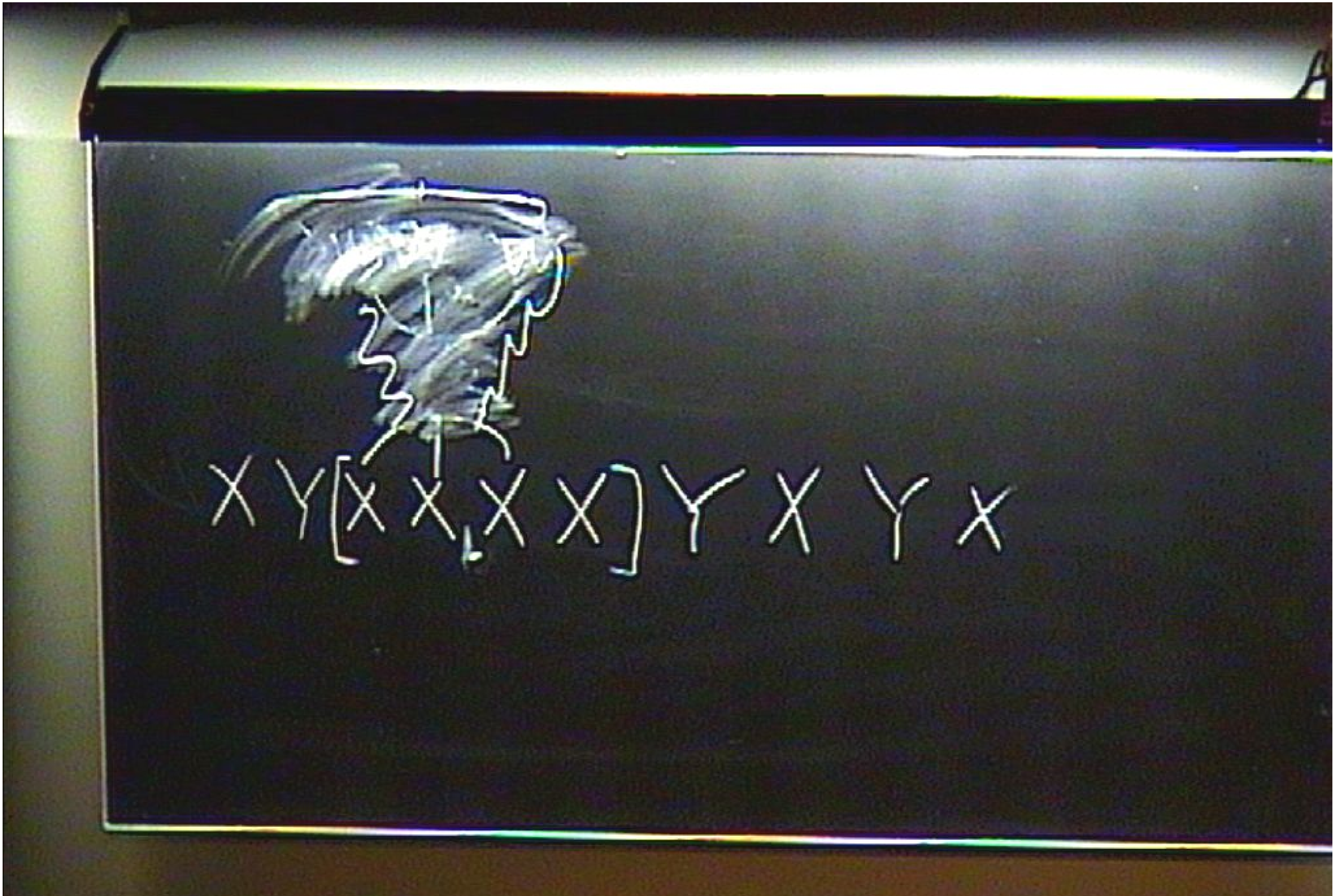
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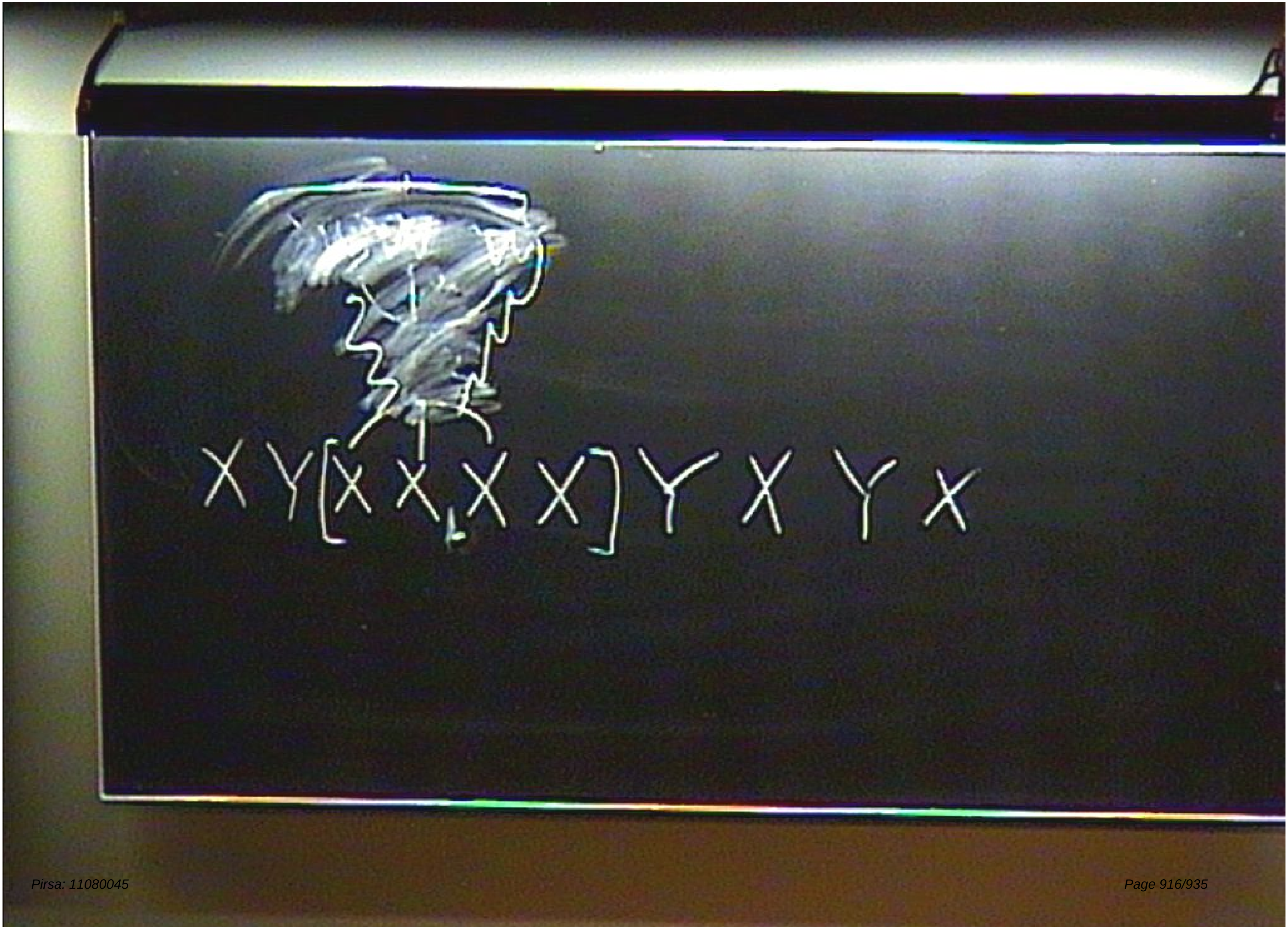
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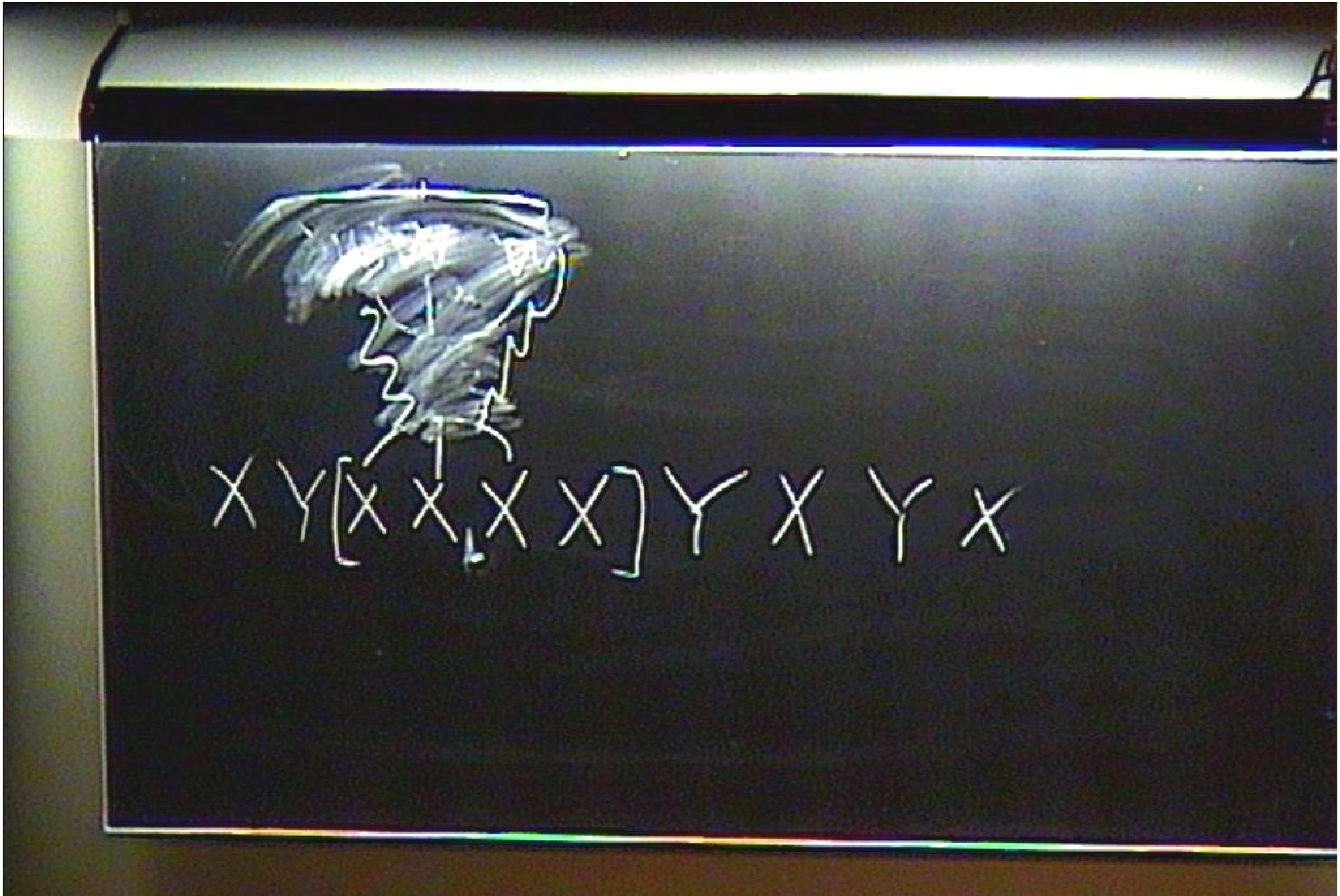
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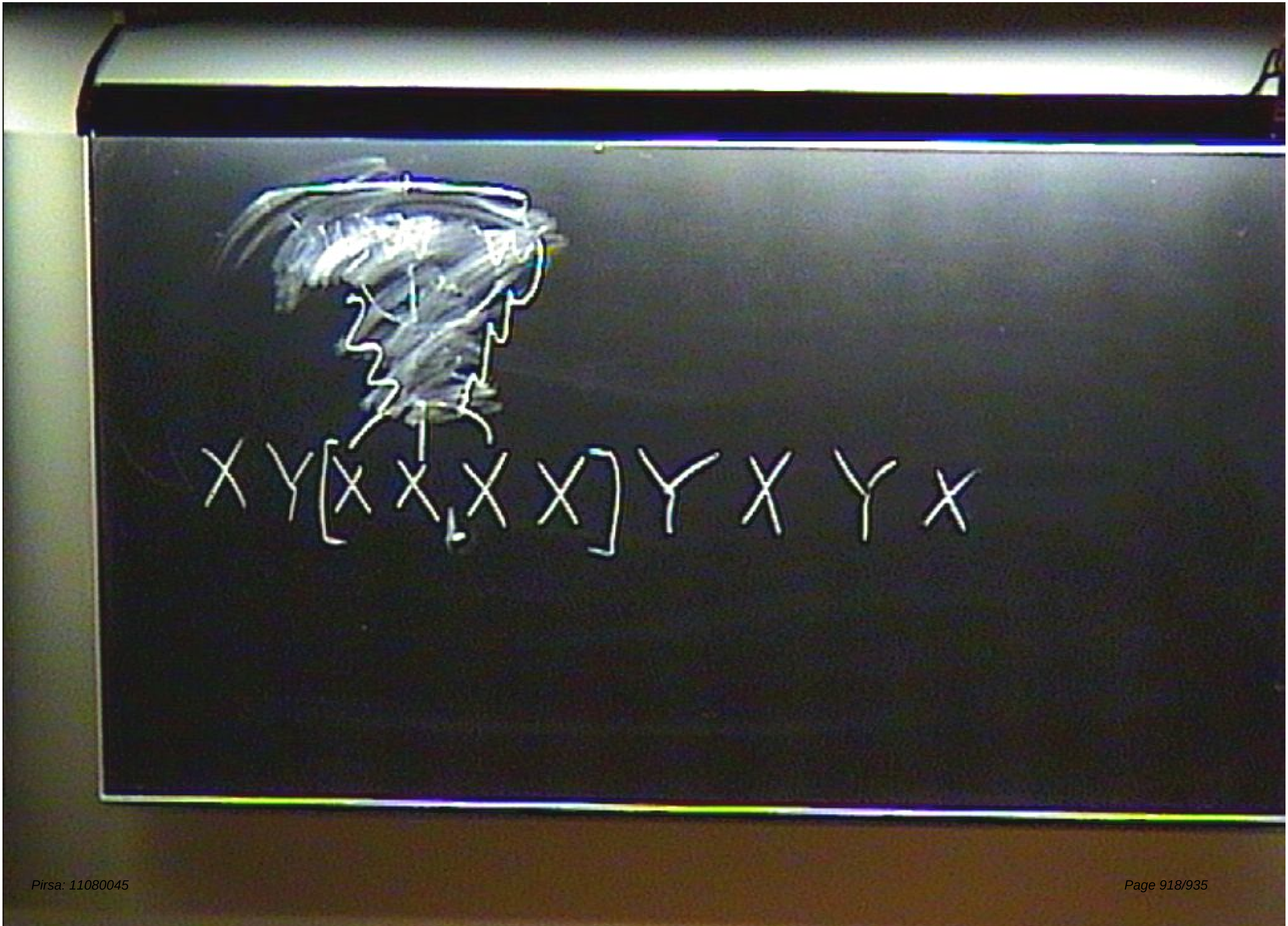
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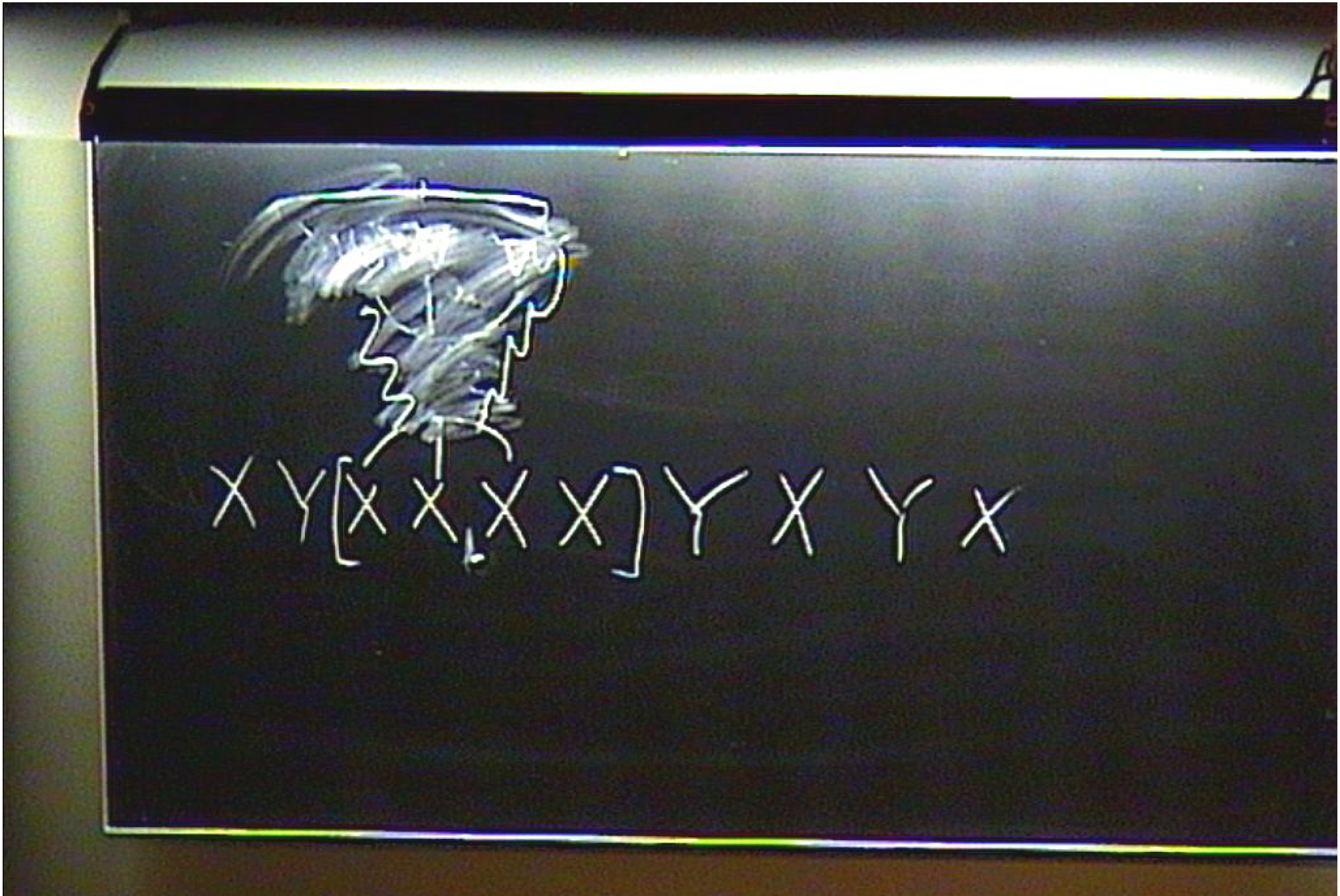
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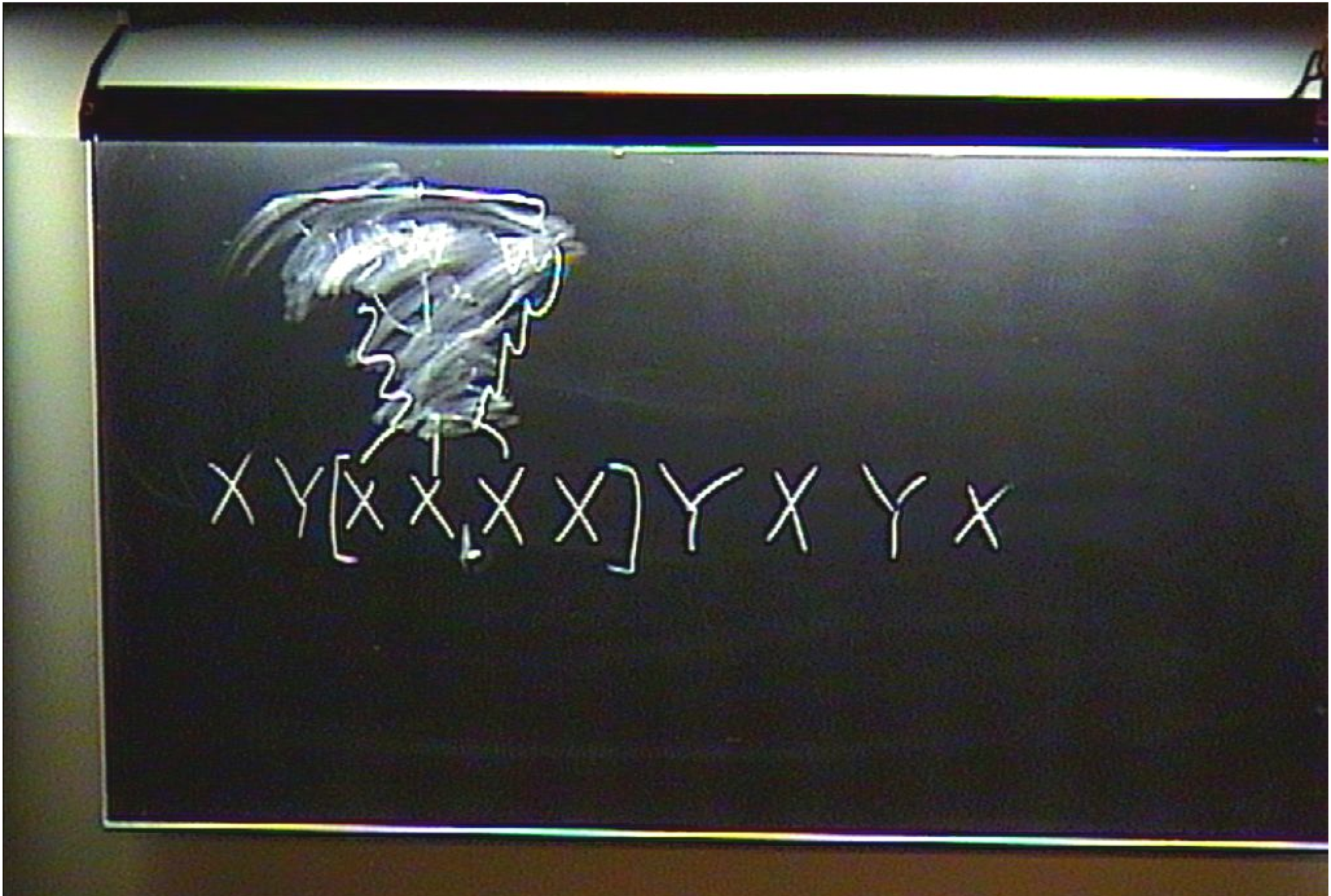
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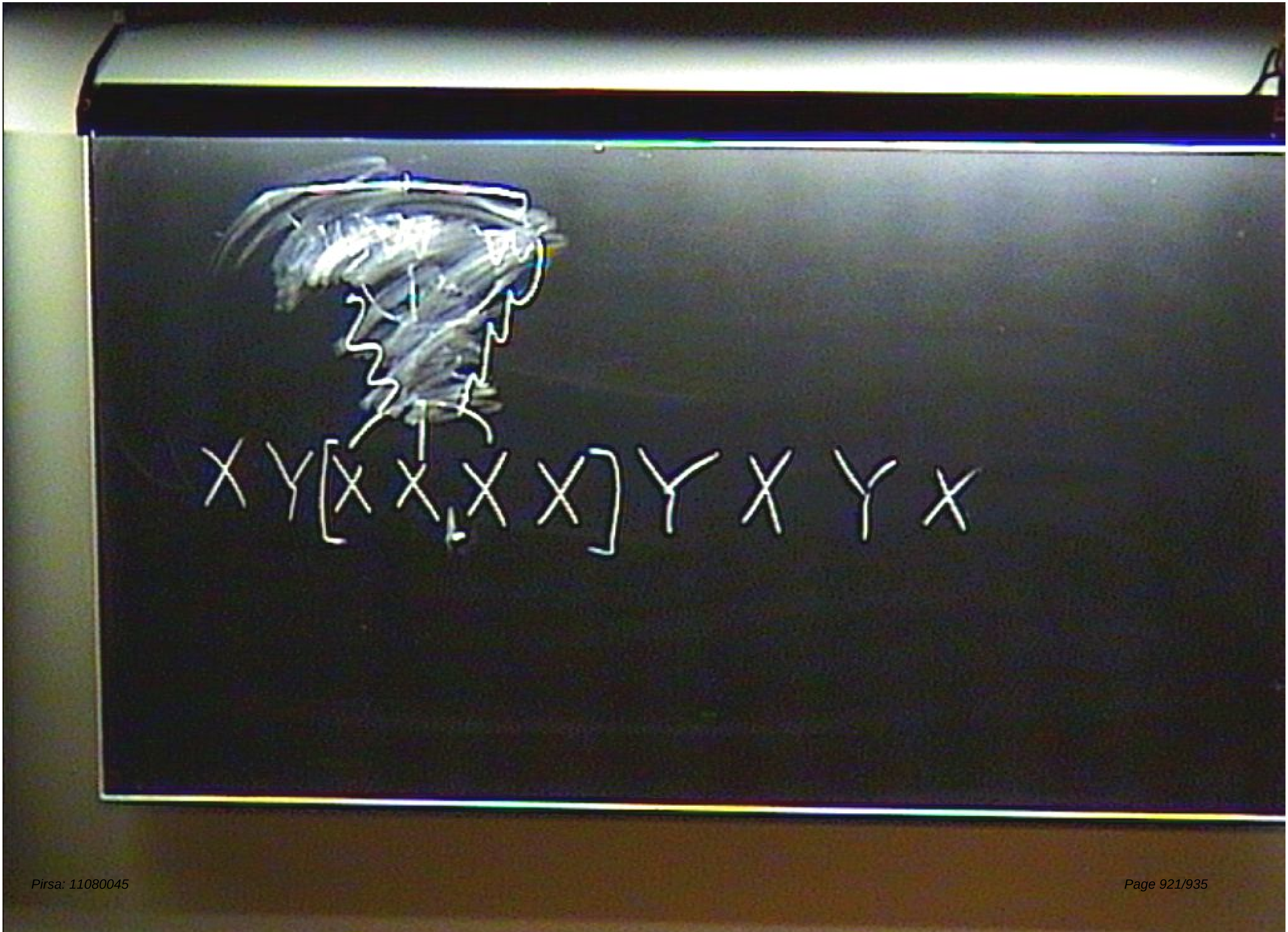
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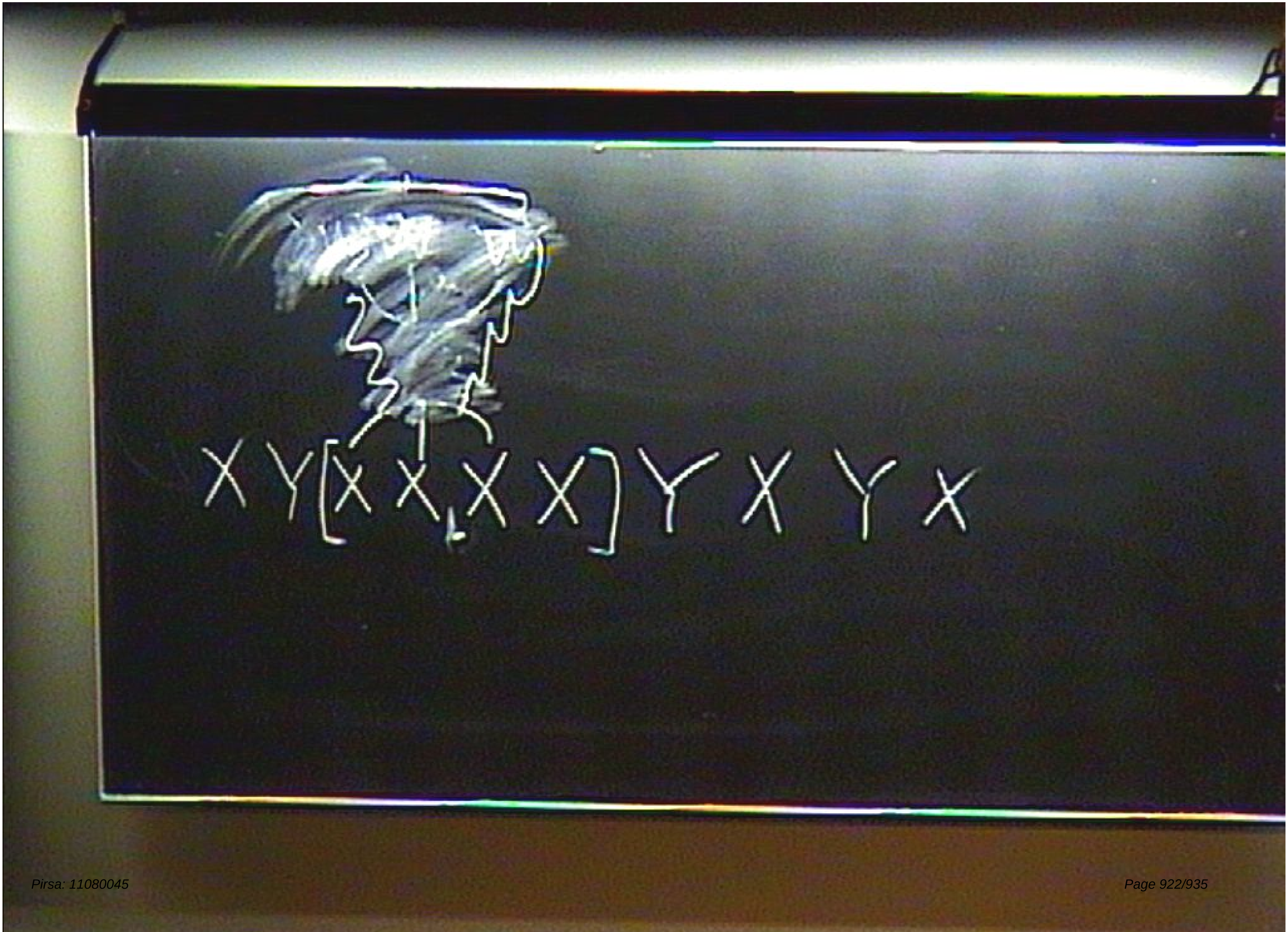
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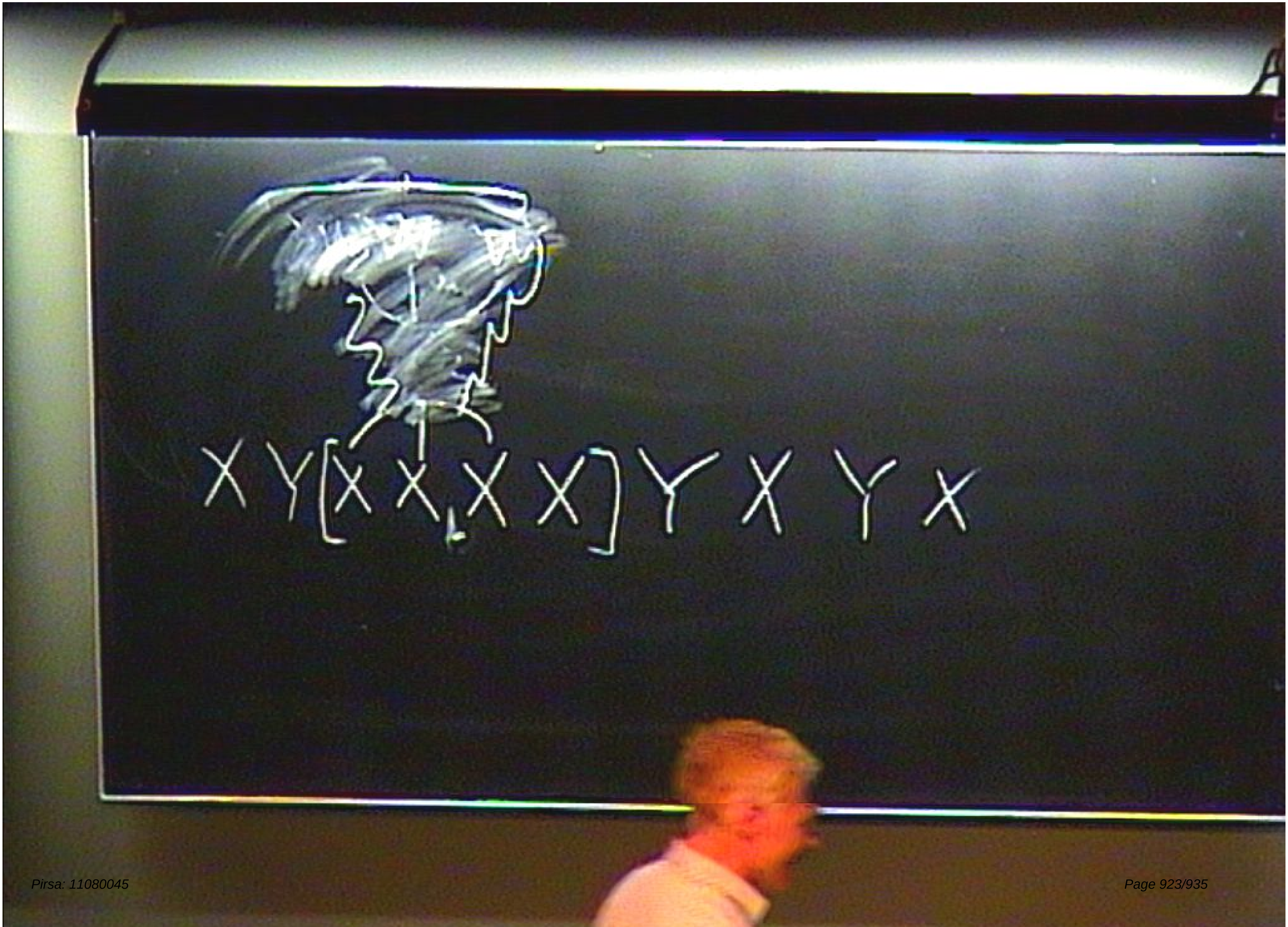
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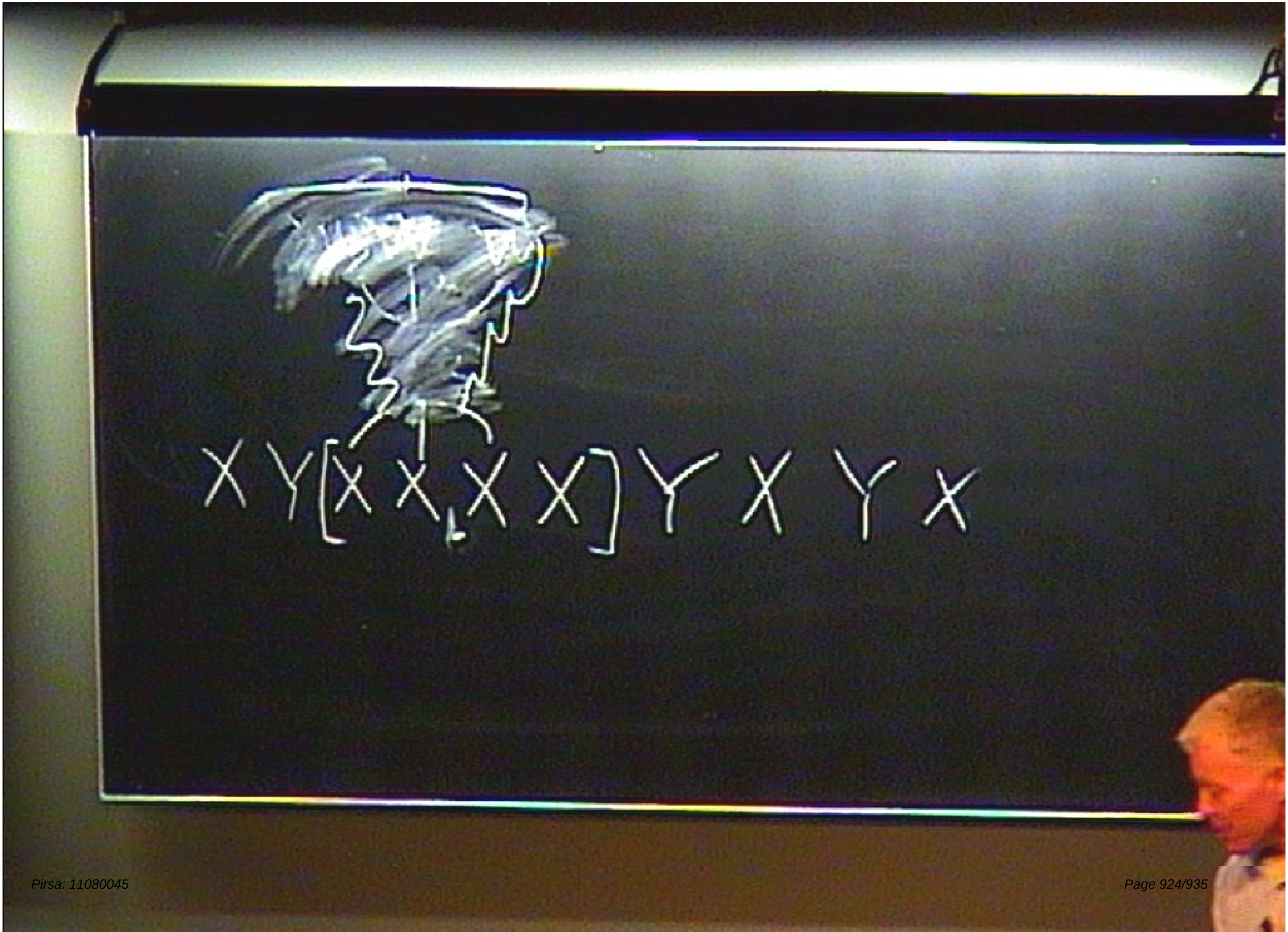
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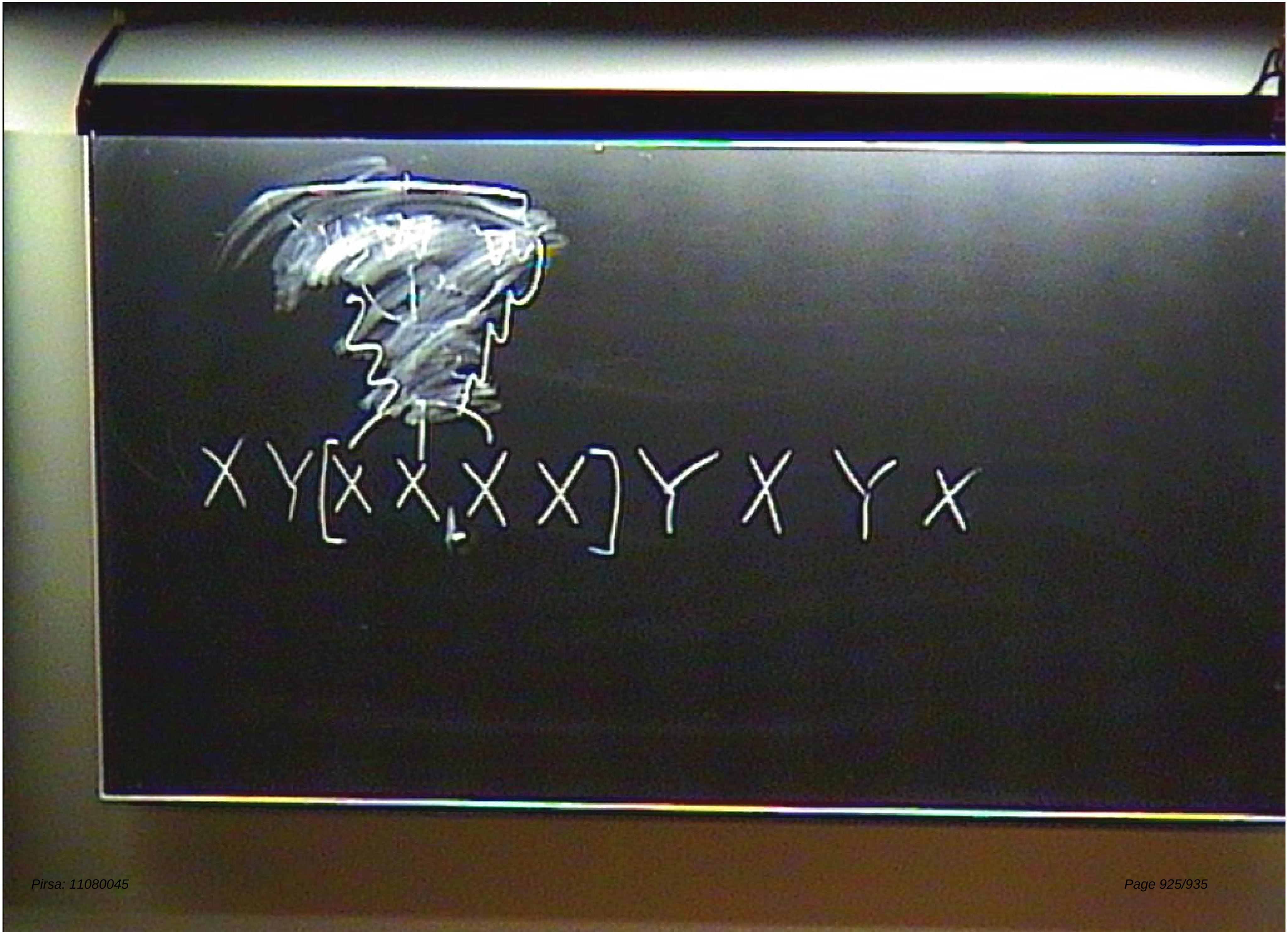
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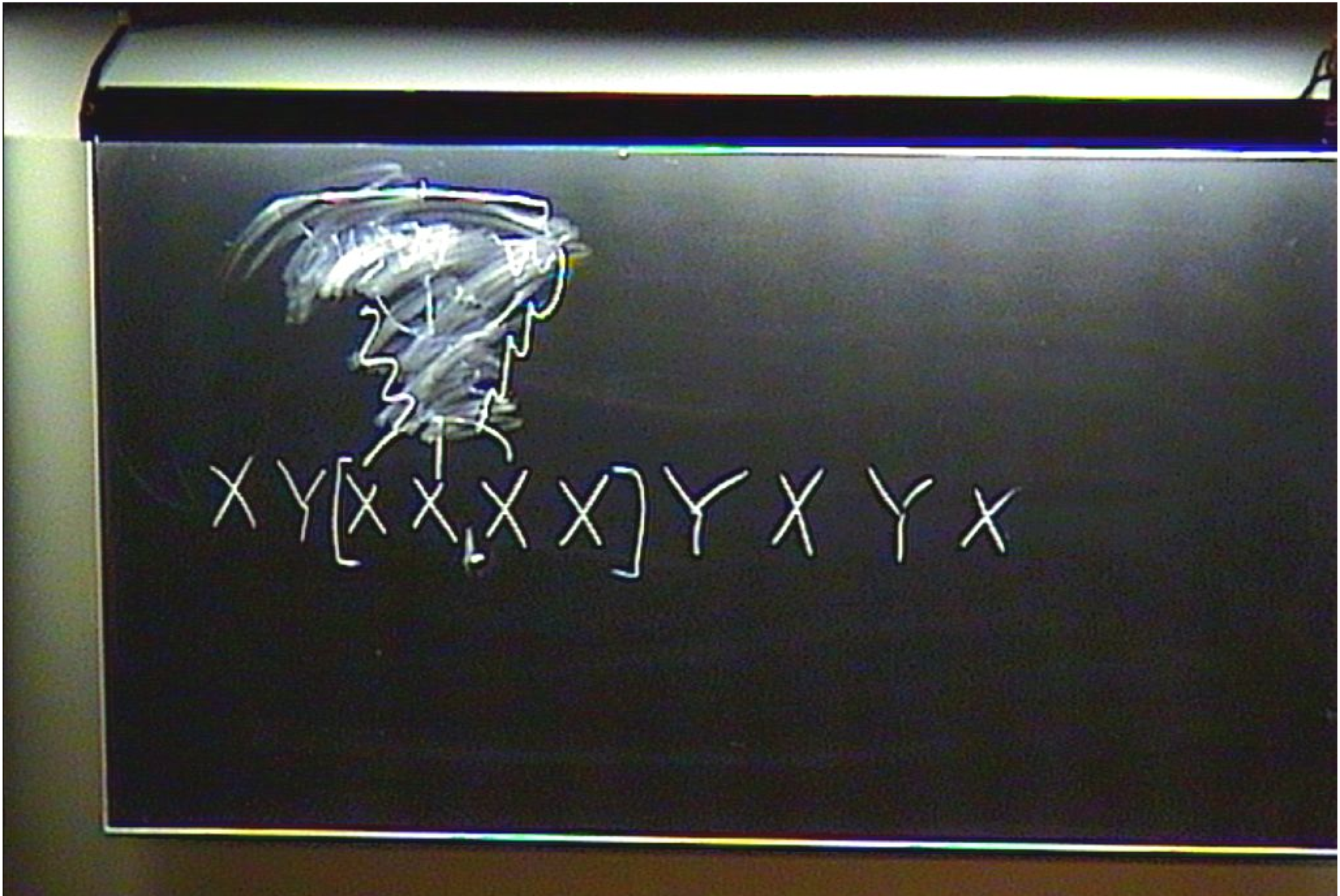
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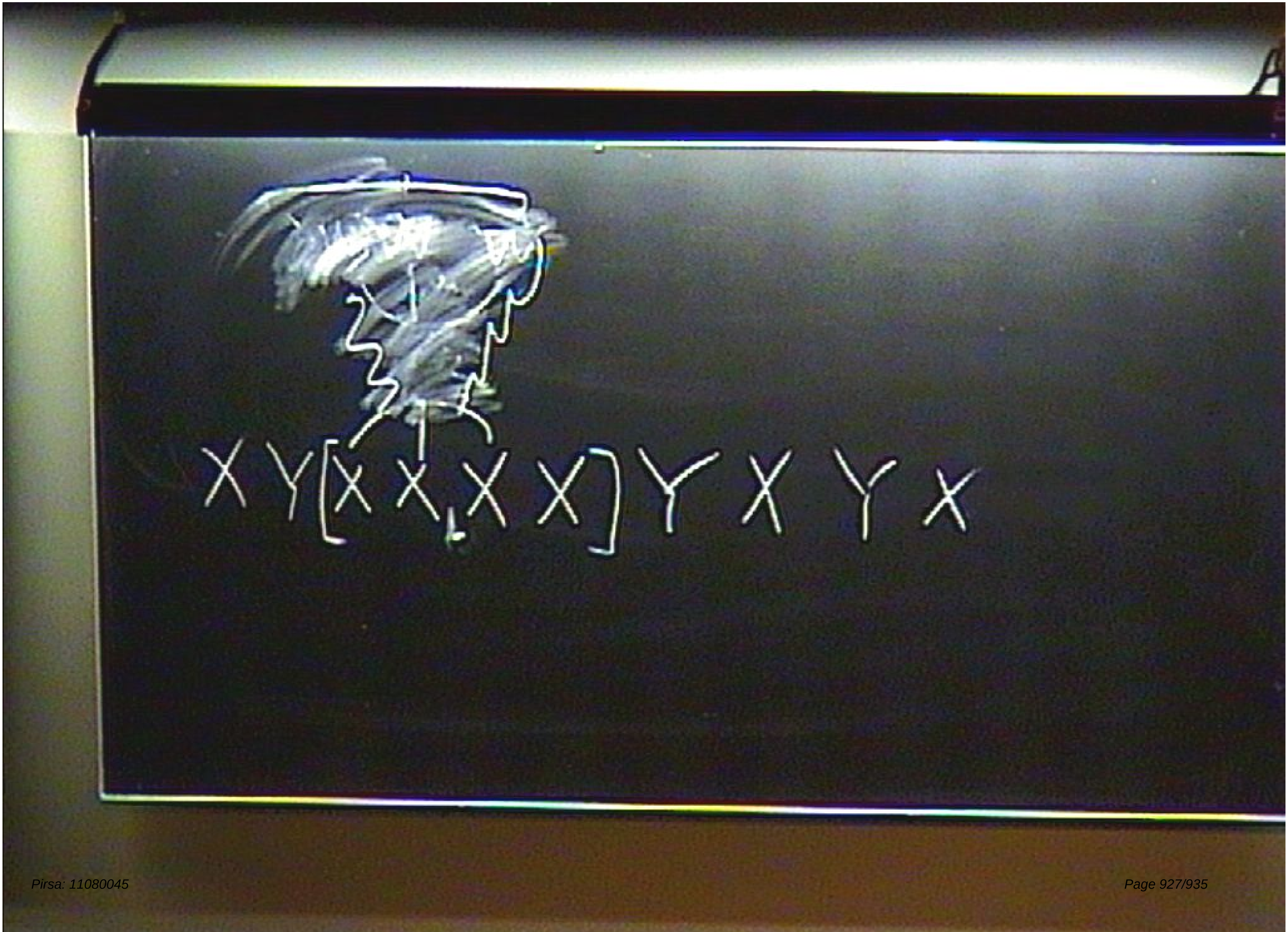
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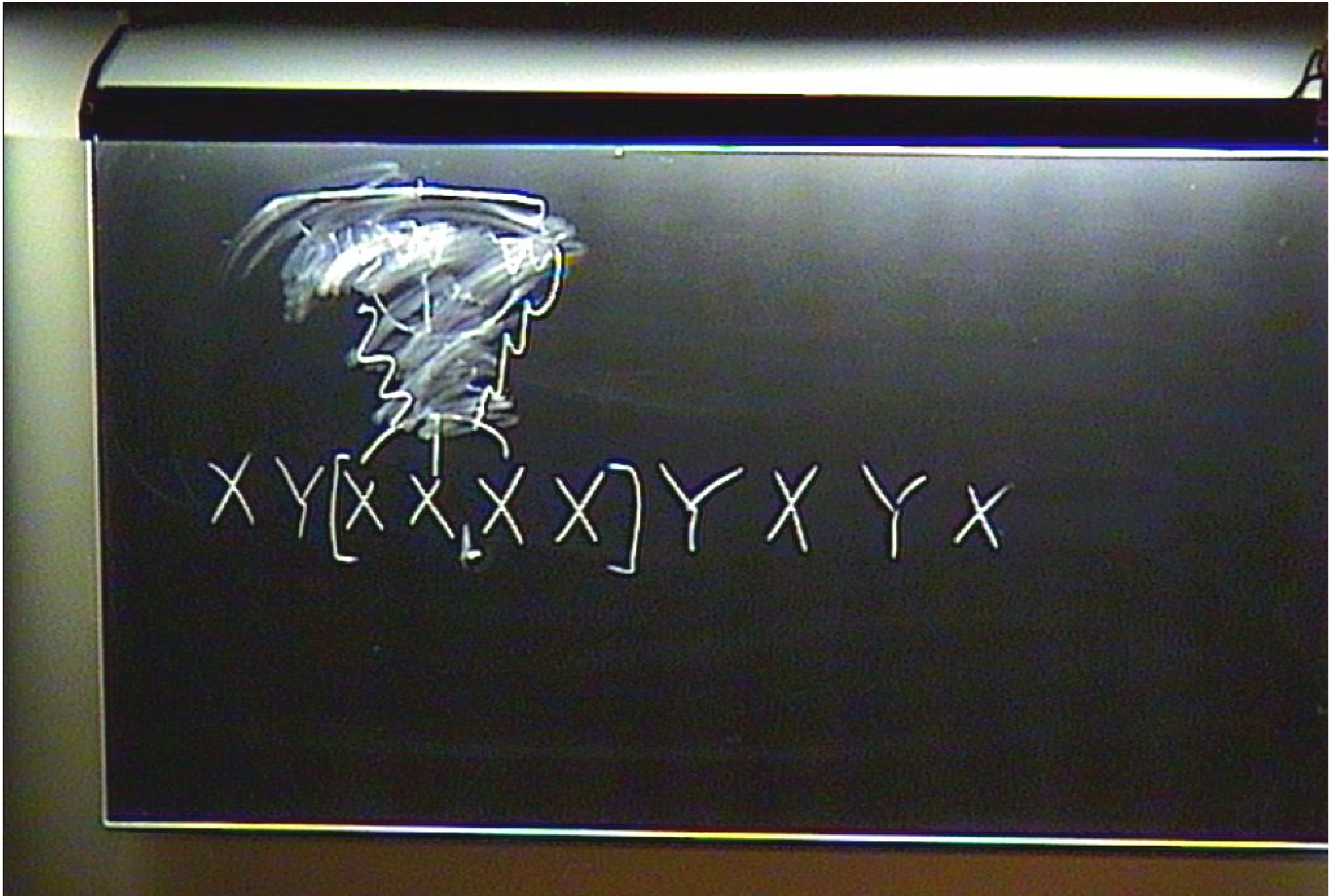
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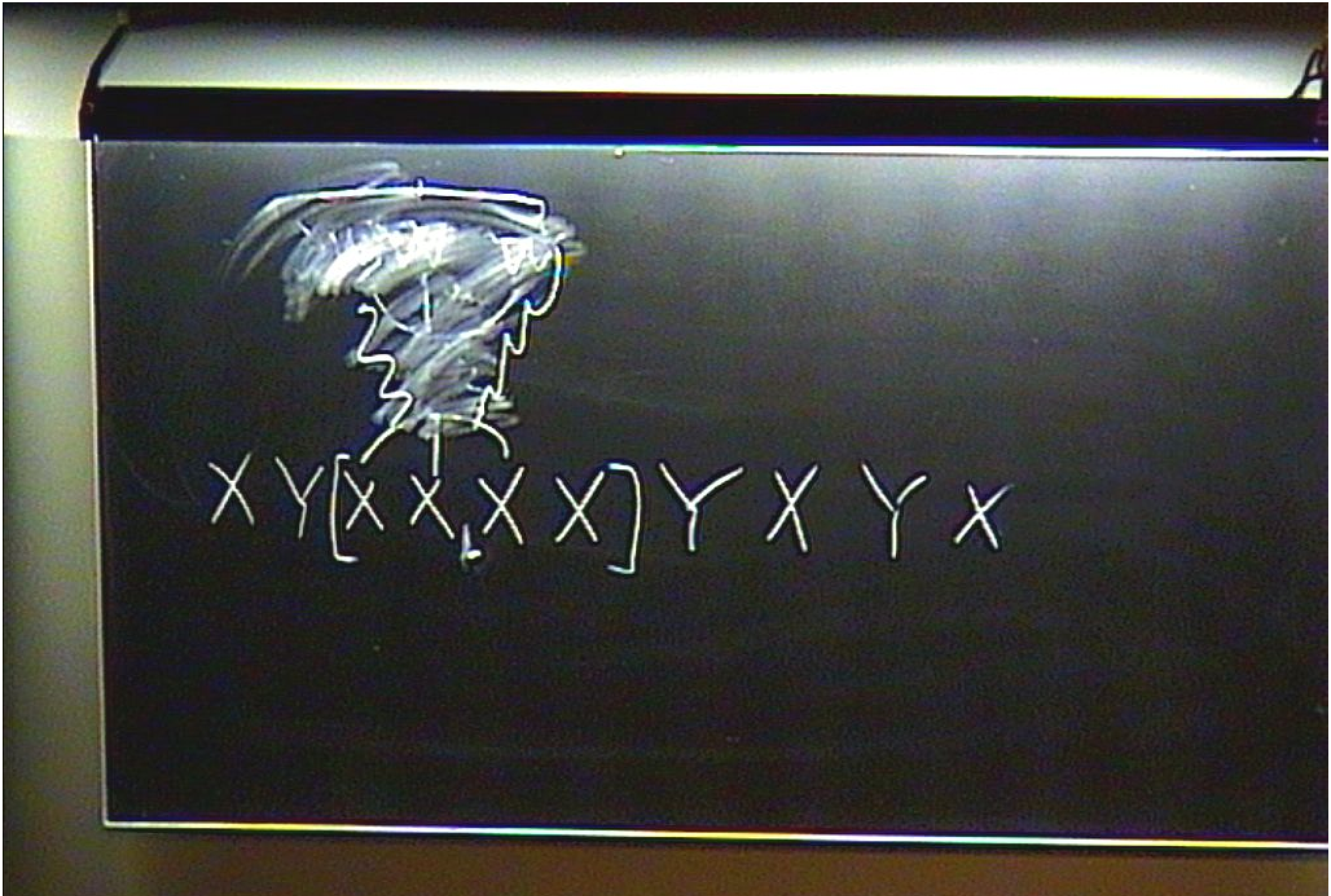
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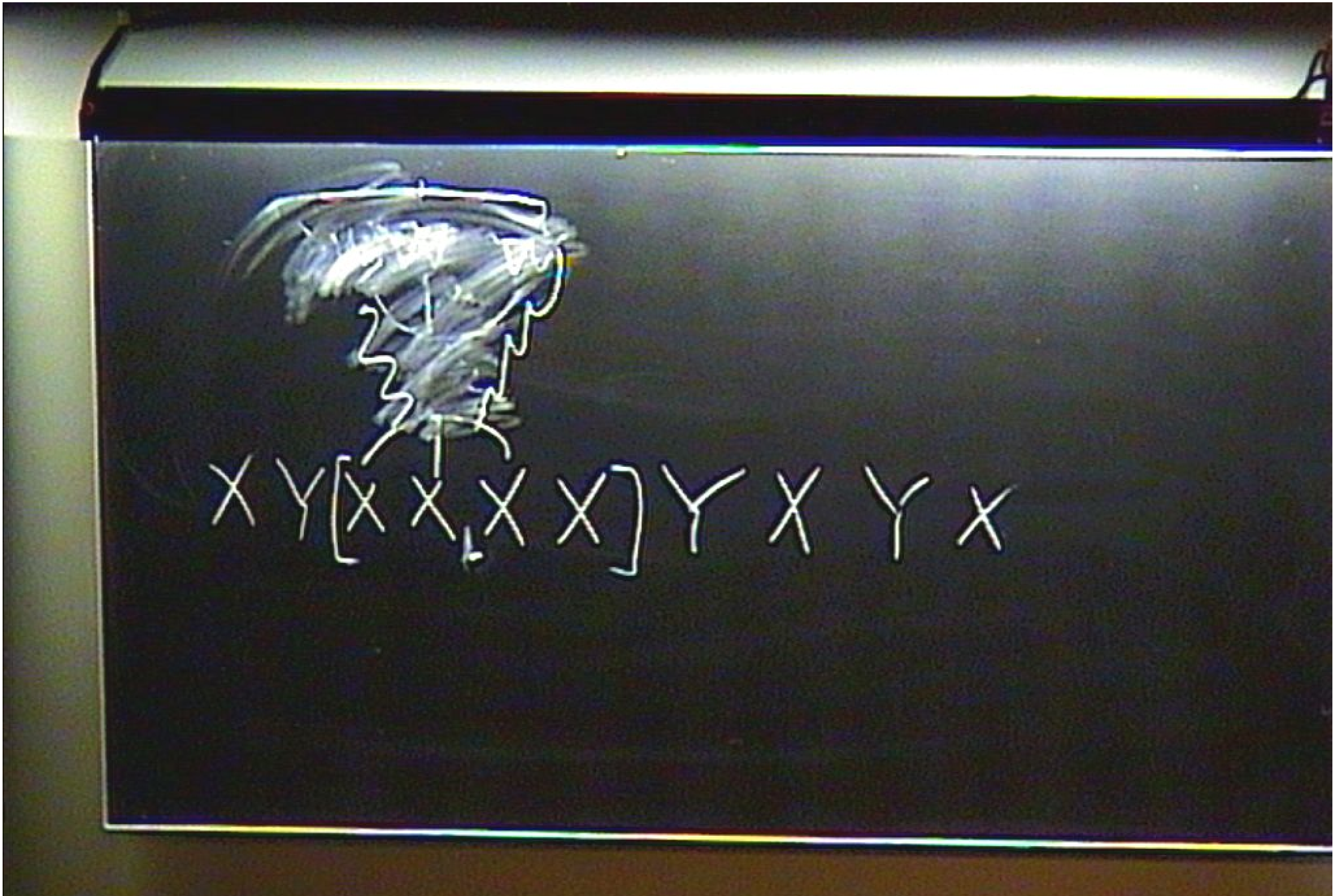
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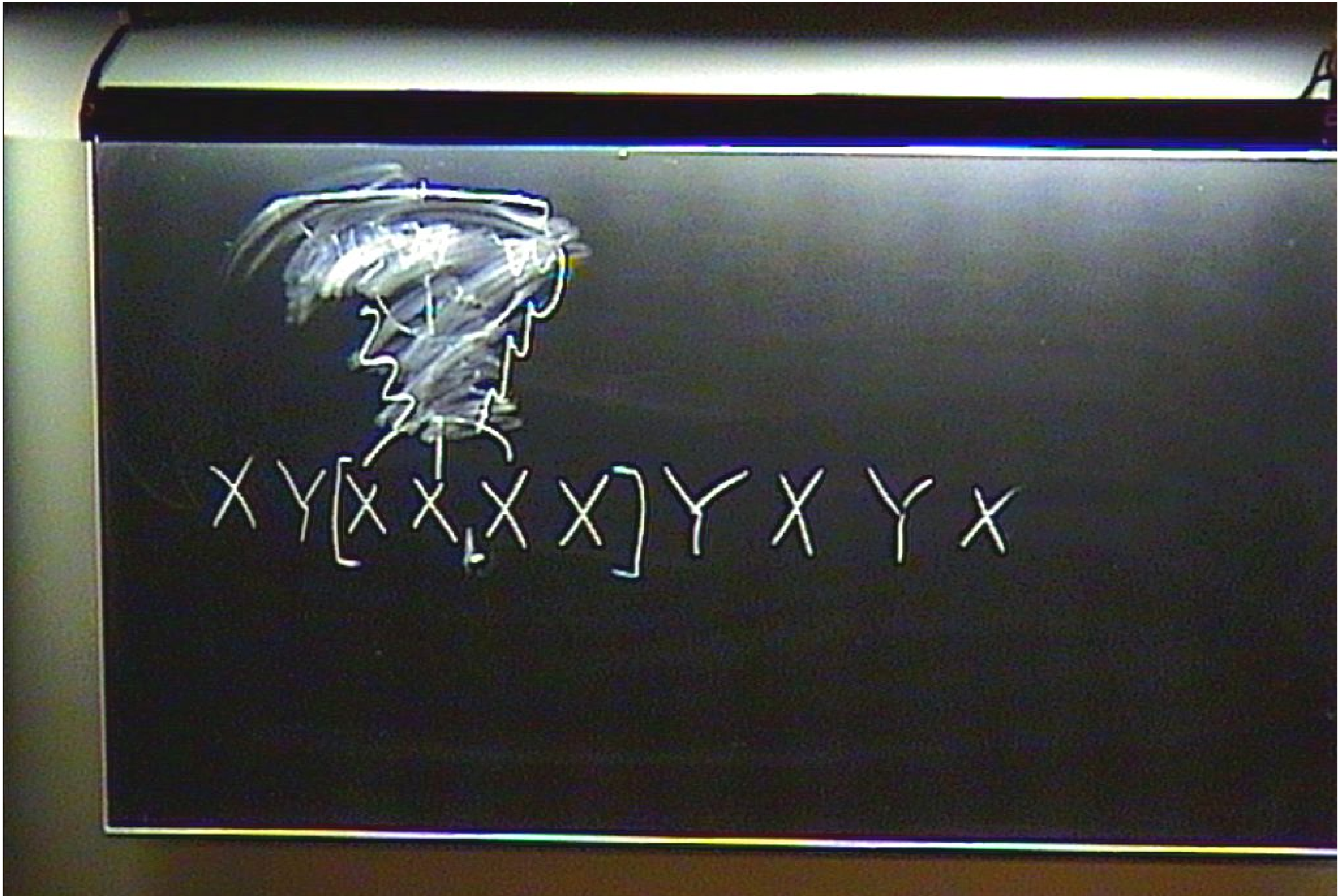
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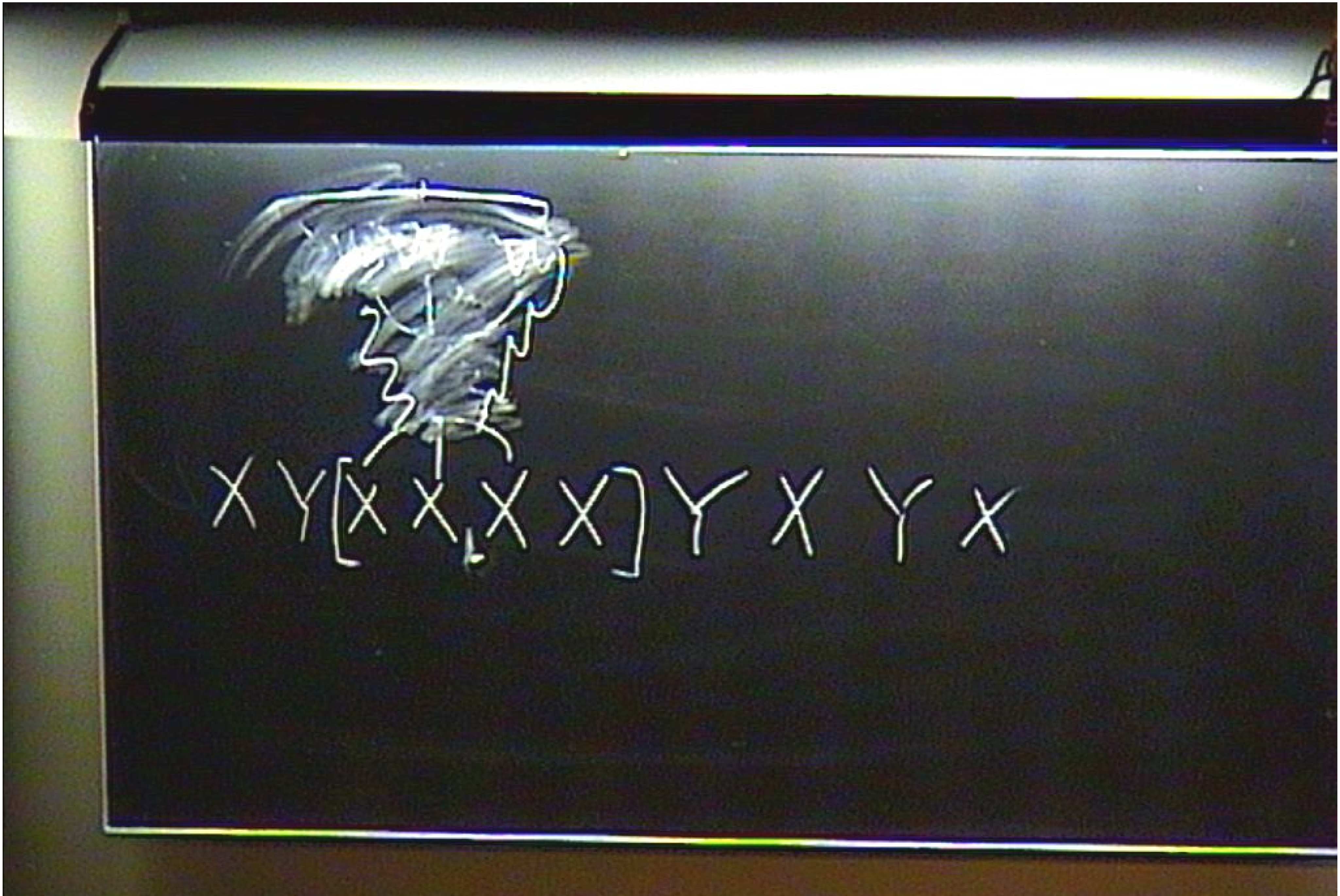
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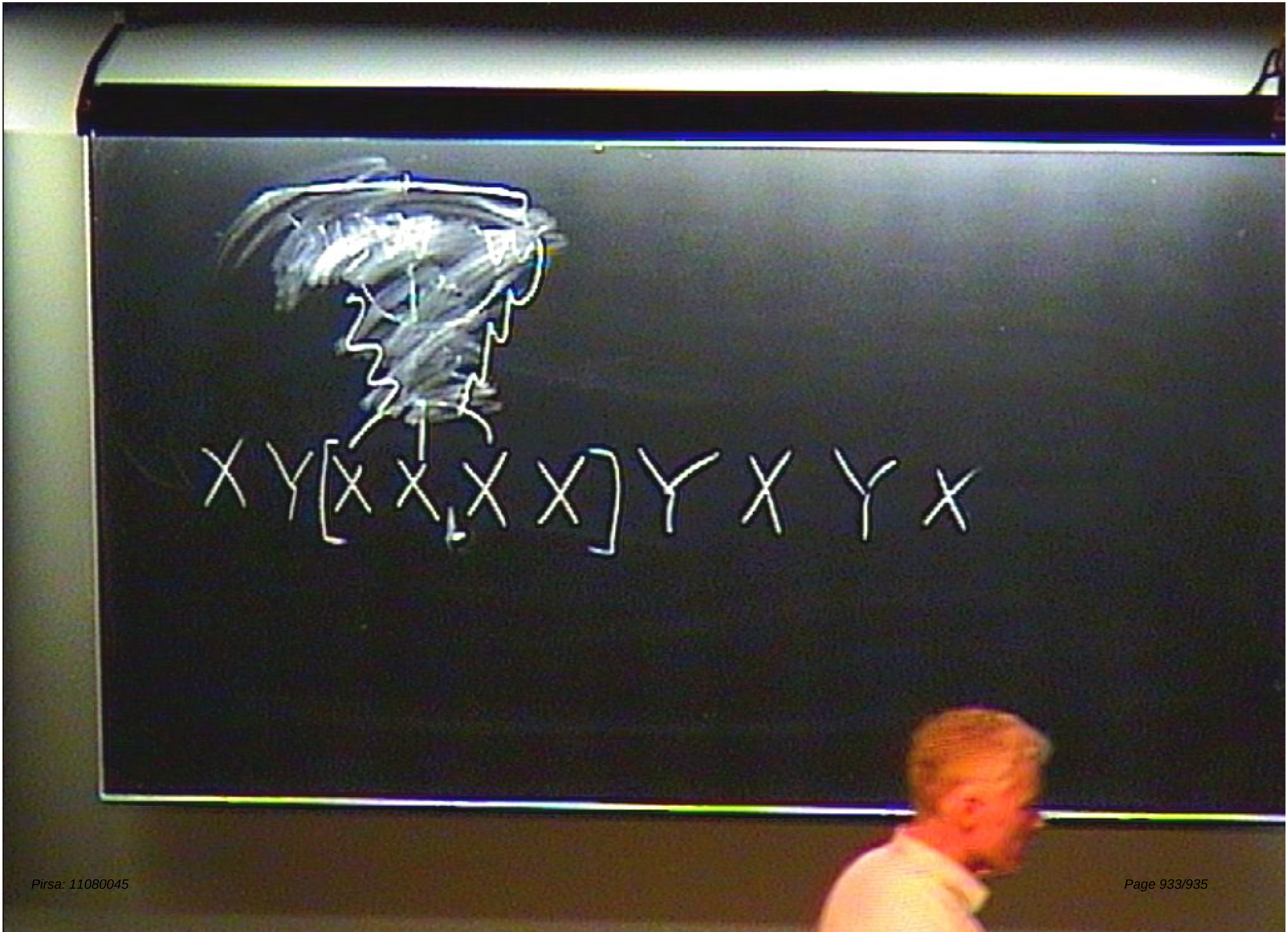
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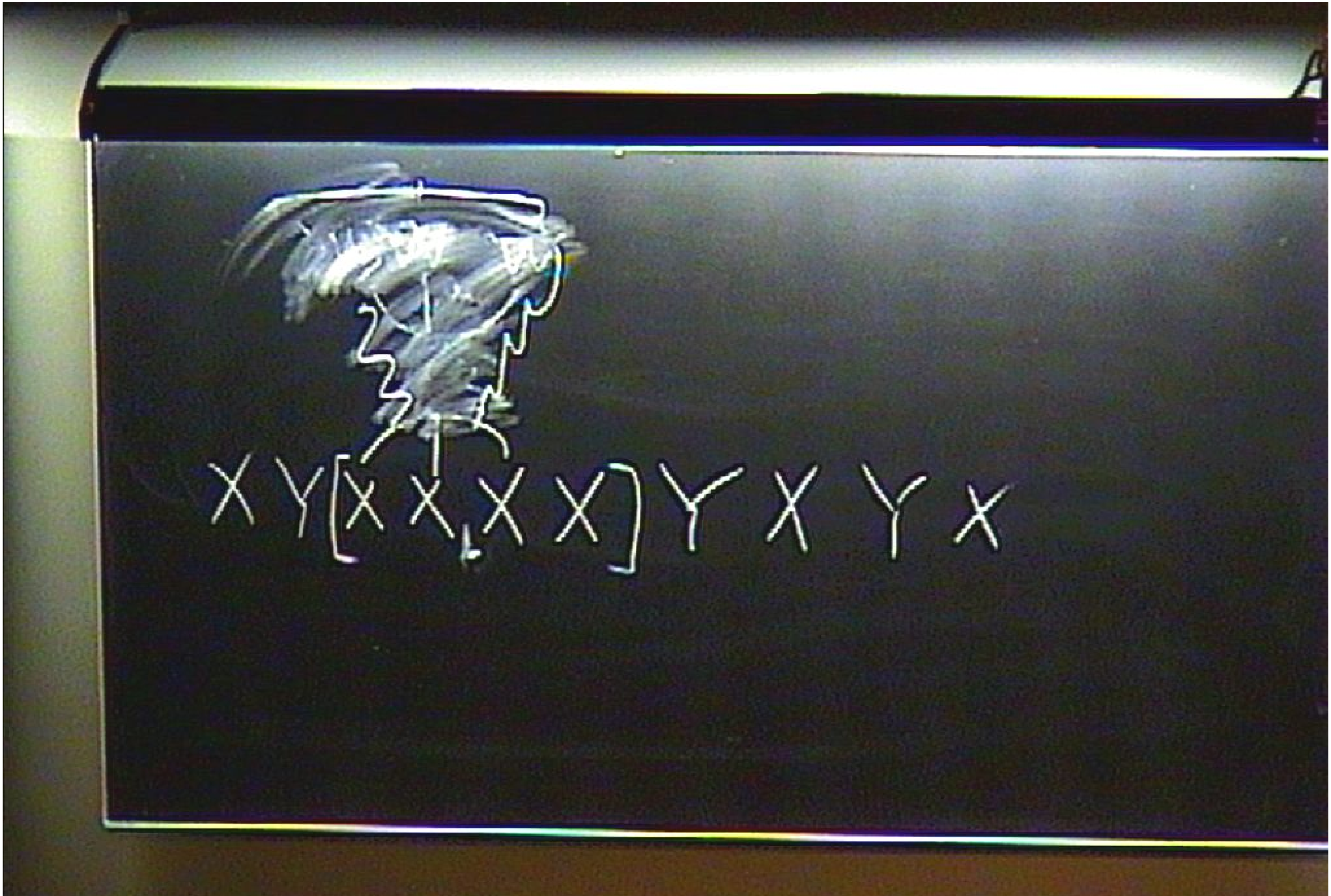
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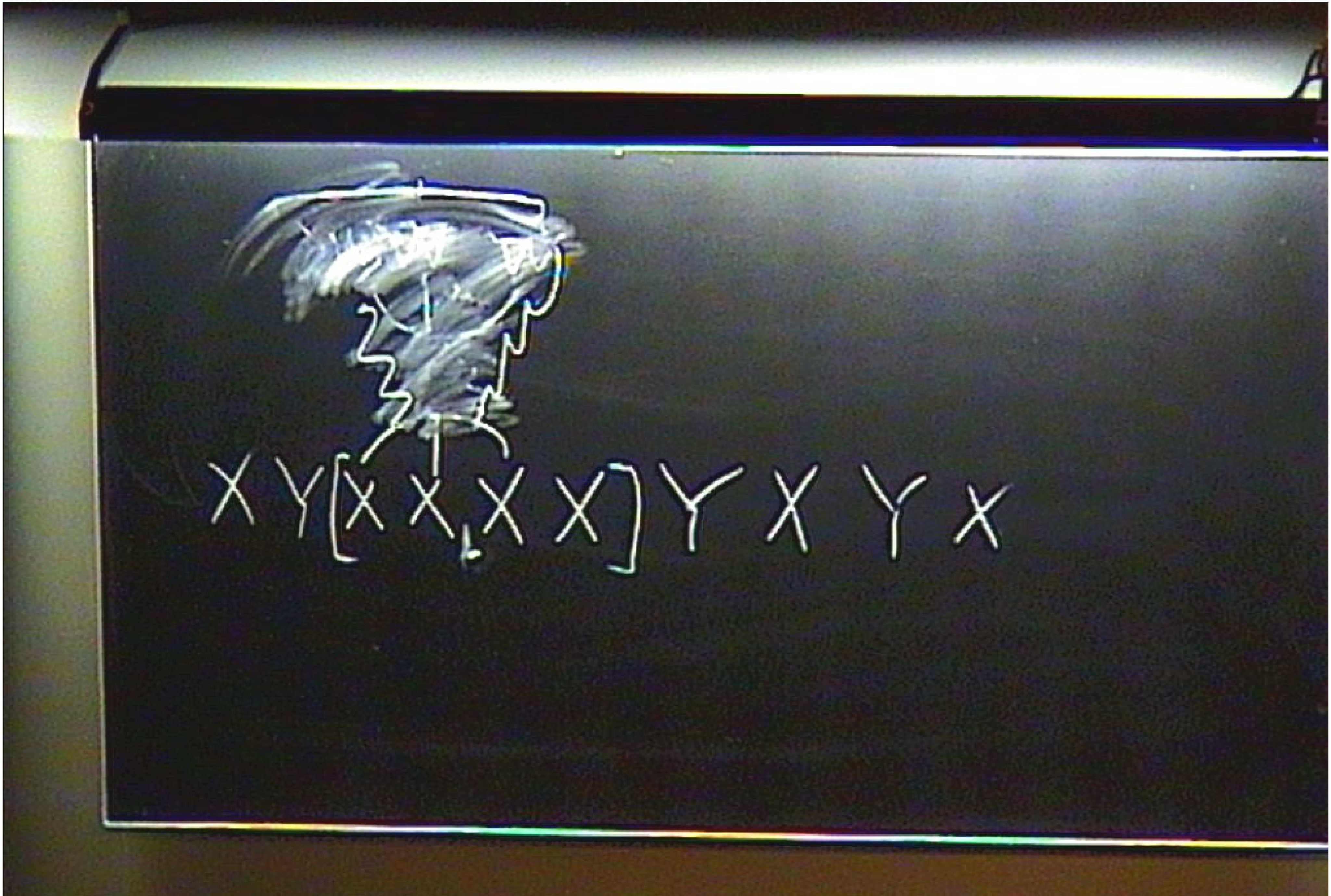
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