Title: The dynamics of diversity

Speakers: Lee Smolin

Series: Colloquium

Date: March 17, 2021 - 2:00 PM

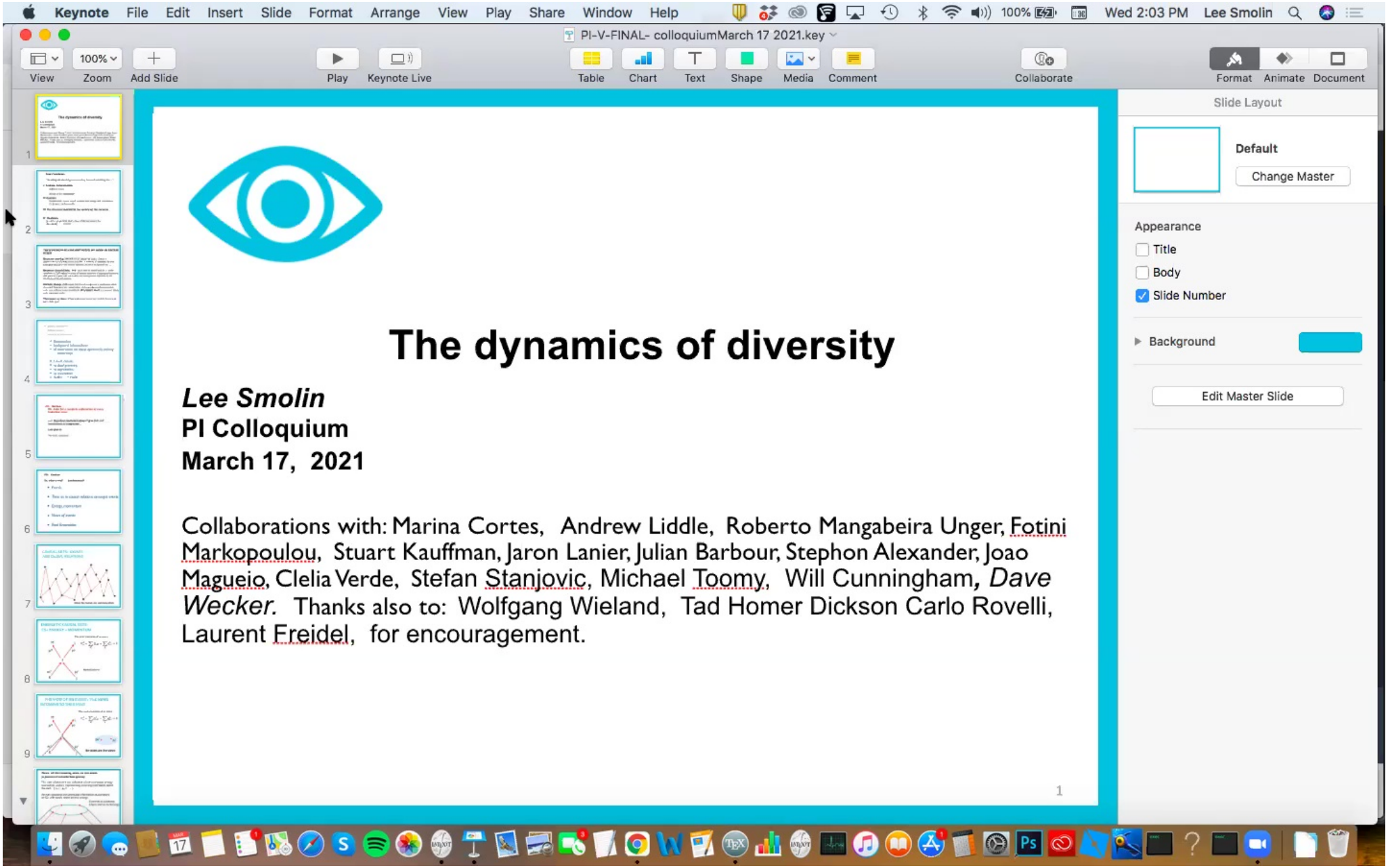
URL: http://pirsa.org/21030005

Abstract: I describe recent progress on a program of research aimed at finding a simultaneous completion of quantum mechanics and general relativity, while also addressing the question of how the universe chose its effective laws out of a vast landscape of possible laws.    This is based on a few principles:   time in the sense of causation is fundamental, as are events, and the views  of events (their backward celestial spheres.) Further the view of every event must be distinct from that of every other.  This is enforced by a choice for potential energy that maximizes the diversity of views of events, called the variety.    Given these postulates, everything else emerges dynamically, including space, spacetime, and quantum dynamics; as the variety turns out to reduce appropriately to Bohmâ€™s quantum potential, which in turn is responsible for quantum non-locality, entanglement etc.  

A consequence of these ideas is that the effective low energy laws, including the values of the dimensionless constants of the standard model,  should evolve dynamically.    I present three realizations of this idea: cosmological natural selection (1992), the principle of precedence (2005), and the hypothesis that the universe may learn how to choose its vacuum out of a landscape of possible vacua through a process formally analogous to machine learning (2021).   I discuss the prospects for observational tests of these ideas.

At the technical level,  some of these ideas are related through the use of matrix modes whose actions are cubic in the matrices, which are tied to topological and gravitational theories.  At a methodological level, issues involving an interplay of reductionist and functionalist reasoning may be discussed.  

Collaborators on recent work include Stephon Alexander, Marina Cortes, William Cunningham,  Stuart Kauffman, Jaron Lanier,  Andrew Liddle,  Joao Magueijo,   Stefan Stanojevic,  Michael W. Toomey, Clelia Verde and Dave Wecker.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The dynamics of diversity
Lee Smolin
PI Colloquium
March 17, 2021
Collaborations with: Marina Cortes, Andrew Liddle, Roberto Mangabeira Unger, Fotini Markopoulou, Stuart Kauffman, Jaron Lanier, Julian Barbour, Stephon Alexander, Joao Magueio, Clelia Verde, Stefan Stanjovic, Michael Toomy, Will Cunningham, Dave Wecker. Thanks also to: Wolfgang Wieland, Tad Homer Dickson Carlo Rovelli, Laurent Freidel, for encouragement.
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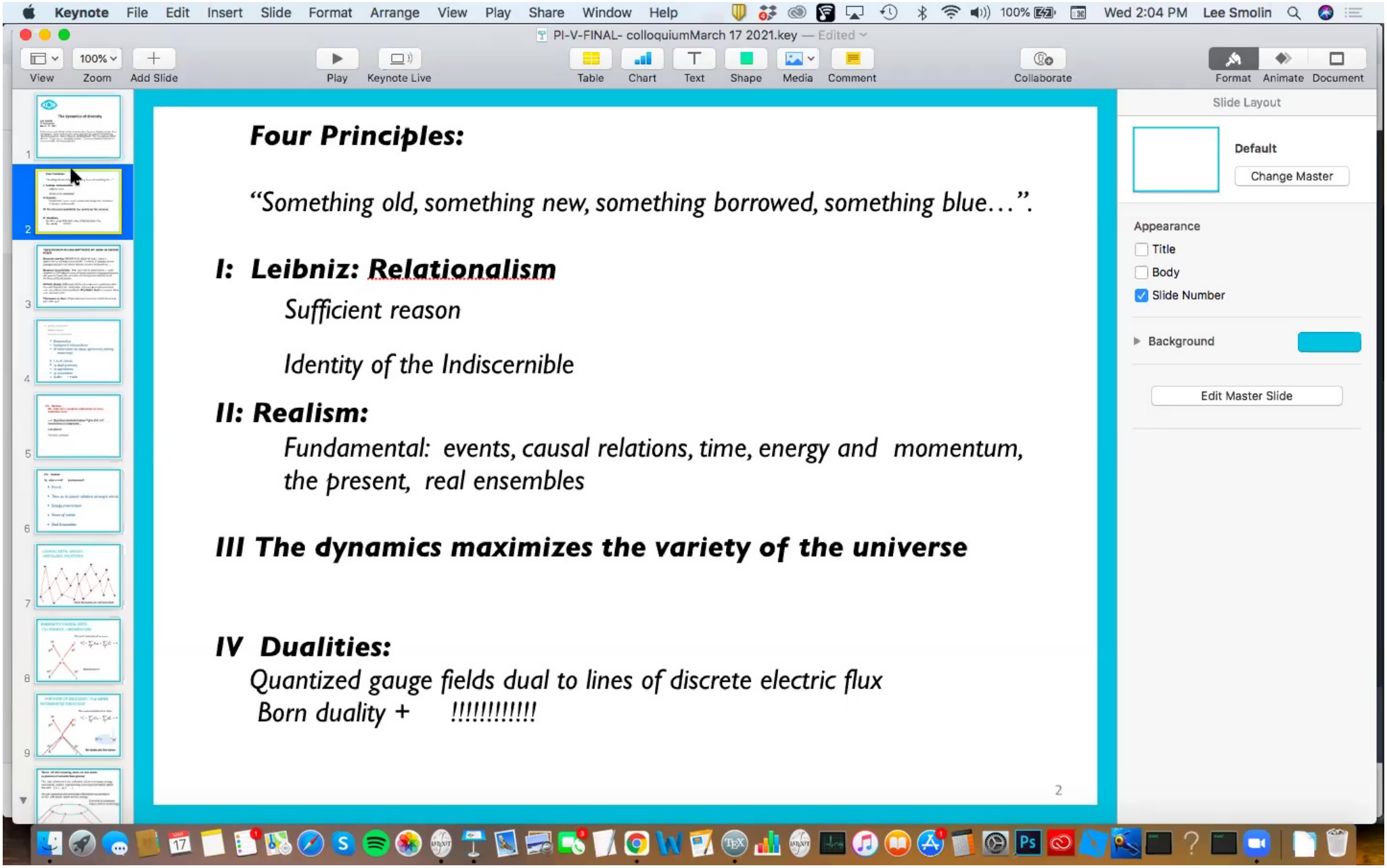
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Four Principles:
"Something old, something new, something borrowed, something blue…".
I: Leibniz: Relationalism
Sufficient reason
Identity of the Indiscernible
II: Realism:
Fundamental: events, causal relations, time, energy and momentum, the present, real ensembles
III The dynamics maximizes the variety of the universe
IV Dualities:
Quantized gauge fields dual to lines of discrete electric flux
Born duality + !!!!!!!!!!!!
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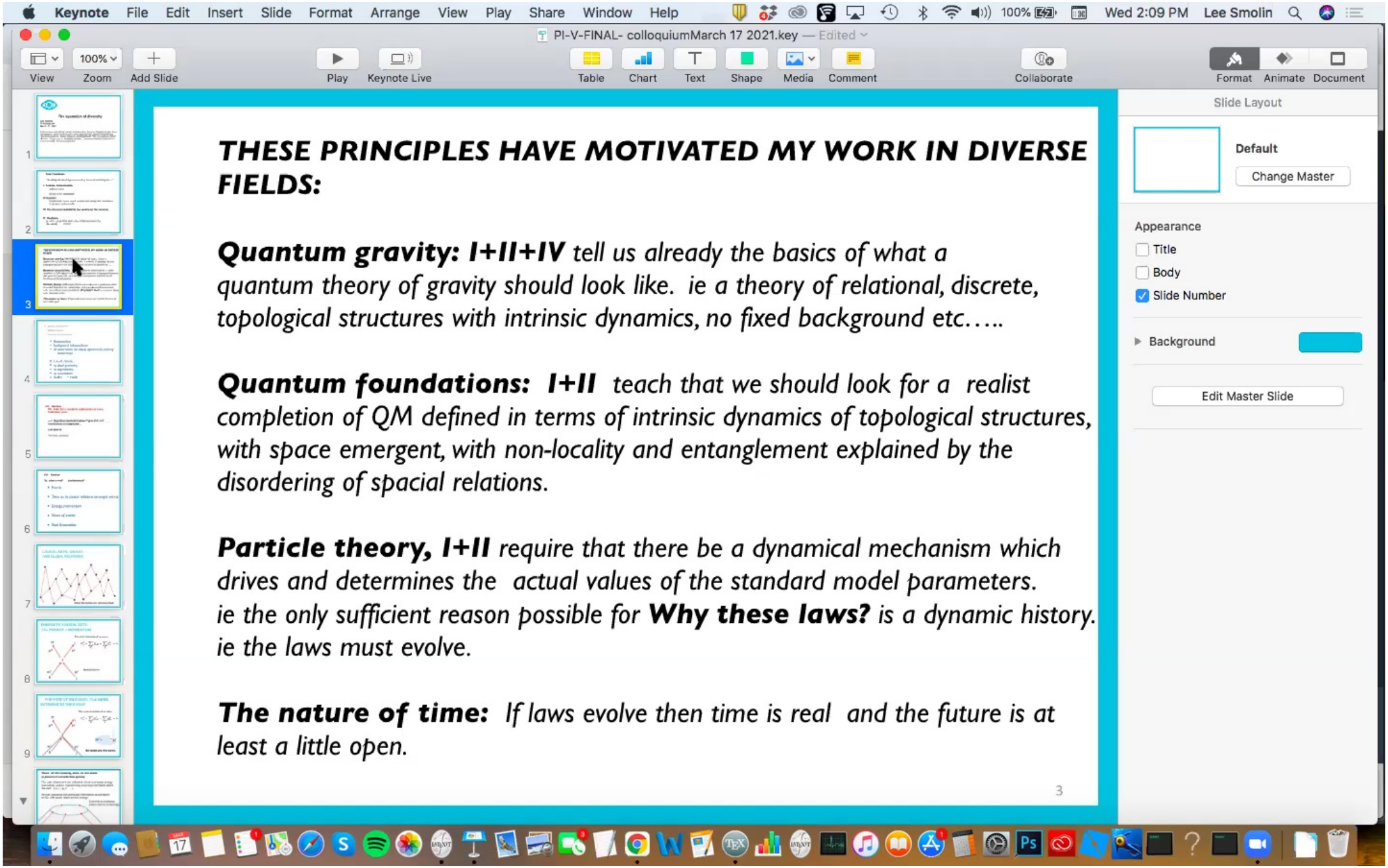
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THESE PRINCIPLES HAVE MOTIVATED MY WORK IN DIVERSE FIELDS:
Quantum gravity: I+II+IV tell us already the basics of what a quantum theory of gravity should look like. ie a theory of relational, discrete, topological structures with intrinsic dynamics, no fixed background etc…..
Quantum foundations: I+II teach that we should look for a realist completion of QM defined in terms of intrinsic dynamics of topological structures, with space emergent, with non-locality and entanglement explained by the disordering of spacial relations.
Particle theory, I+II require that there be a dynamical mechanism which drives and determines the actual values of the standard model parameters.
ie the only sufficient reason possible for Why these laws? is a dynamic history.
ie the laws must evolve.
The nature of time: If laws evolve then time is real and the future is at least a little open.
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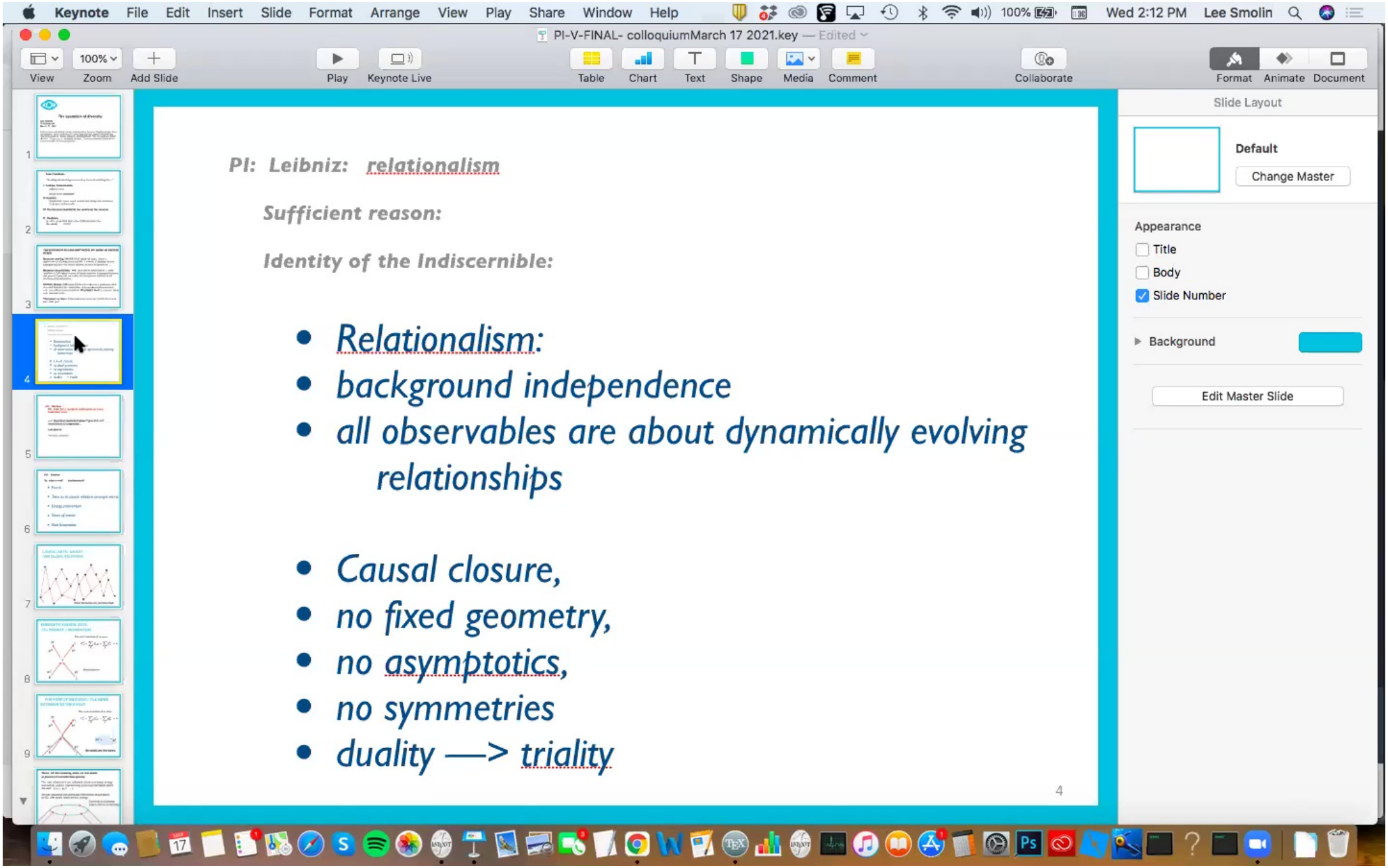
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PI: Leibniz: relationalism
Sufficient reason:
Identity of the Indiscernible:
Relationalism:
background independence
all observables are about dynamically evolving relationships
Causal closure,
no fixed geometry,
no asymptotics,
no symmetries
duality —> triality
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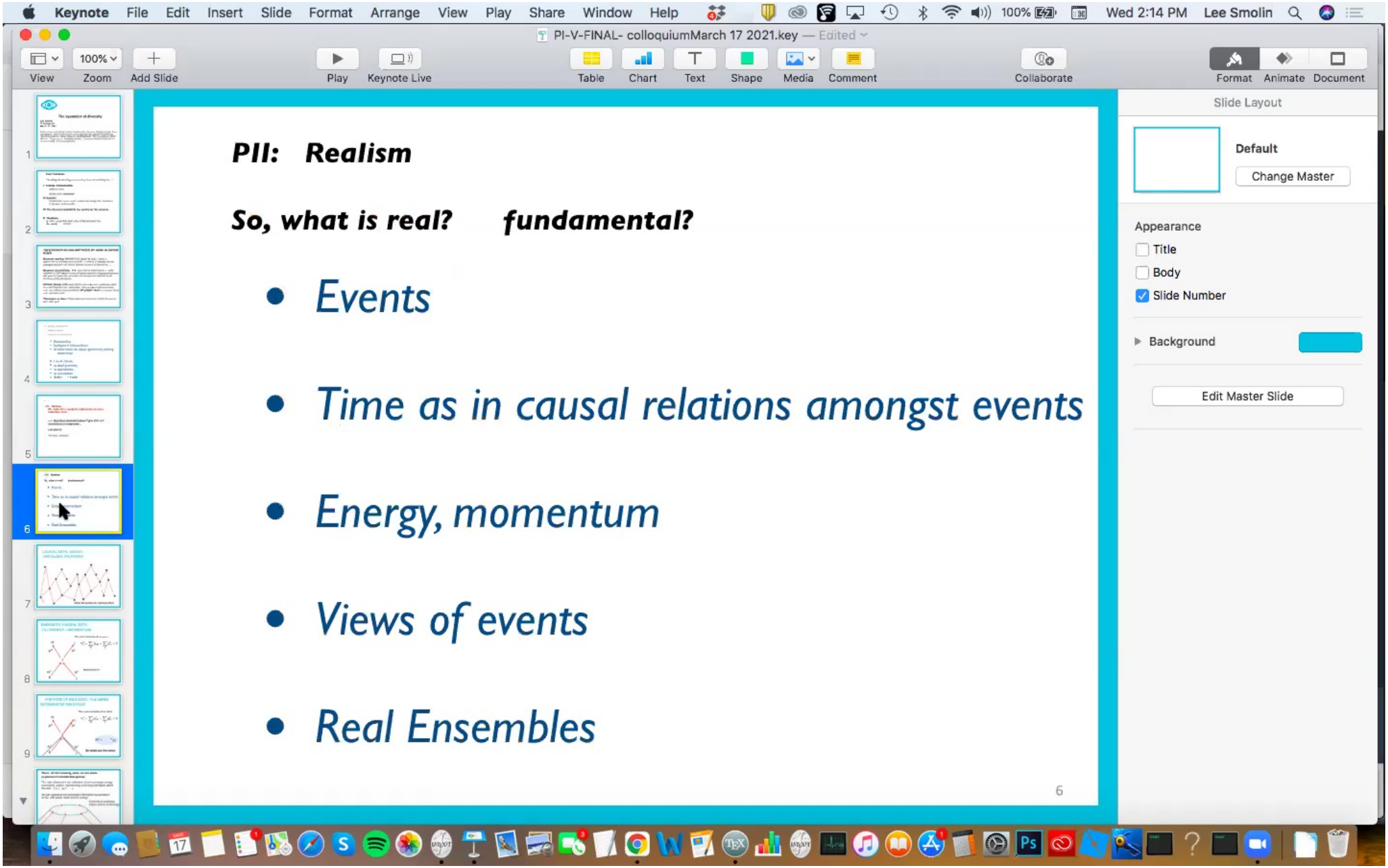
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PII: Realism
So, what is real? fundamental?
Events
Time as in causal relations amongst events
Energy, momentum
Views of events
Real Ensembles
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**PII: Realism**

**We hope for a complete explanation of every individual event**

**—> Quantum mechanics doesn't give this and hence needs a completion...**

**Lets find it:**

*Non-local, contextual*

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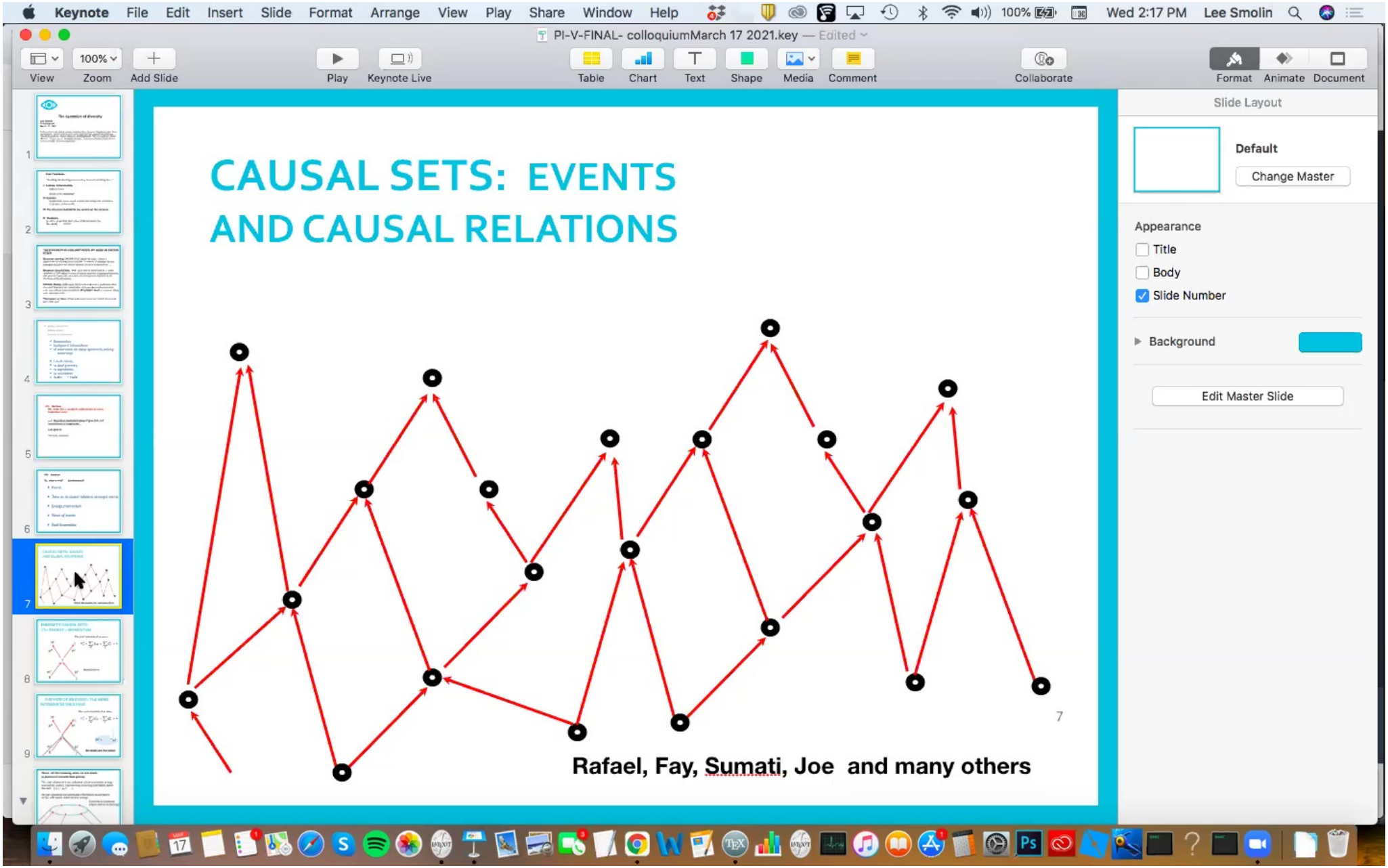
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CAUSAL SETS: EVENTS
AND CAUSAL RELATIONS
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Rafael, Fay, Sumati, Joe and many others
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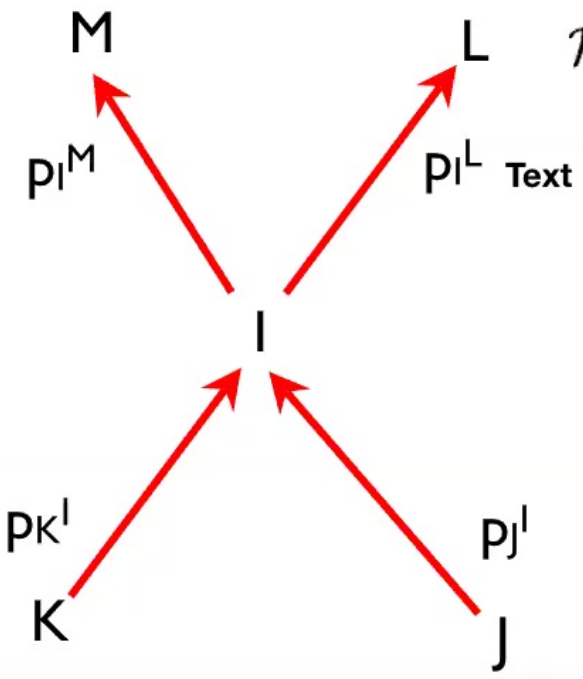
# ENERGETIC CAUSAL SETS:
# CS+ ENERGY + MOMENTUM

The total momenta of an event

$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0$$




Text

Marina Cortes+ls

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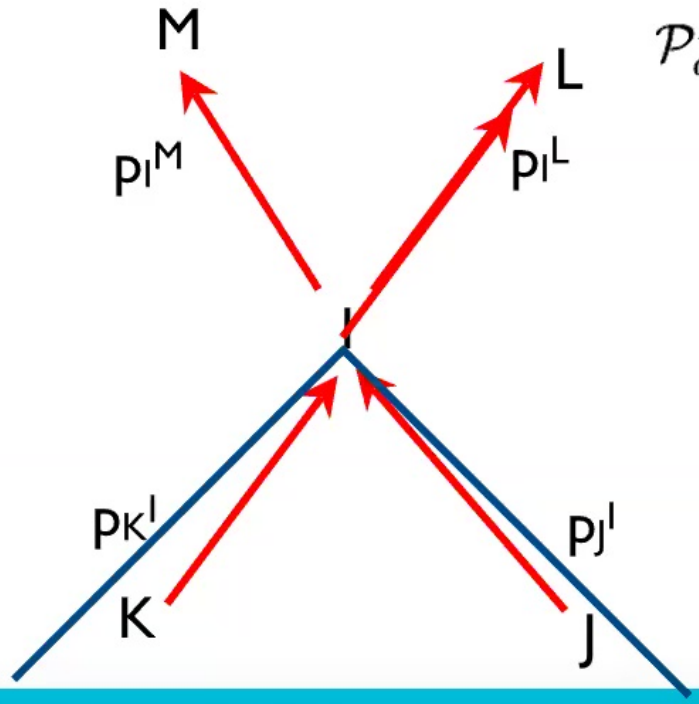
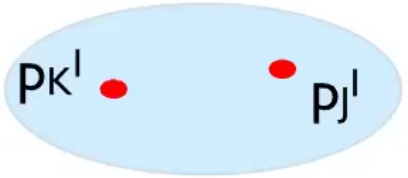
# THE VIEW OF AN EVENT: THE NEWS INCOMING TO THE EVENT

The total momenta of an event

$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0$$




**Be-ables are the views**

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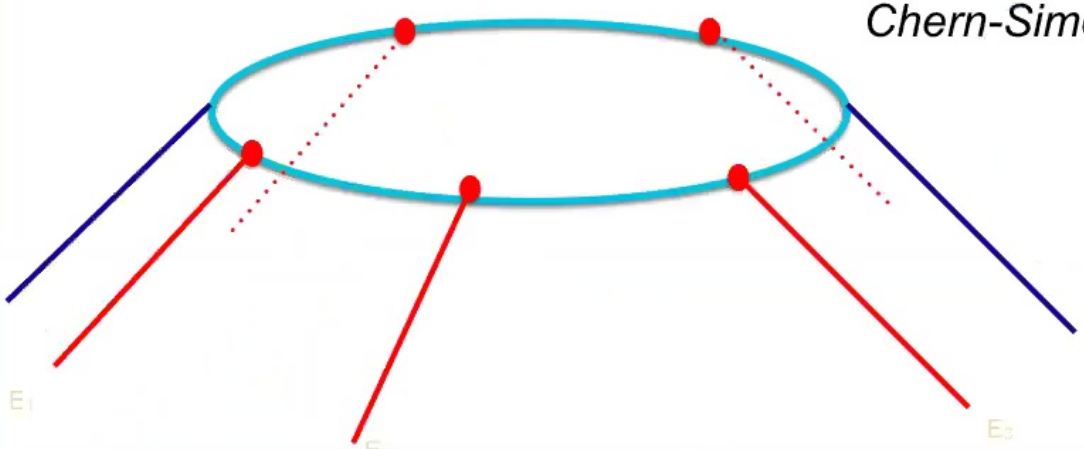
## Views: all the incoming news , to one event.

## (a punctured celestial two sphere)

The view of an event is a collection of null or timeline energy momentum vectors, representing incoming information about the past. $\{ p_a{}^J , p_a{}^K , \ldots \}$.

We can represent the directional information as points on an S2, with labels which are the energy.

*Connects to boundary Chern-Simons technology*



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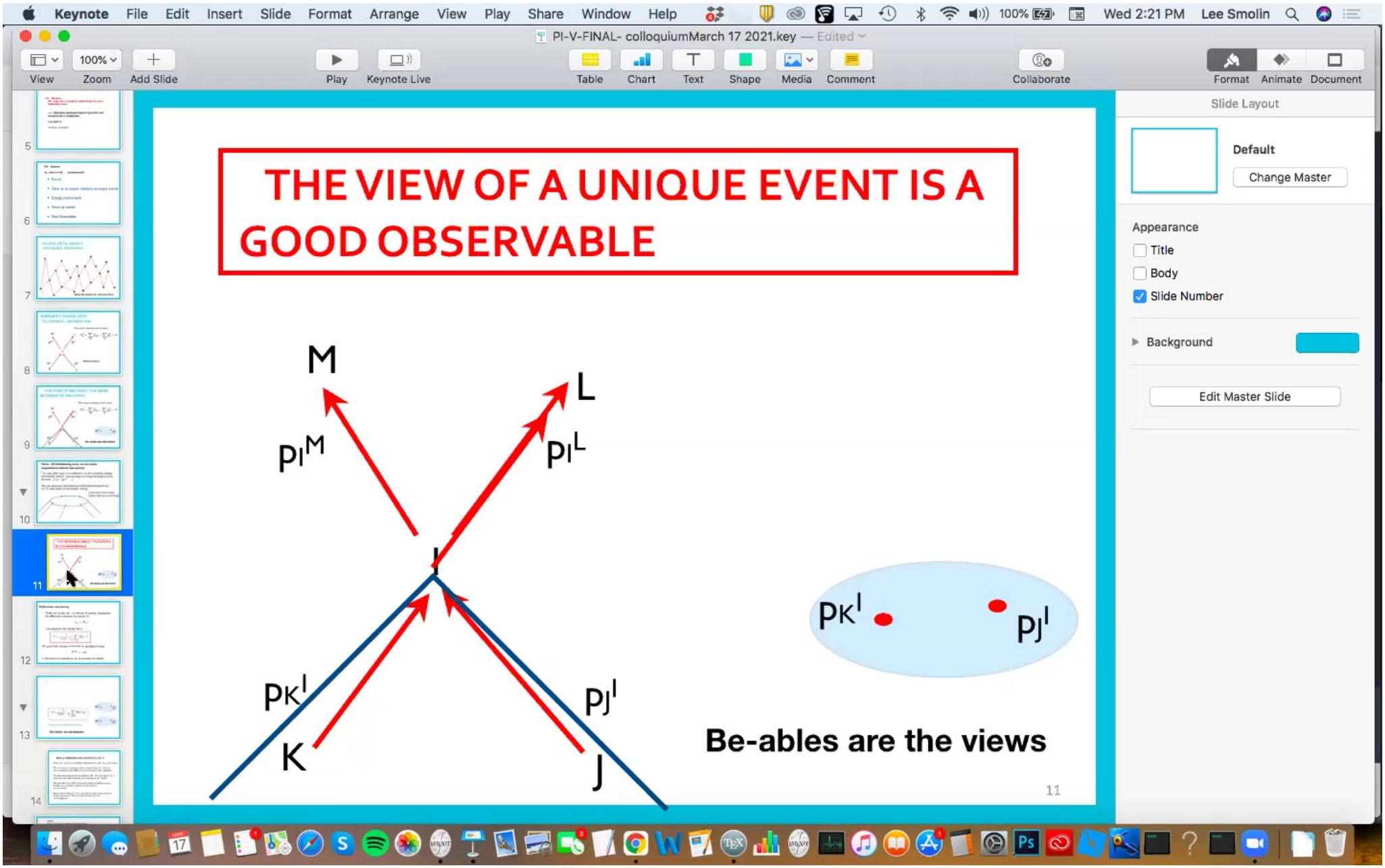
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THE VIEW OF A UNIQUE EVENT IS A GOOD OBSERVABLE
M
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$p_I^M$
$p_I^L$
I
$p_K^I$
$p_J^I$
K
J
$p_K^I$
$p_J^I$
Be-ables are the views
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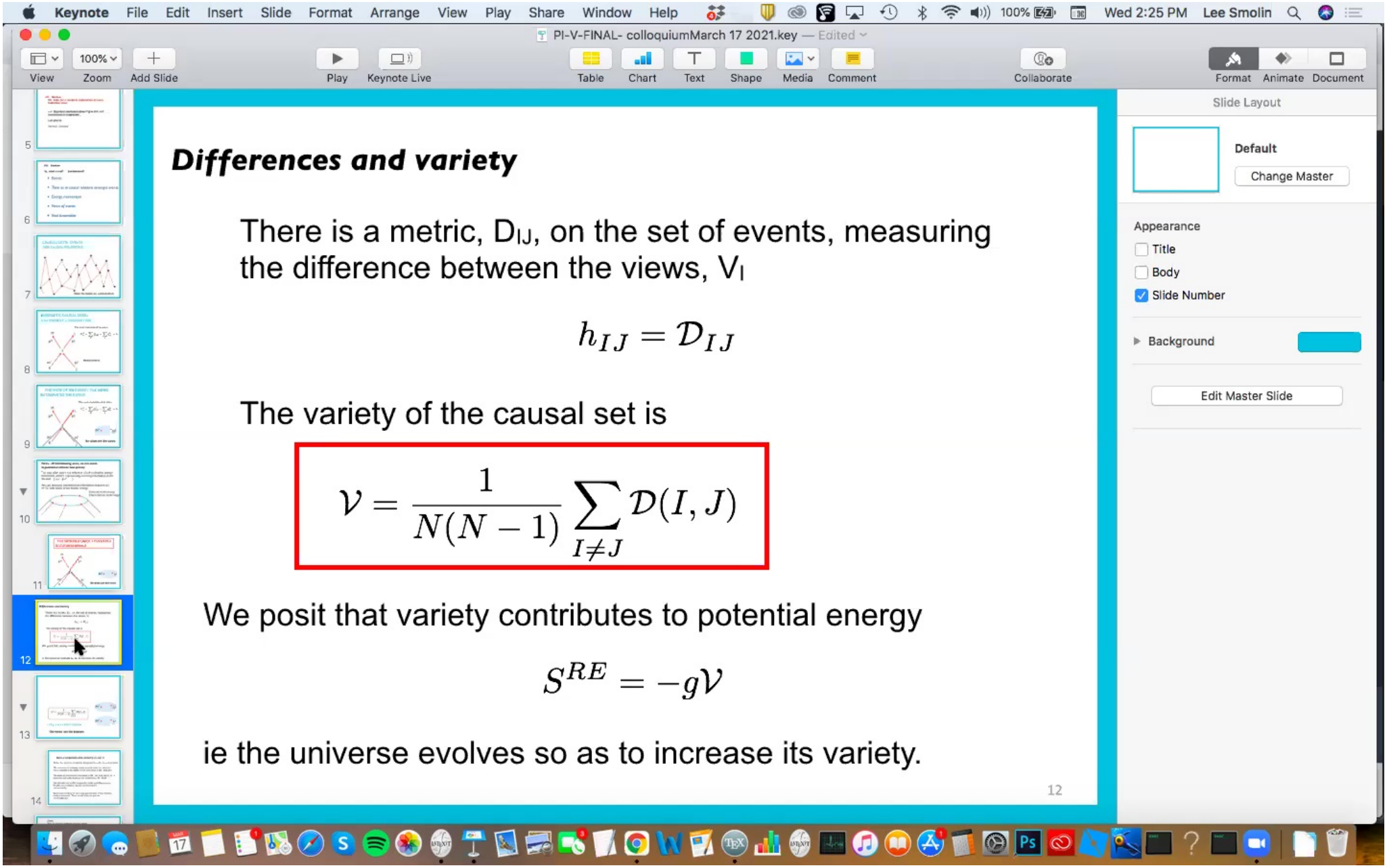
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Differences and variety
There is a metric, $D_{IJ}$, on the set of events, measuring the difference between the views, $V_I$
$$h_{IJ} = \mathcal{D}_{IJ}$$
The variety of the causal set is
$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{I \neq J} \mathcal{D}(I,J)$$
We posit that variety contributes to potential energy
$$S^{RE} = -g\mathcal{V}$$
ie the universe evolves so as to increase its variety.
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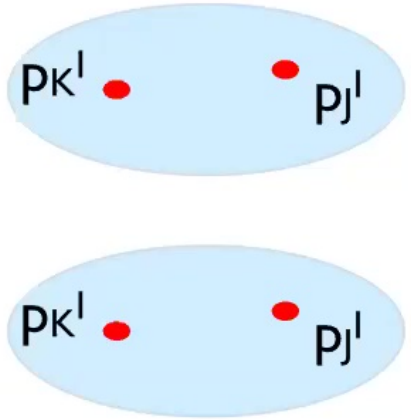
$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{I \neq J} \mathcal{D}(I, J)$$




__> PP3: EACH VIEW IS UNIQUE:

**The views are the beables**

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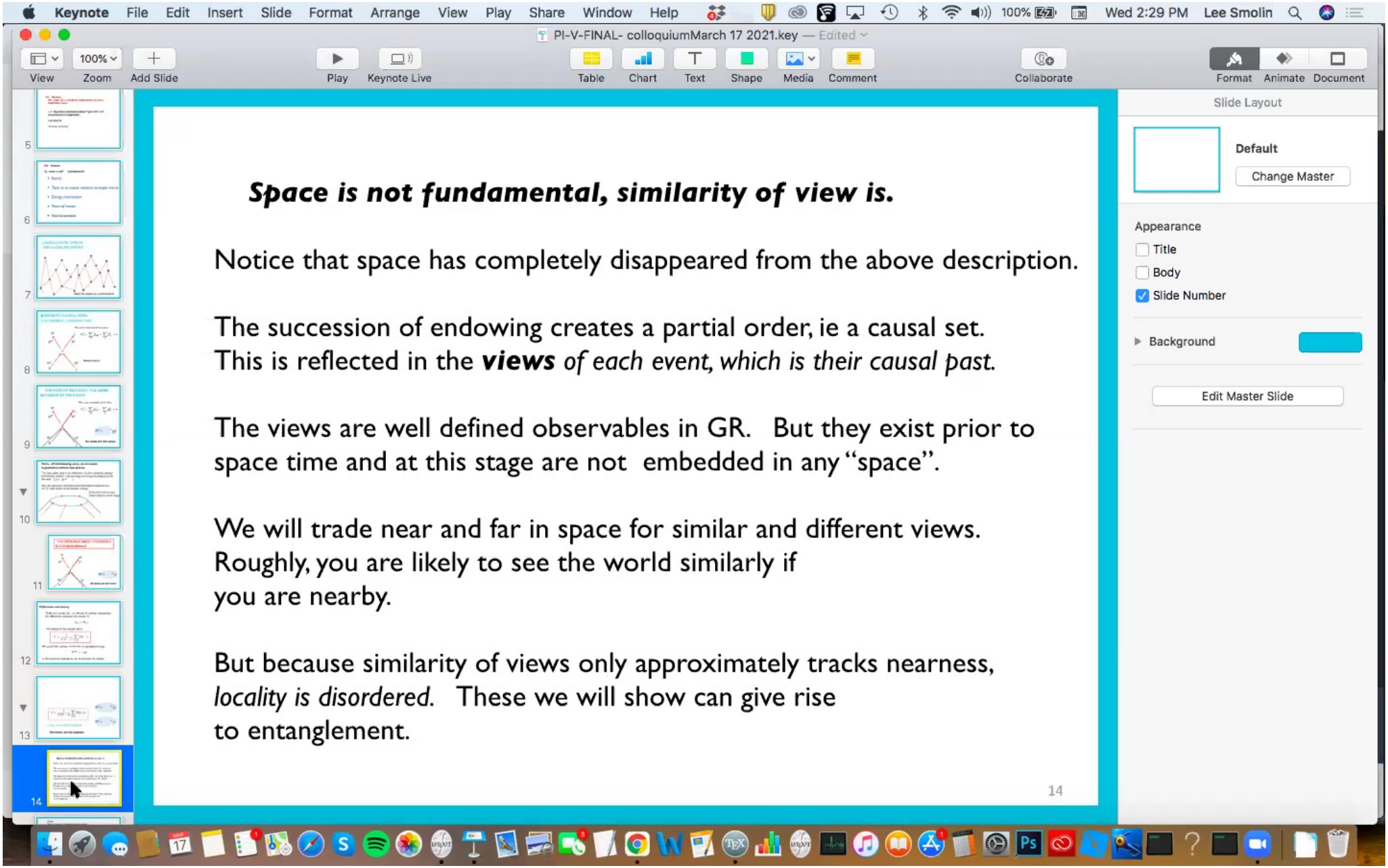
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Space is not fundamental, similarity of view is.
Notice that space has completely disappeared from the above description.
The succession of endowing creates a partial order, ie a causal set.
This is reflected in the views of each event, which is their causal past.
The views are well defined observables in GR. But they exist prior to space time and at this stage are not embedded in any "space".
We will trade near and far in space for similar and different views.
Roughly, you are likely to see the world similarly if you are nearby.
But because similarity of views only approximately tracks nearness, locality is disordered. These we will show can give rise to entanglement.
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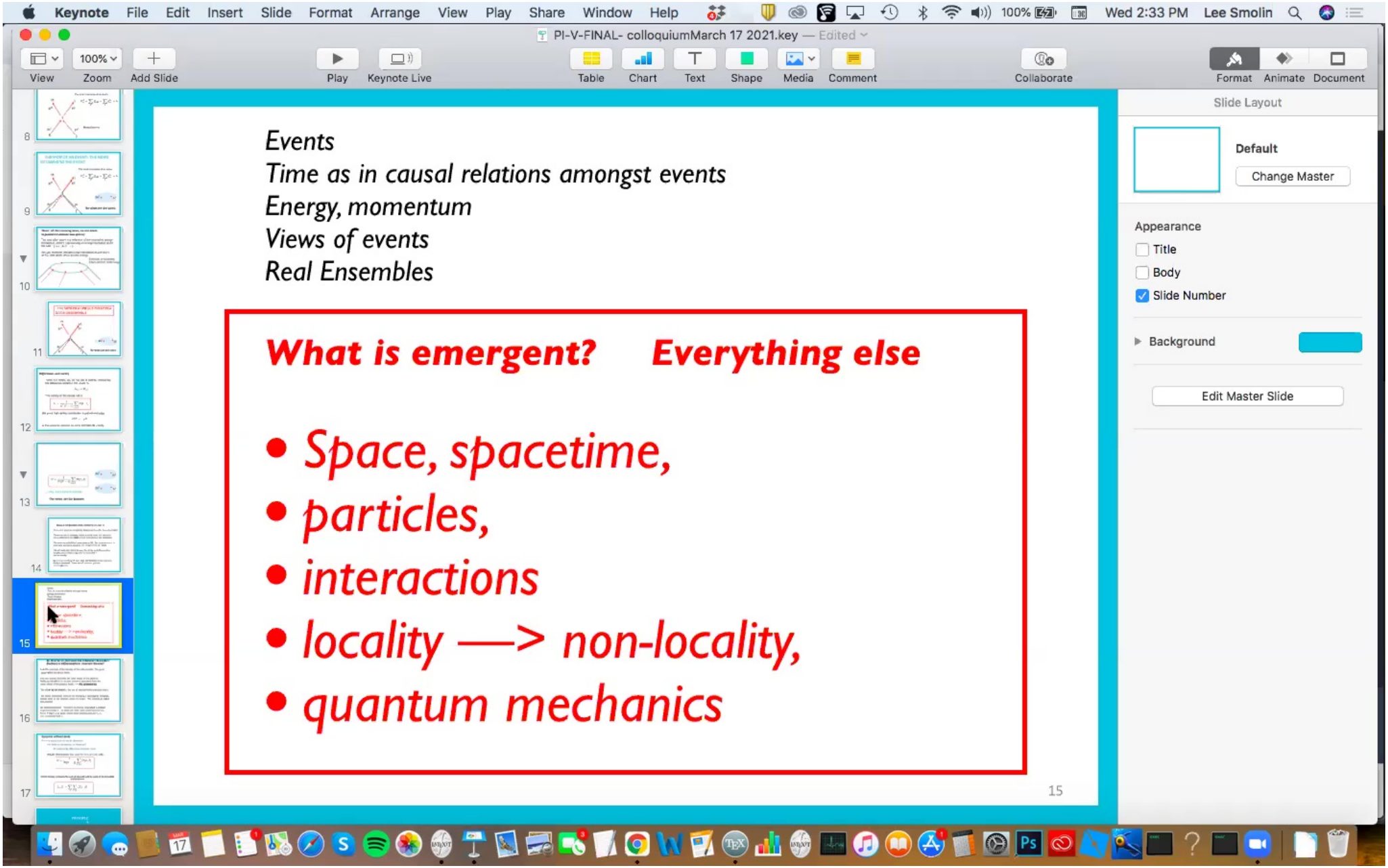
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Events
Time as in causal relations amongst events
Energy, momentum
Views of events
Real Ensembles
What is emergent? Everything else
• Space, spacetime,
• particles,
• interactions
• locality —> non-locality,
• quantum mechanics
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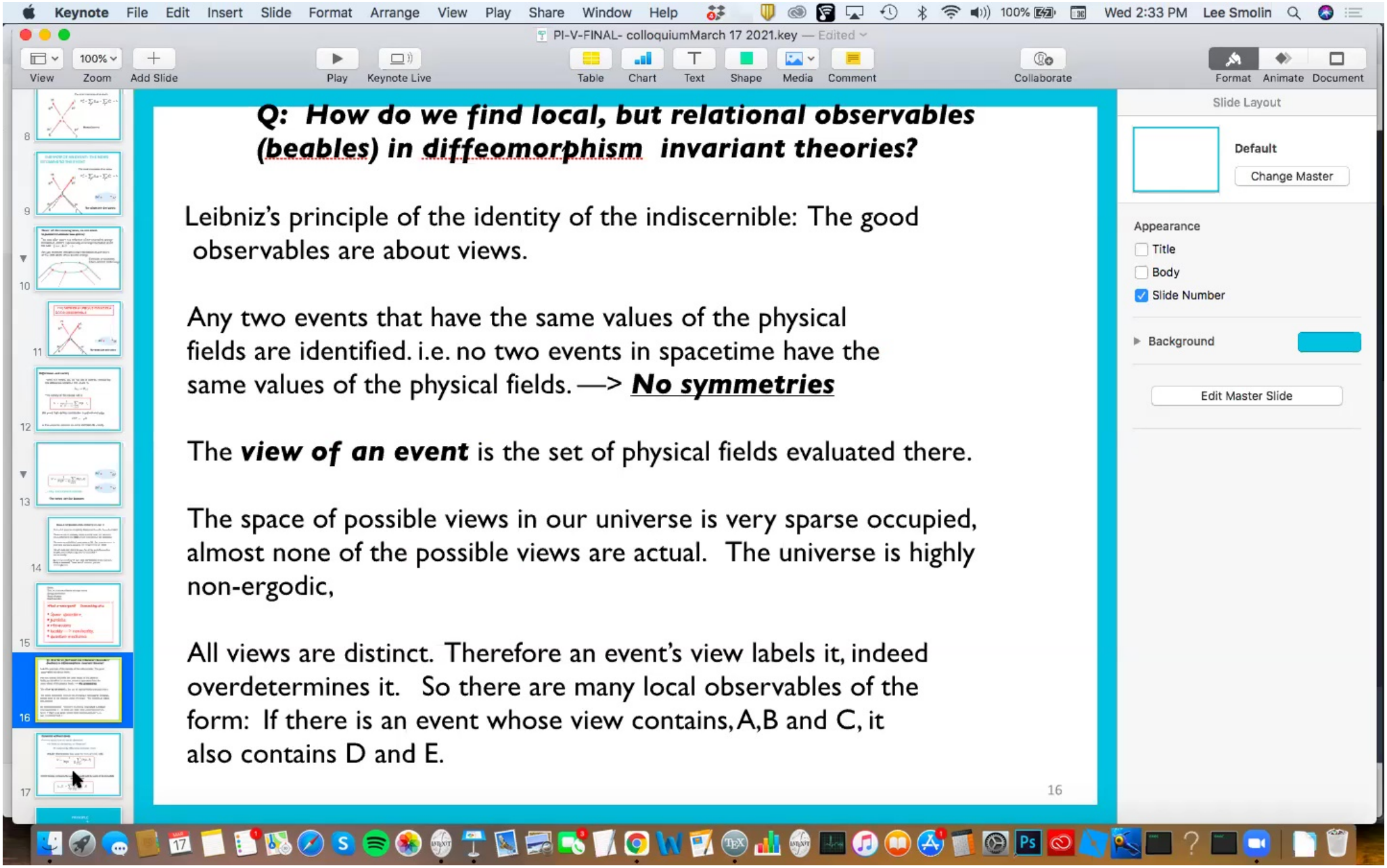
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Q: How do we find local, but relational observables (beables) in diffeomorphism invariant theories?
Leibniz's principle of the identity of the indiscernible: The good observables are about views.
Any two events that have the same values of the physical fields are identified. i.e. no two events in spacetime have the same values of the physical fields. —> No symmetries
The view of an event is the set of physical fields evaluated there.
The space of possible views in our universe is very sparse occupied, almost none of the possible views are actual. The universe is highly non-ergodic,
All views are distinct. Therefore an event's view labels it, indeed overdetermines it. So there are many local observables of the form: If there is an event whose view contains, A,B and C, it also contains D and E.
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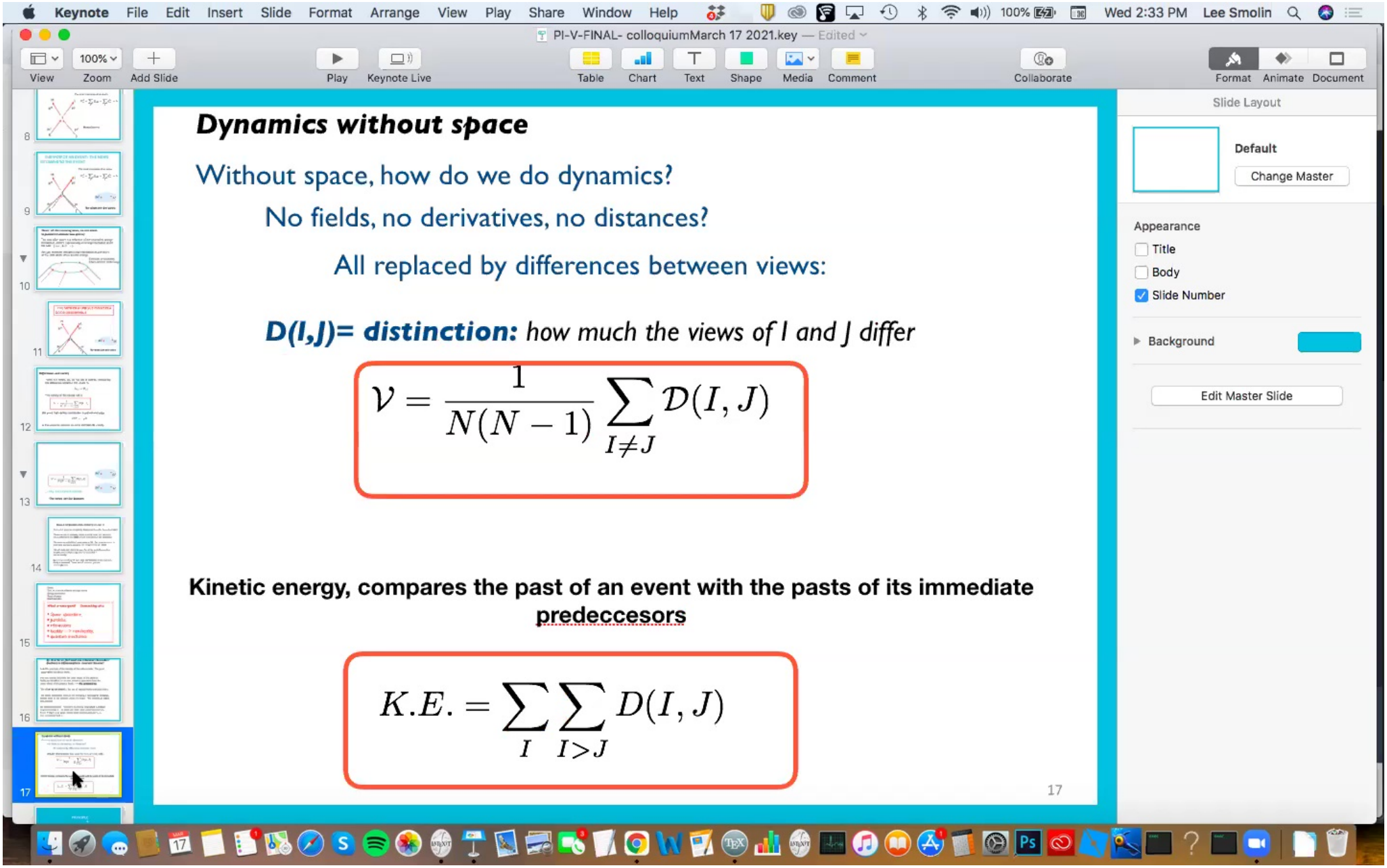
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Dynamics without space
Without space, how do we do dynamics?
No fields, no derivatives, no distances?
All replaced by differences between views:
D(I,J)= distinction: how much the views of I and J differ
$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{I \neq J} \mathcal{D}(I,J)$$
Kinetic energy, compares the past of an event with the pasts of its immediate predeccesors
$$K.E. = \sum_{I} \sum_{I>J} D(I,J)$$
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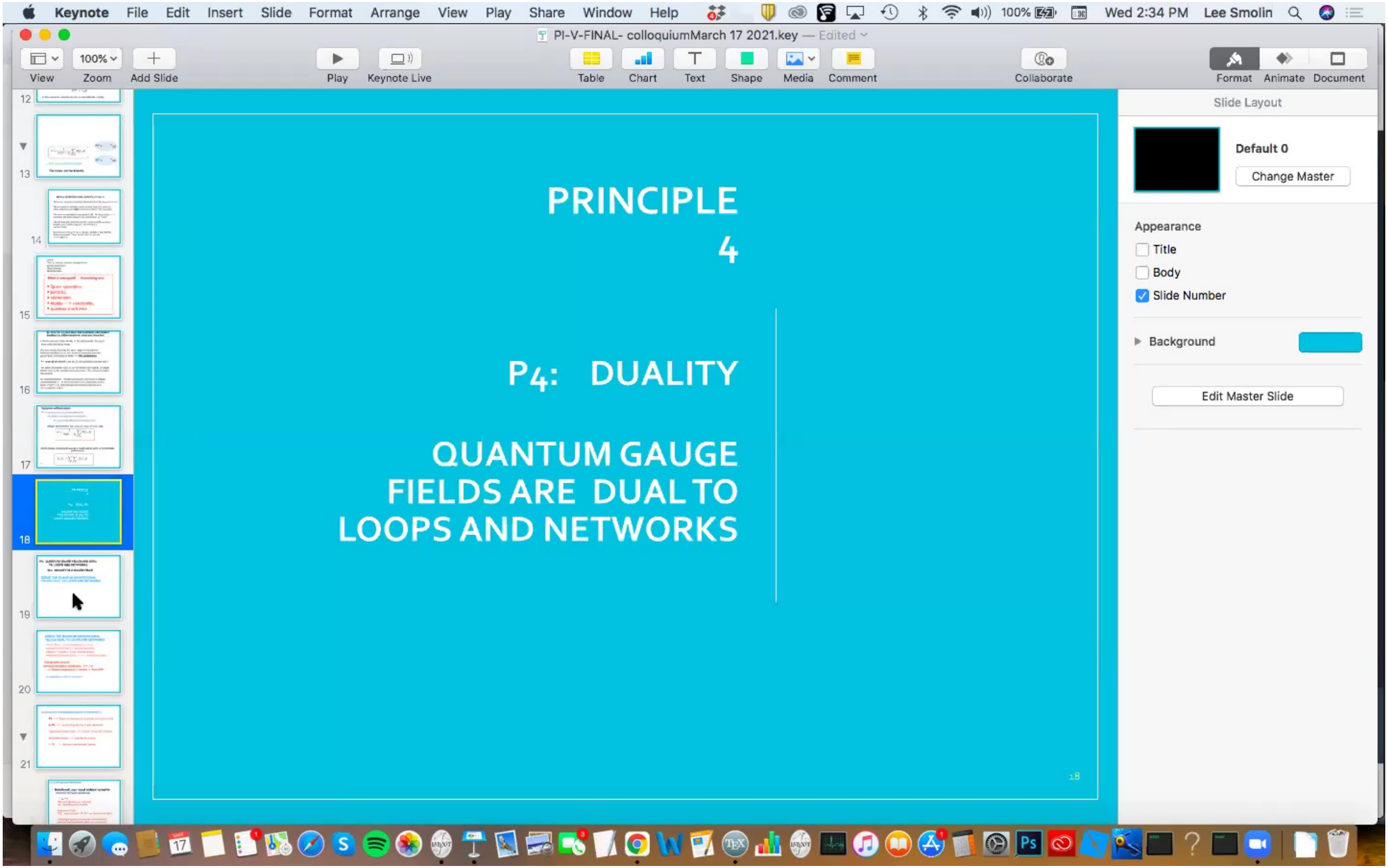
PRINCIPLE
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P4: DUALITY
QUANTUM GAUGE FIELDS ARE DUAL TO LOOPS AND NETWORKS
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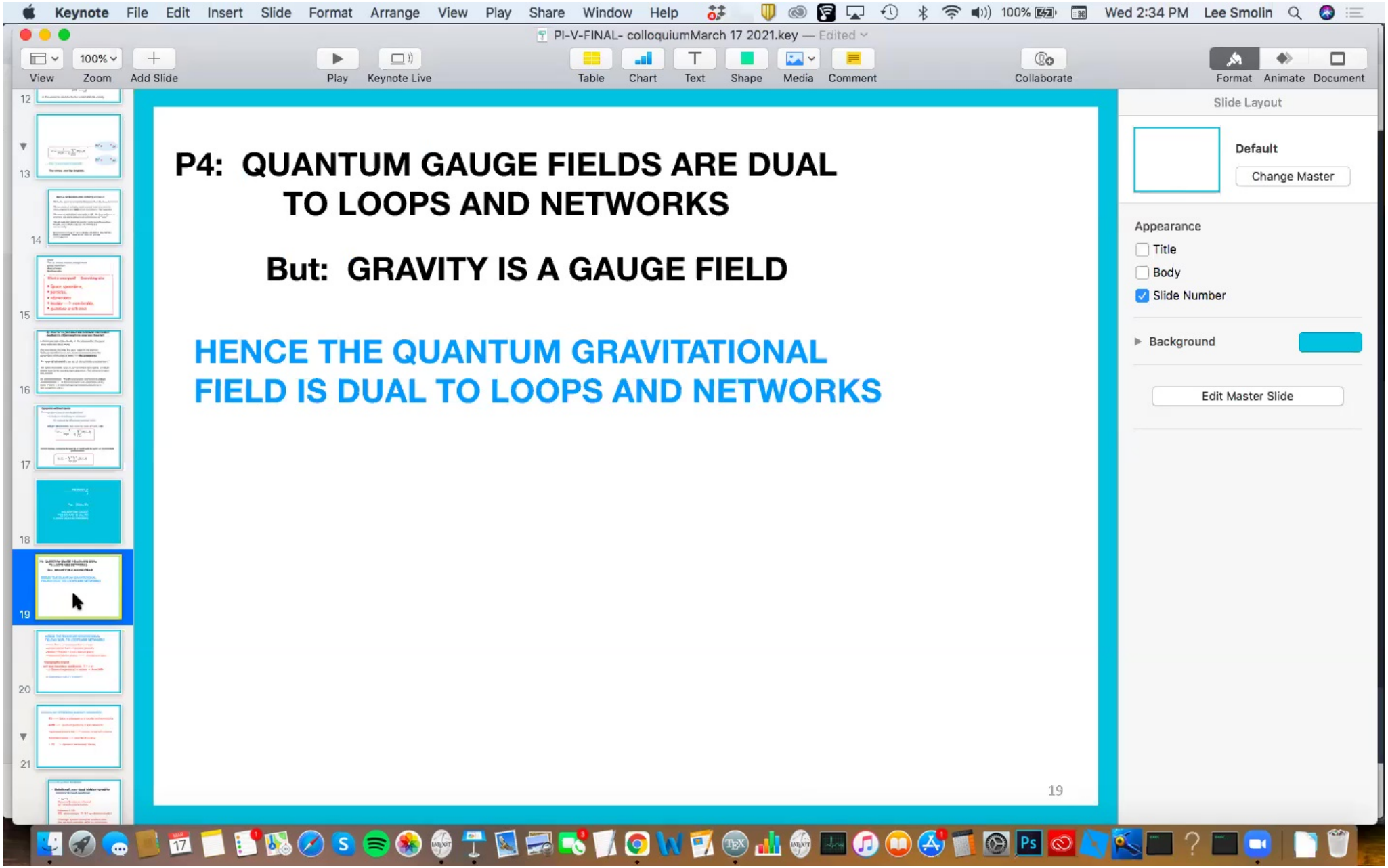
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P4: QUANTUM GAUGE FIELDS ARE DUAL TO LOOPS AND NETWORKS
But: GRAVITY IS A GAUGE FIELD
HENCE THE QUANTUM GRAVITATIONAL FIELD IS DUAL TO LOOPS AND NETWORKS
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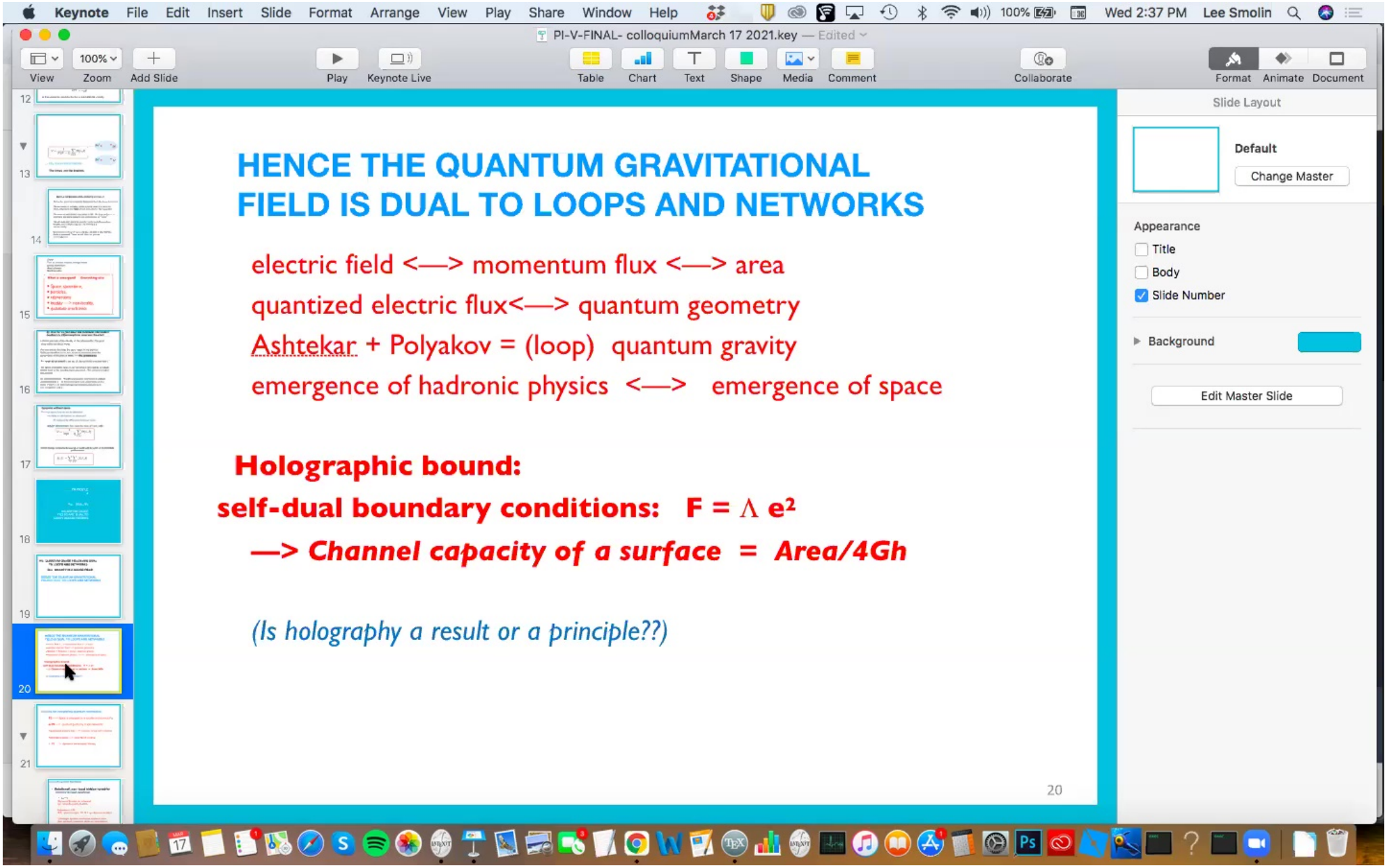
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HENCE THE QUANTUM GRAVITATIONAL FIELD IS DUAL TO LOOPS AND NETWORKS
electric field <—> momentum flux <—> area
quantized electric flux<—> quantum geometry
Ashtekar + Polyakov = (loop) quantum gravity
emergence of hadronic physics <—> emergence of space
Holographic bound:
self-dual boundary conditions: F = Λ e²
—> Channel capacity of a surface = Area/4Gh
(Is holography a result or a principle??)
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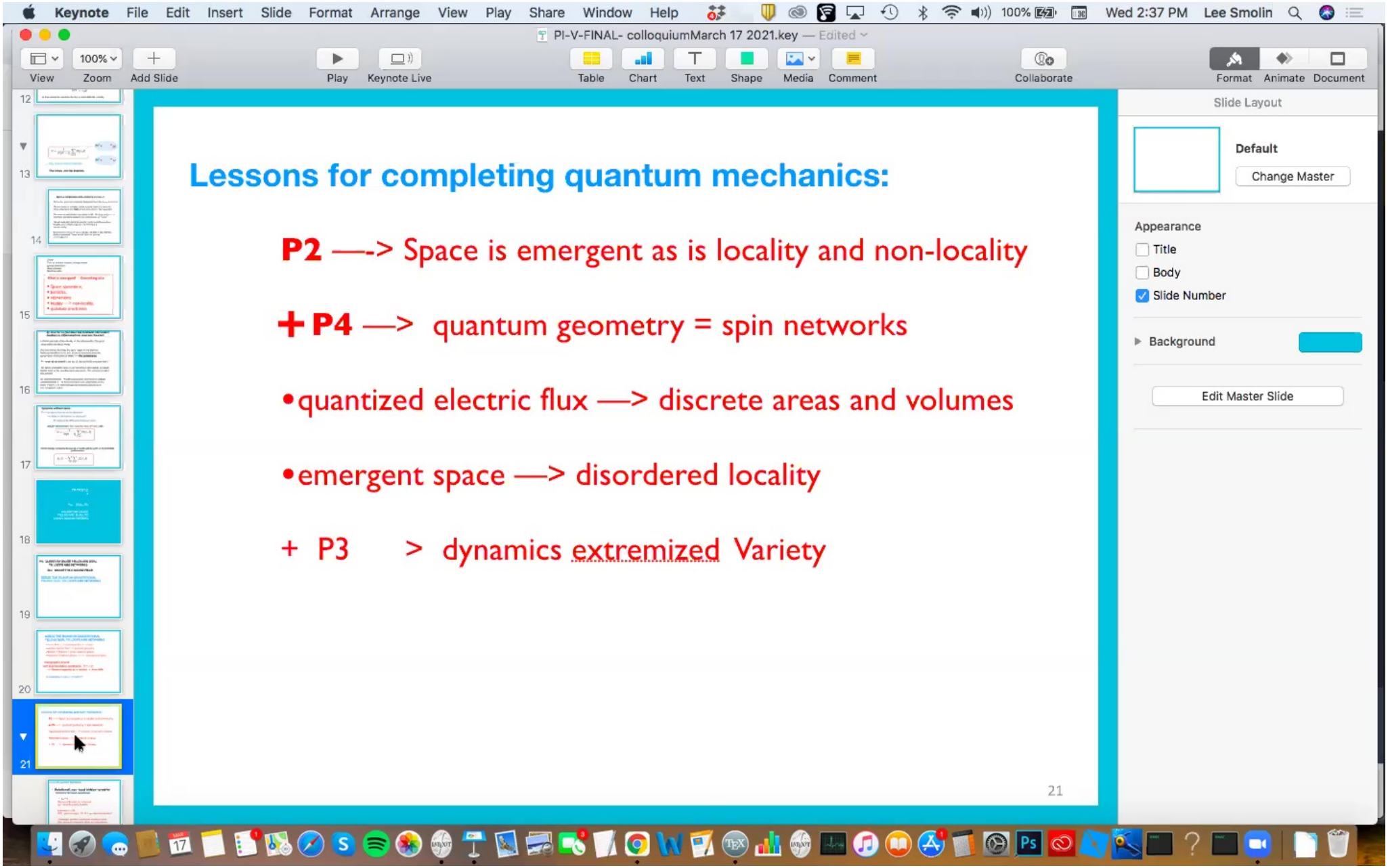
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Lessons for completing quantum mechanics:
P2 —-> Space is emergent as is locality and non-locality
+ P4 —> quantum geometry = spin networks
•quantized electric flux —> discrete areas and volumes
•emergent space —> disordered locality
+ P3 > dynamics extremized Variety
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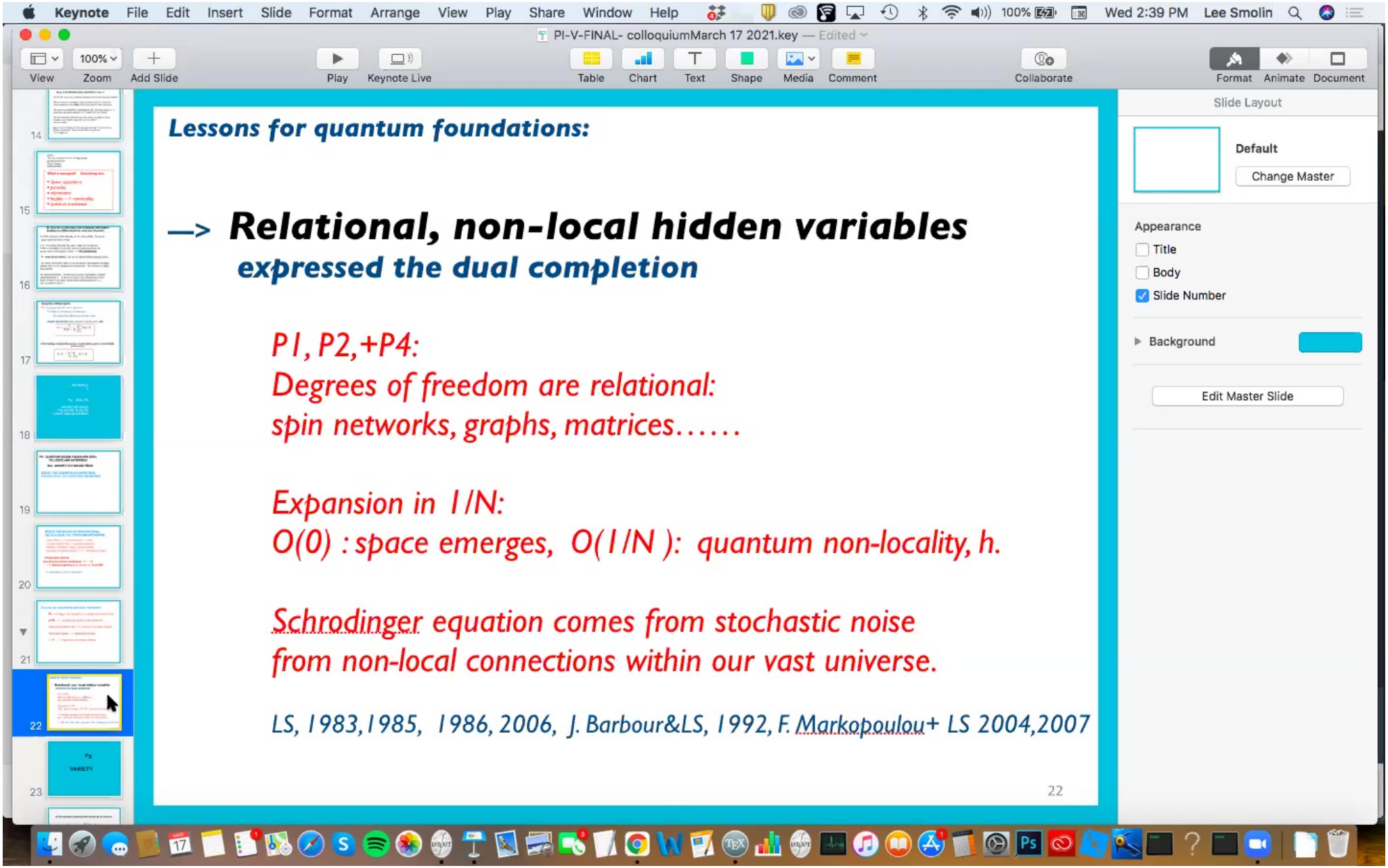
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Lessons for quantum foundations:
—> Relational, non-local hidden variables
expressed the dual completion
P1, P2,+P4:
Degrees of freedom are relational:
spin networks, graphs, matrices……
Expansion in 1/N:
O(0) : space emerges, O(1/N ): quantum non-locality, h.
Schrodinger equation comes from stochastic noise
from non-local connections within our vast universe.
LS, 1983,1985, 1986, 2006, J. Barbour&LS, 1992, F. Markopoulou+ LS 2004,2007
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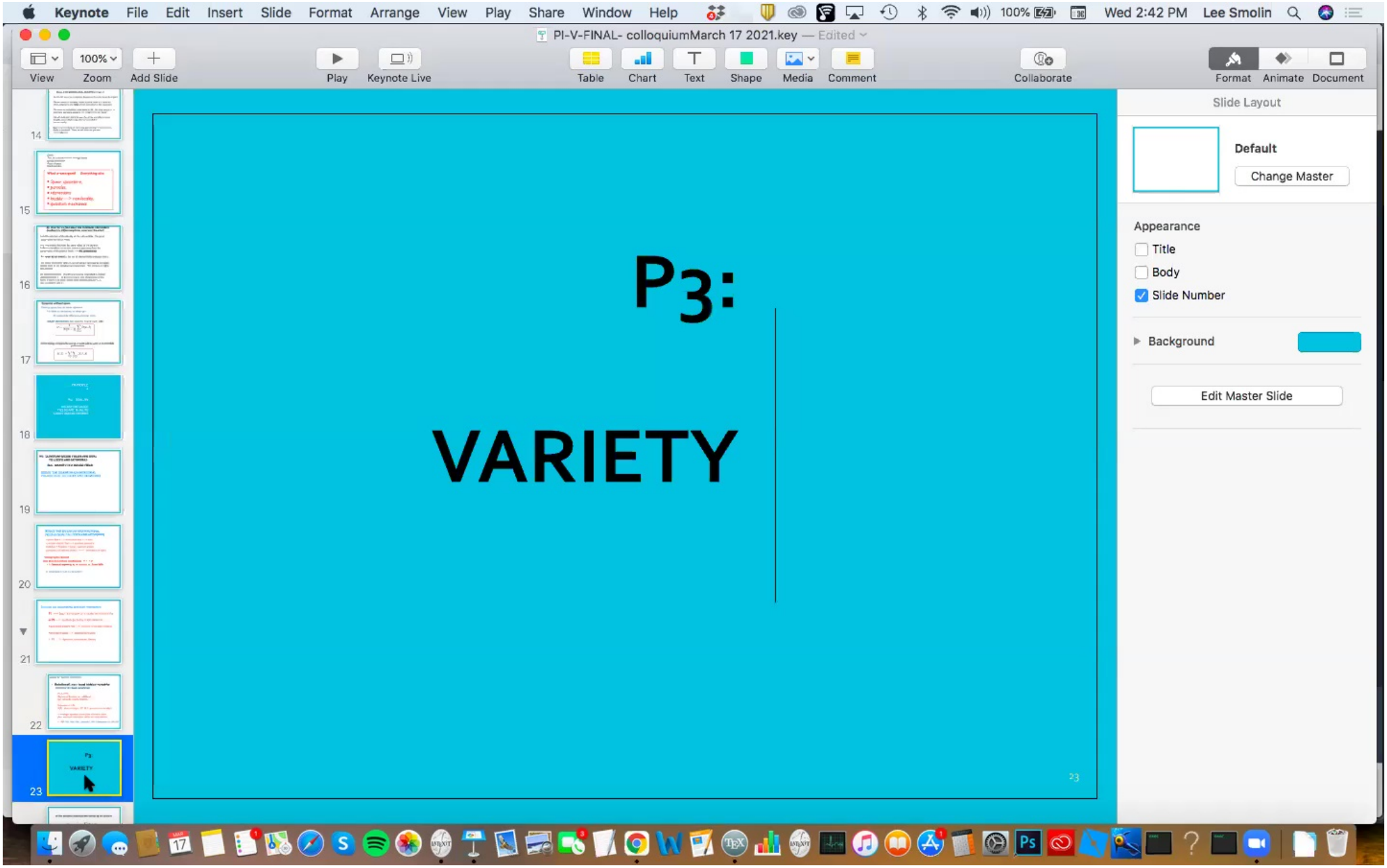
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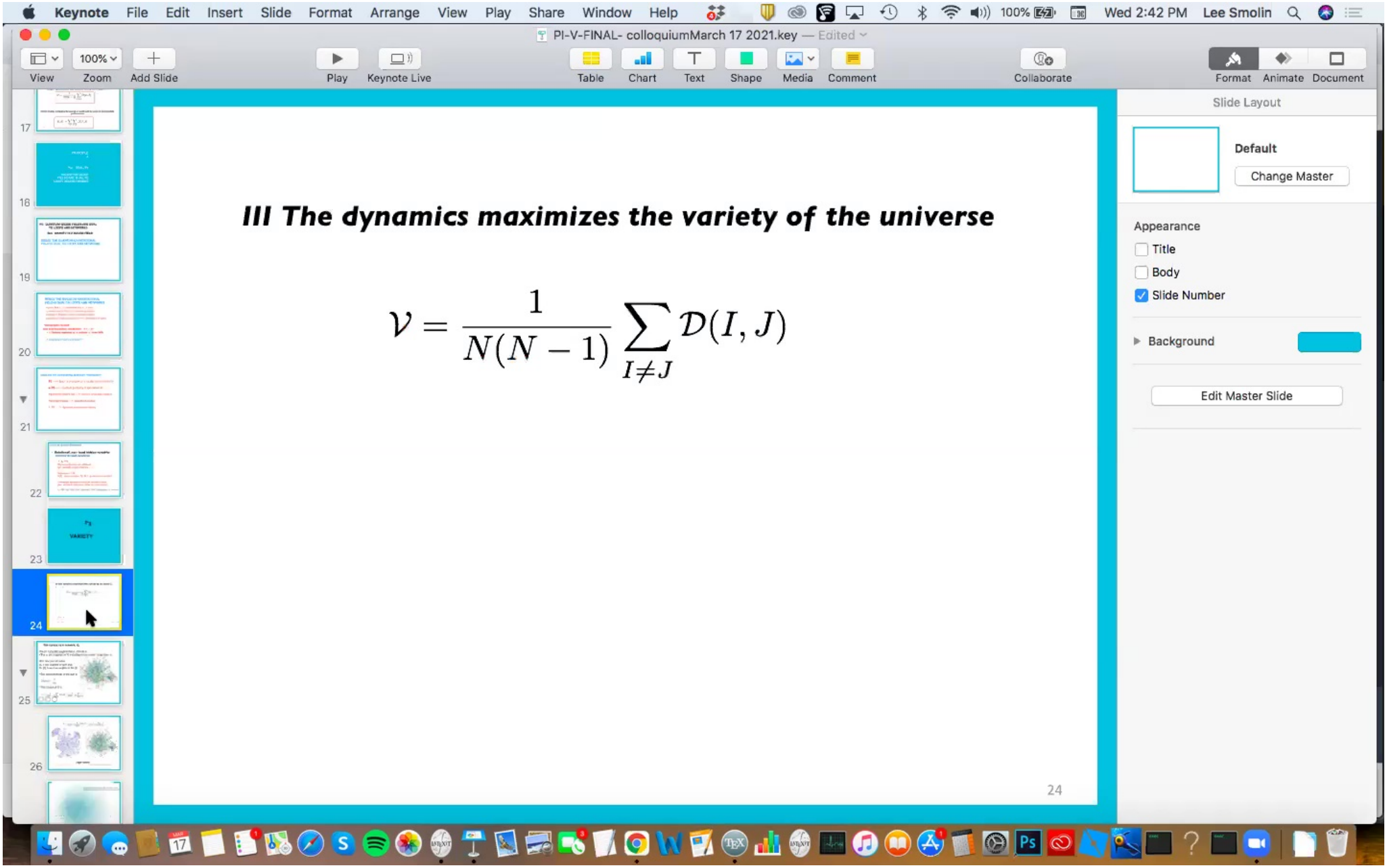
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III The dynamics maximizes the variety of the universe
$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{I \neq J} \mathcal{D}(I,J)$$
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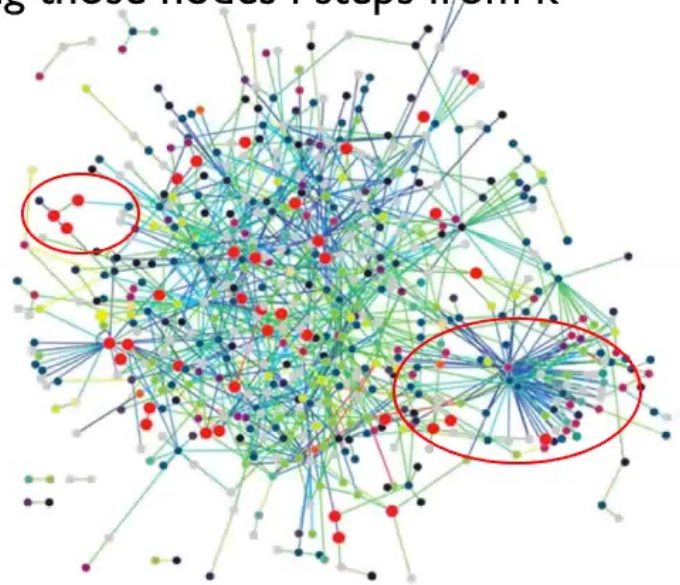
## *The variety of a network, G,*

- $N_l(k)$ is the l'th neighborhood of node k
- This is the subgraph of G including those nodes l steps from k



- For any pair of nodes, $n_{kl}$ is the smallest n such that $N_n(k)$ is not isomorphic to $N_n(l)$

- The distinctiveness of the pair is

$$D(k,l) = \frac{1}{n_{kl}}$$

- The variety of G is

$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{k \neq l} D(k,l) = \frac{1}{N(N-1)} \sum_{k \neq l} \frac{1}{n_{kl}}$$

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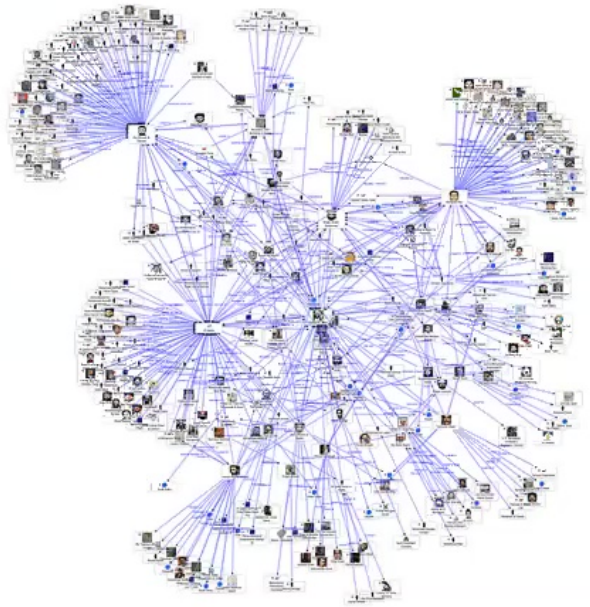
$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{k \neq l} D(k,l) = \frac{1}{N(N-1)} \sum_{k,l} \frac{1}{n_{kl}}$$



**High variety**

healthandsociety.columbia.edu

http://en.wikipedia.org/wiki/Interactome

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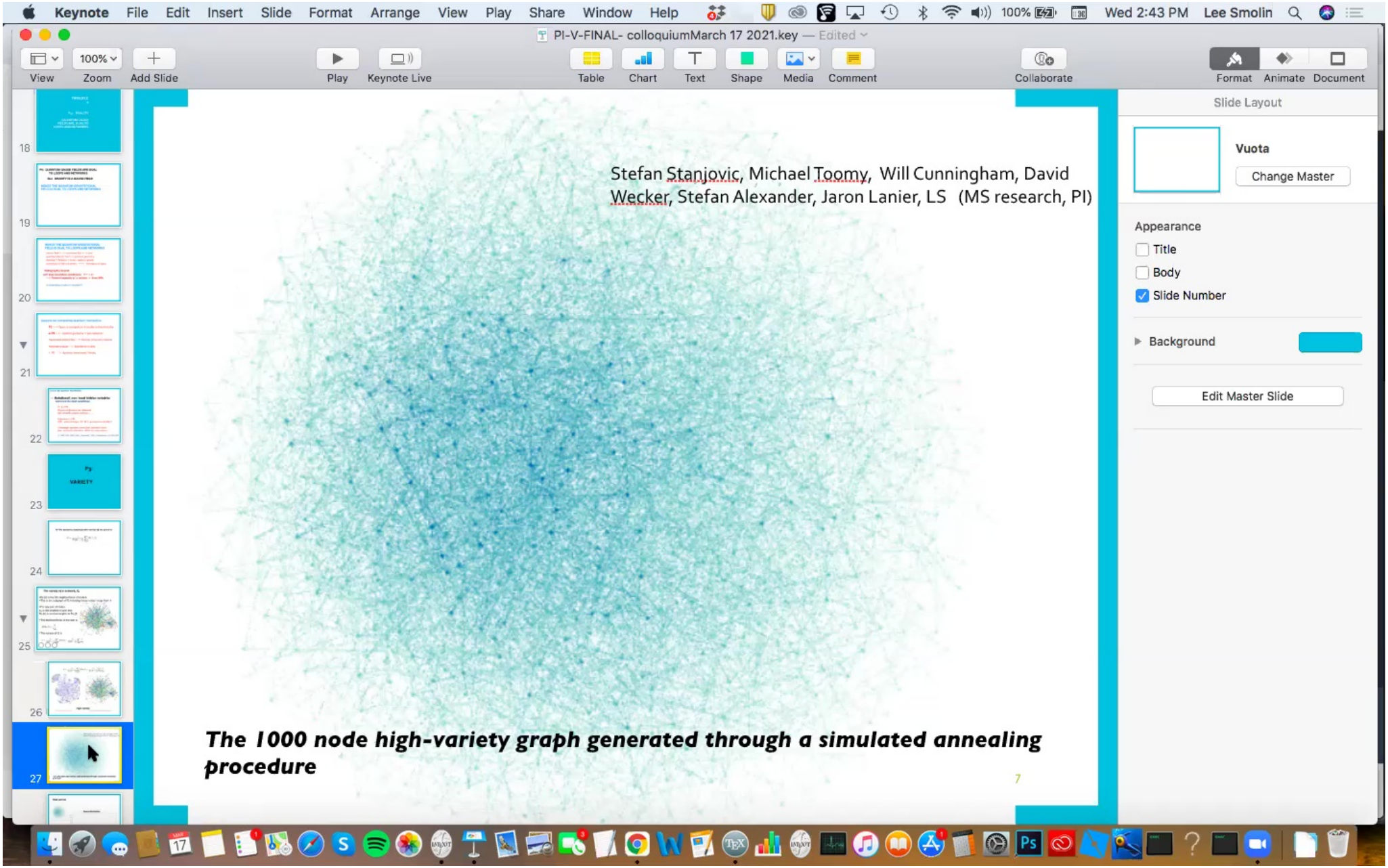
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Stefan Stanjovic, Michael Toomy, Will Cunningham, David Wecker, Stefan Alexander, Jaron Lanier, LS (MS research, PI)
The 1000 node high-variety graph generated through a simulated annealing procedure
7
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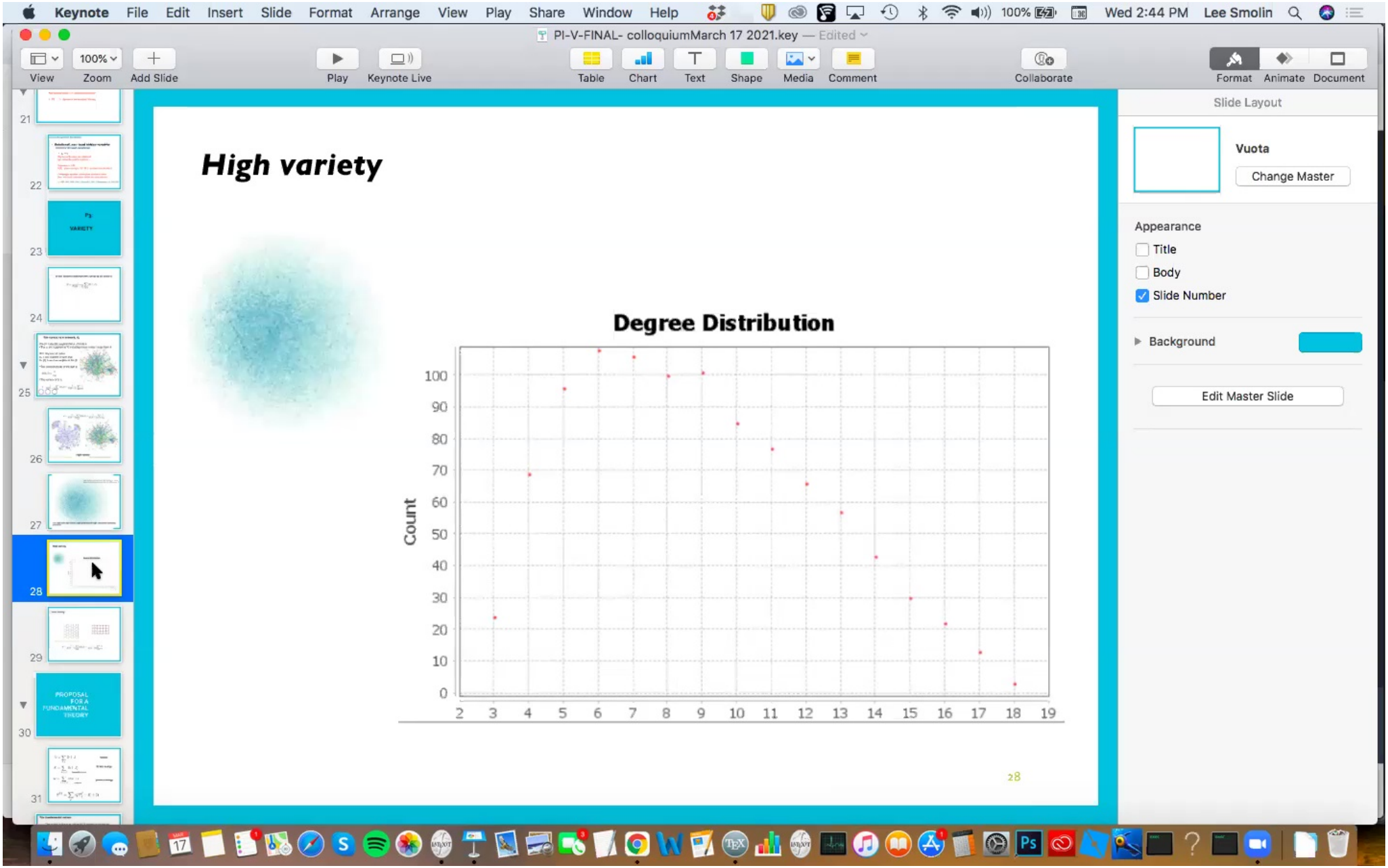
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High variety
Degree Distribution
Count
100 90 80 70 60 50 40 30 20 10 0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
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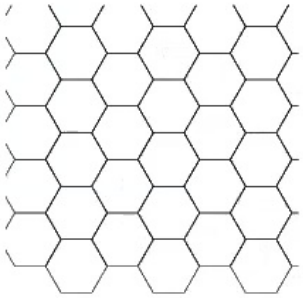
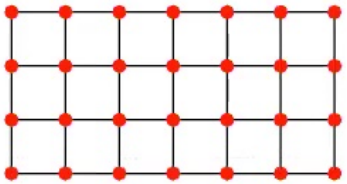
# Low variety





http://mathworld.wolfram.com/HexagonalGrid.html

$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{k \neq l} D(k,l) = \frac{1}{N(N-1)} \sum_{k \neq l} \frac{1}{n_{kl}}$$

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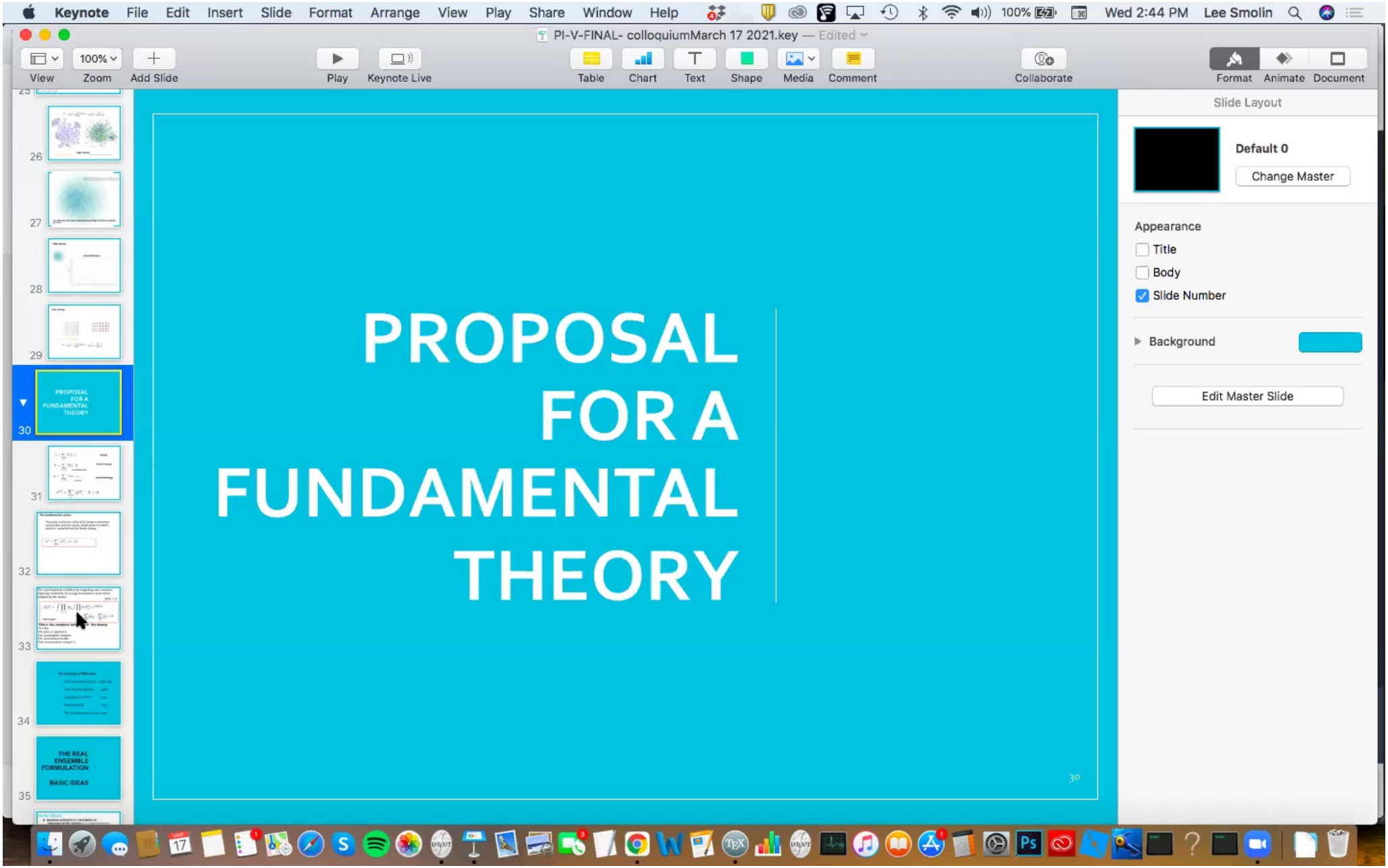
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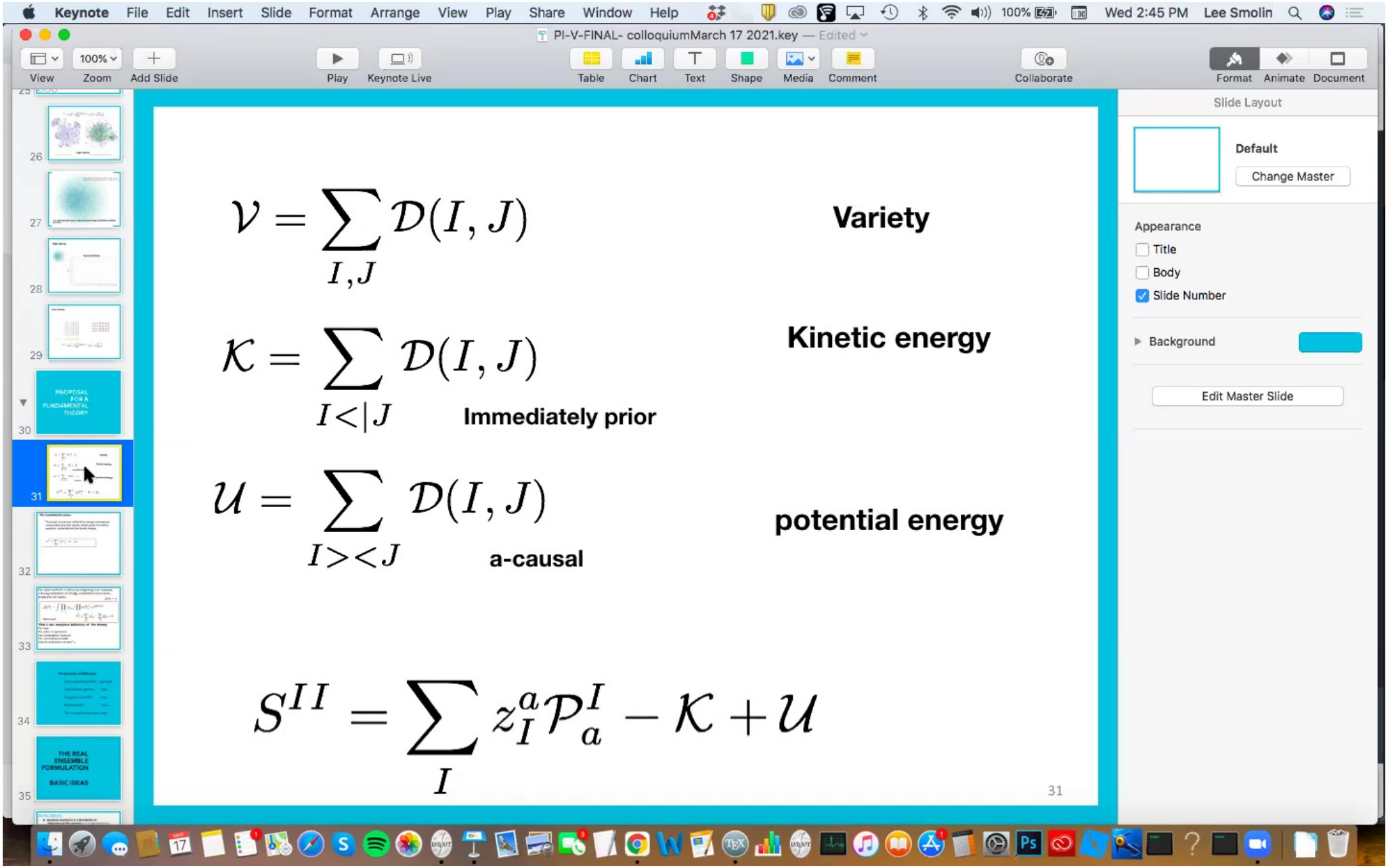
PROPOSAL FOR A FUNDAMENTAL THEORY
30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$\mathcal{V} = \sum_{I,J} \mathcal{D}(I,J)$
Variety
$\mathcal{K} = \sum_{I<|J} \mathcal{D}(I,J)$
Kinetic energy
Immediately prior
$\mathcal{U} = \sum_{I><J} \mathcal{D}(I,J)$
potential energy
a-causal
$S^{II} = \sum_{I} z_I^a \mathcal{P}_a^I - \mathcal{K} + \mathcal{U}$
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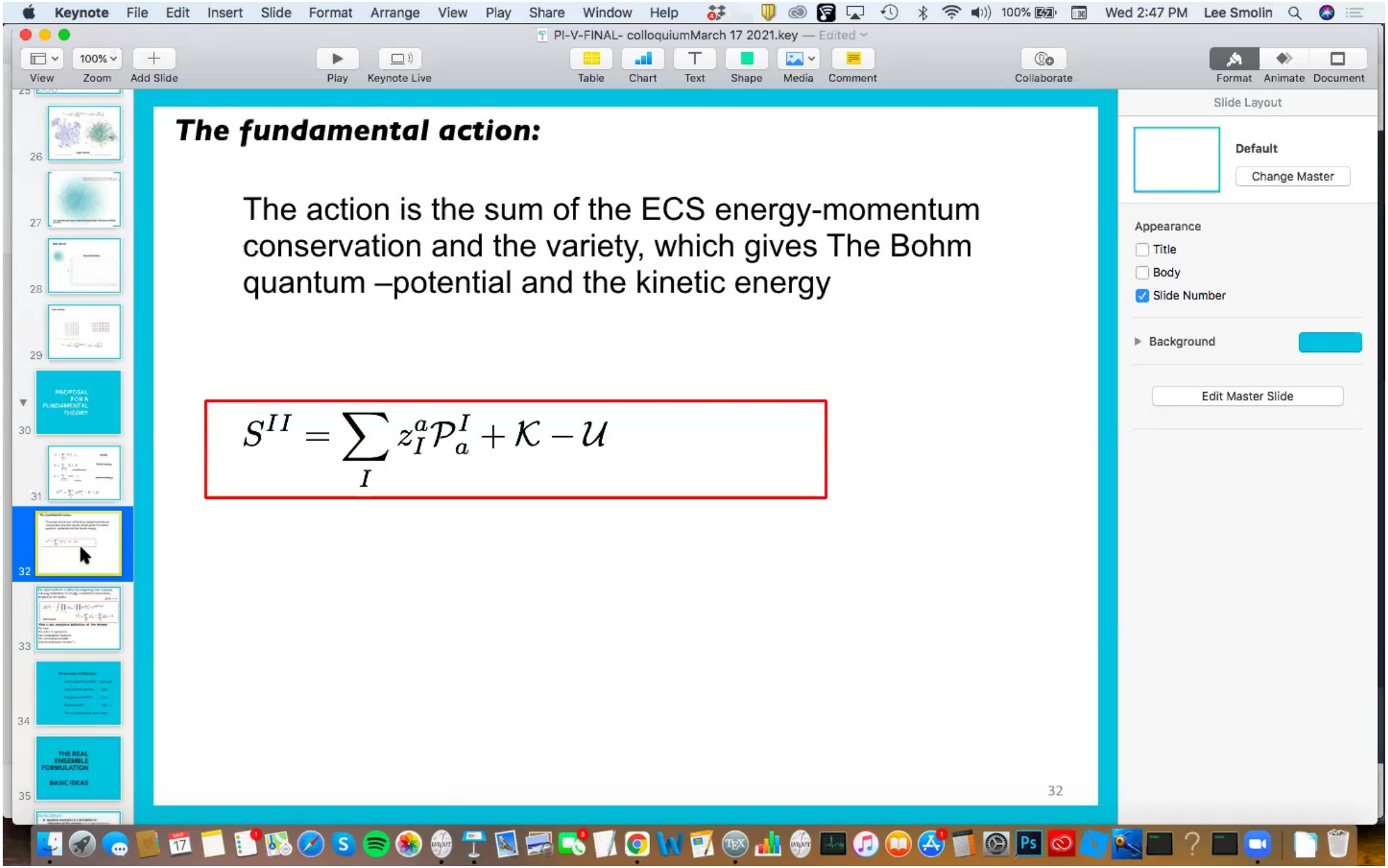
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The fundamental action:
The action is the sum of the ECS energy-momentum conservation and the variety, which gives The Bohm quantum –potential and the kinetic energy
$S^{II} = \sum_I z_I^a \mathcal{P}_a^I + \mathcal{K} - \mathcal{U}$
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The total amplitude is defined by integrating over momenta, imposing constraints, for energy-momentum conservation, weighed by the variety.

Q=K + U

$$\mathcal{A}[P] = \int \prod_{I>J} dp_{aJ}^{I} \prod_{I} \delta(\mathcal{P}_a^I)\ e^{ig\mathcal{Q}(p)}$$

$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0$$

"Half-integral"

**This is the complete definition of the theory.**

No hbar

No space or spacetime

No commutation relations

No uncertainty principle

Non-local, because variety V is.

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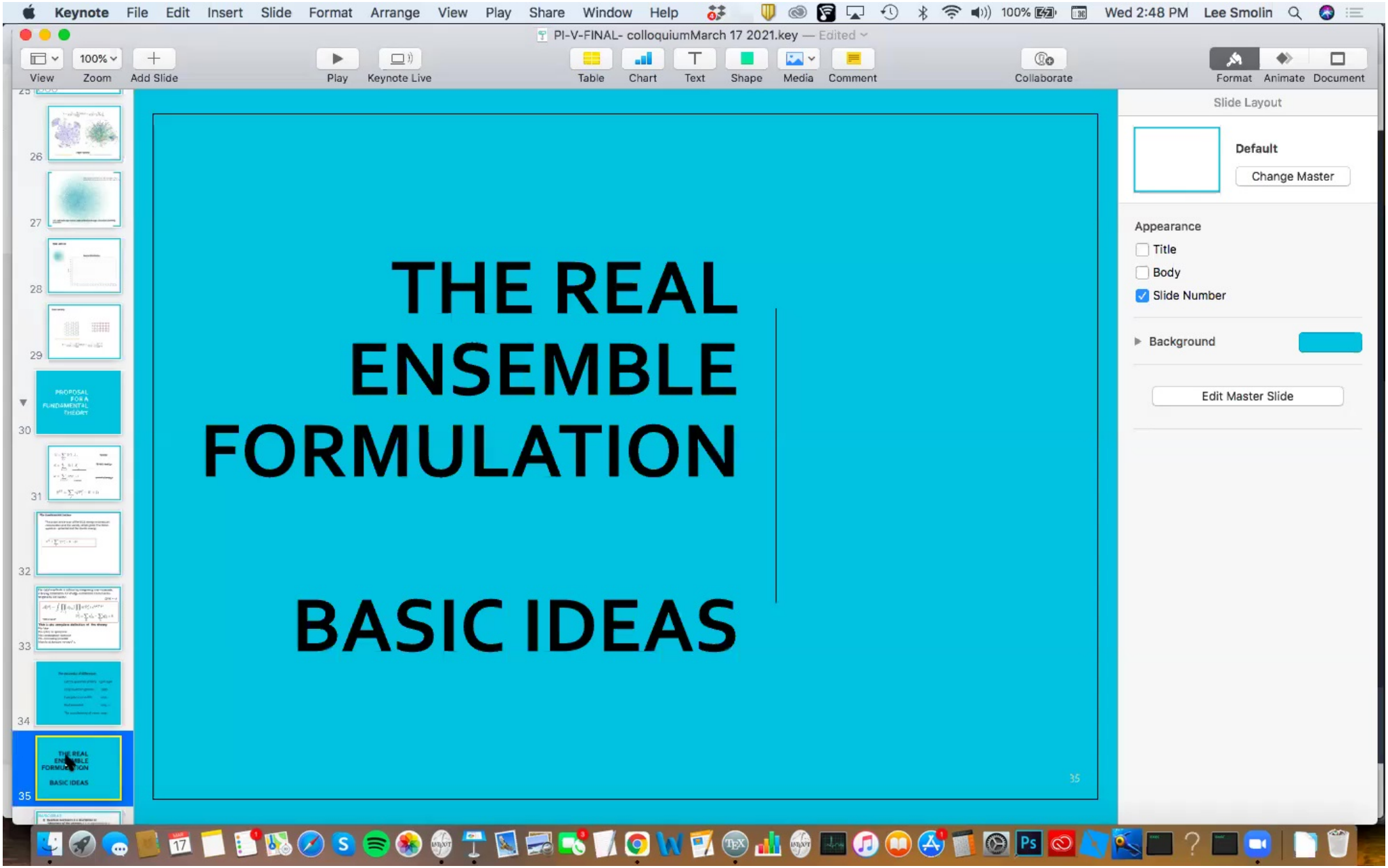
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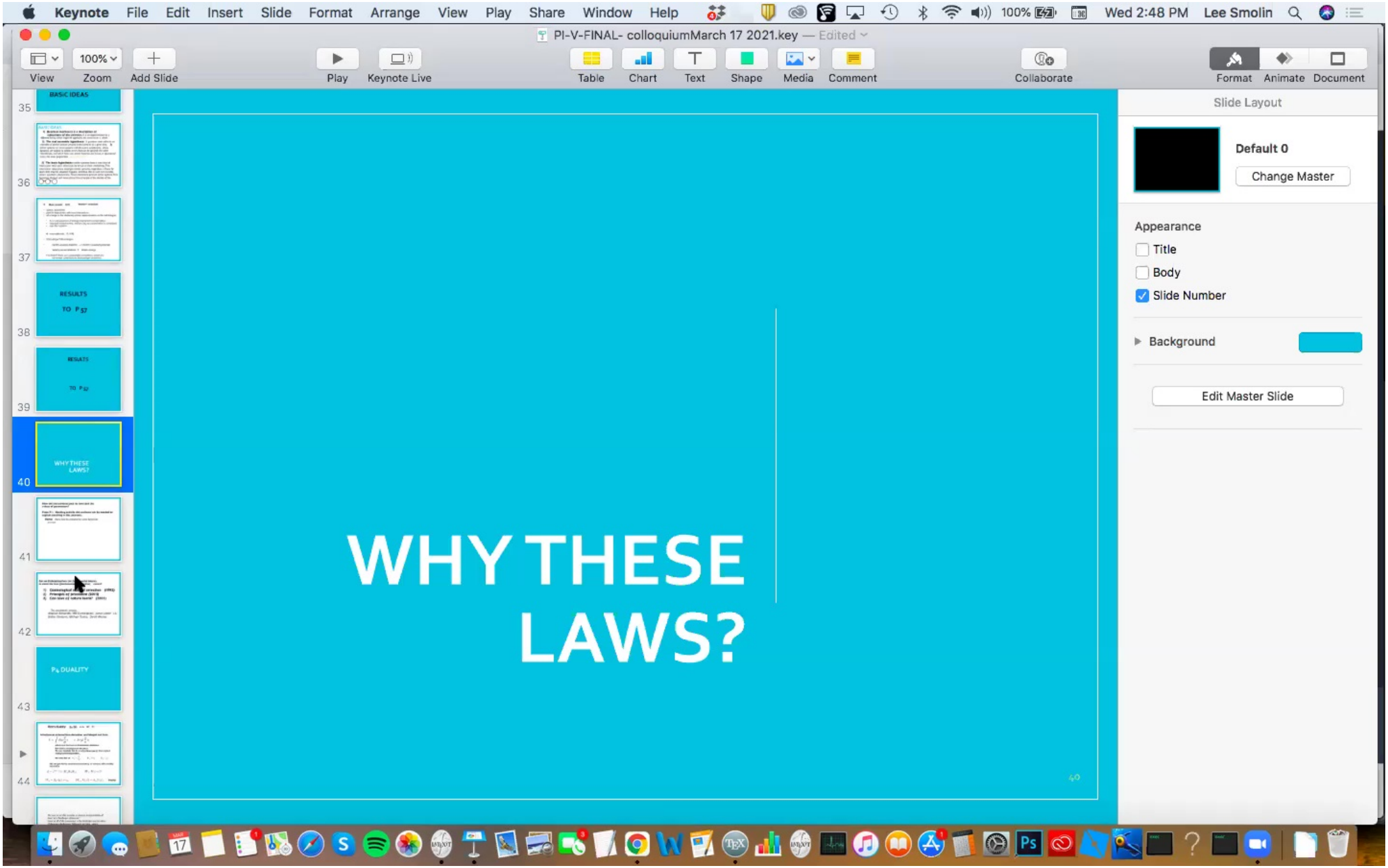
THE REAL ENSEMBLE FORMULATION
BASIC IDEAS
35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WHY THESE LAWS?

# Born duality: $p_a$ (s) <-> $x^b$ (s)

**Introduce an external time derivative and integral and form**

$$S = \int dtp\frac{d}{dt}x \qquad = Tr[p]\frac{d}{dt}[x]$$

**which is at the heart of Hamiltonian dynamics.**

**But d/dt is a background structure.**
**We can translate this to a matrix langauge ad then make it background independent.:**

**We write this as** $W_0 = [\frac{d}{dt}]$ $W_1 = [x]$ $W_2 = [p]$

**We can get that by spontaneous breaking of a theory with a triality symmetry**

$$S = \epsilon^{abc}\ Tr\left(W_a W_b W_c\right) \qquad [W_a, W_b] = 0$$

$$W_a = \partial_a s(x) + a_a \qquad [W_a, X(x)] = \partial_a X(x) \qquad \textbf{\textit{Triality}}$$

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## Diverse reductions/compactifications of the cubic matrix model:

$$S^m = Tr\ M^3$$

- *Relativistic particle dynamics in any dimension*
- *Chern-Simons theory for any Lie algebra*
- *BF theory in 4d*
- *Plebanski action for general relativity in 4d*
- *Plebanski action extended to unification with Yang-Mills theory for any Lie algebra*
- *…….. with Higgs……..*
- *with M valued in the exceptional Jordan algebra: Matrix string of Dikgraph Verlinde²*

***Chern-Simons theory is the boundary theory of BF and Plebanski***

***These all have a triality invariance-especially important for the last.***

***So hidden this large duality of theories is a bulk boundary correspondence.***

***(recall we already have channel capacity of surface = Area /hG***

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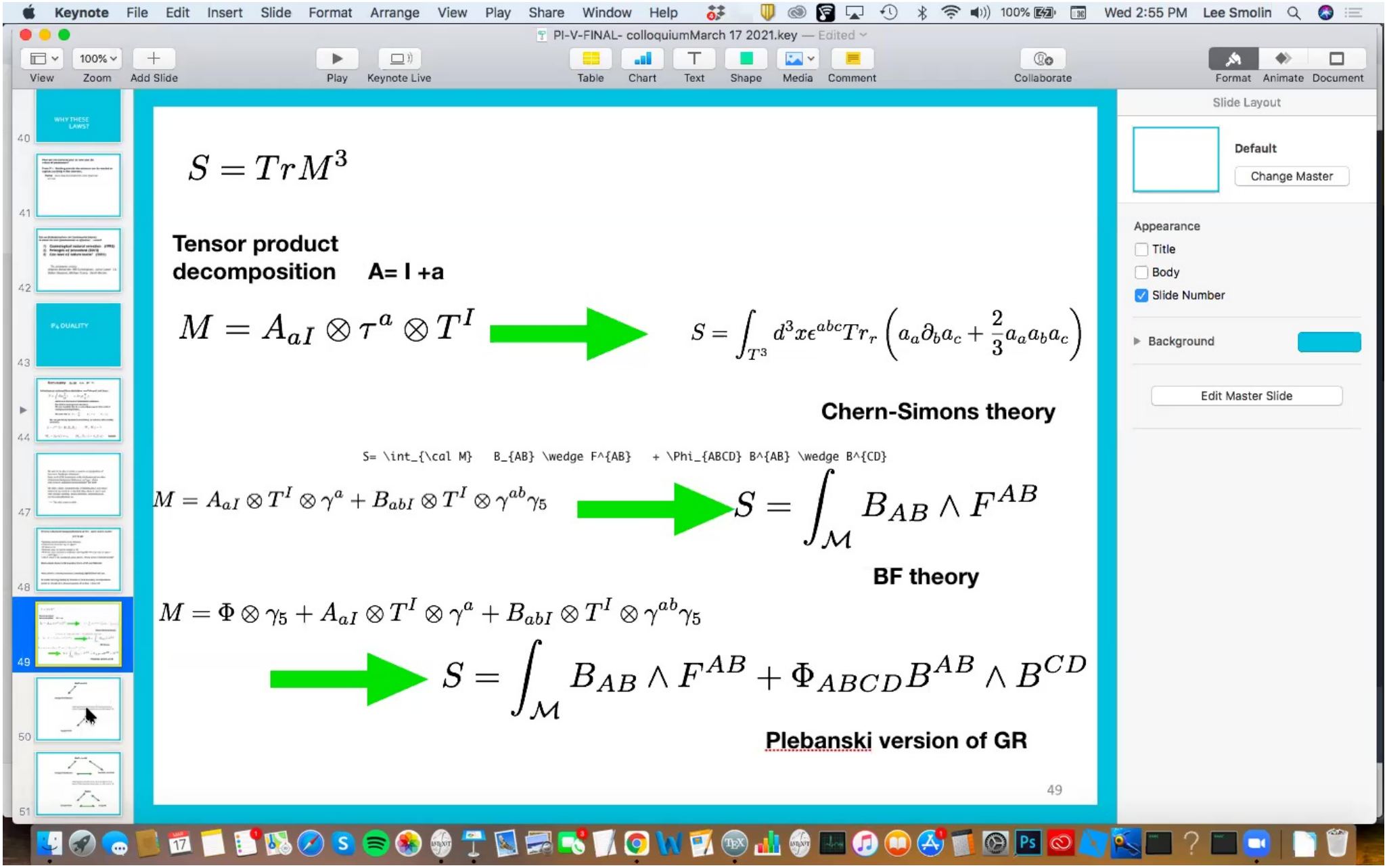
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$S = TrM^3$
Tensor product decomposition A= I +a
$M = A_{aI} \otimes \tau^a \otimes T^I$
$S = \int_{T^3} d^3x \epsilon^{abc} Tr_r \left( a_a \partial_b a_c + \frac{2}{3} a_a a_b a_c \right)$
Chern-Simons theory
S= \int_{\cal M} B_{AB} \wedge F^{AB} + \Phi_{ABCD} B^{AB} \wedge B^{CD}
$M = A_{aI} \otimes T^I \otimes \gamma^a + B_{abI} \otimes T^I \otimes \gamma^{ab} \gamma_5$
$S = \int_{\mathcal{M}} B_{AB} \wedge F^{AB}$
BF theory
$M = \Phi \otimes \gamma_5 + A_{aI} \otimes T^I \otimes \gamma^a + B_{abI} \otimes T^I \otimes \gamma^{ab} \gamma_5$
$S = \int_{\mathcal{M}} B_{AB} \wedge F^{AB} + \Phi_{ABCD} B^{AB} \wedge B^{CD}$
Plebanski version of GR
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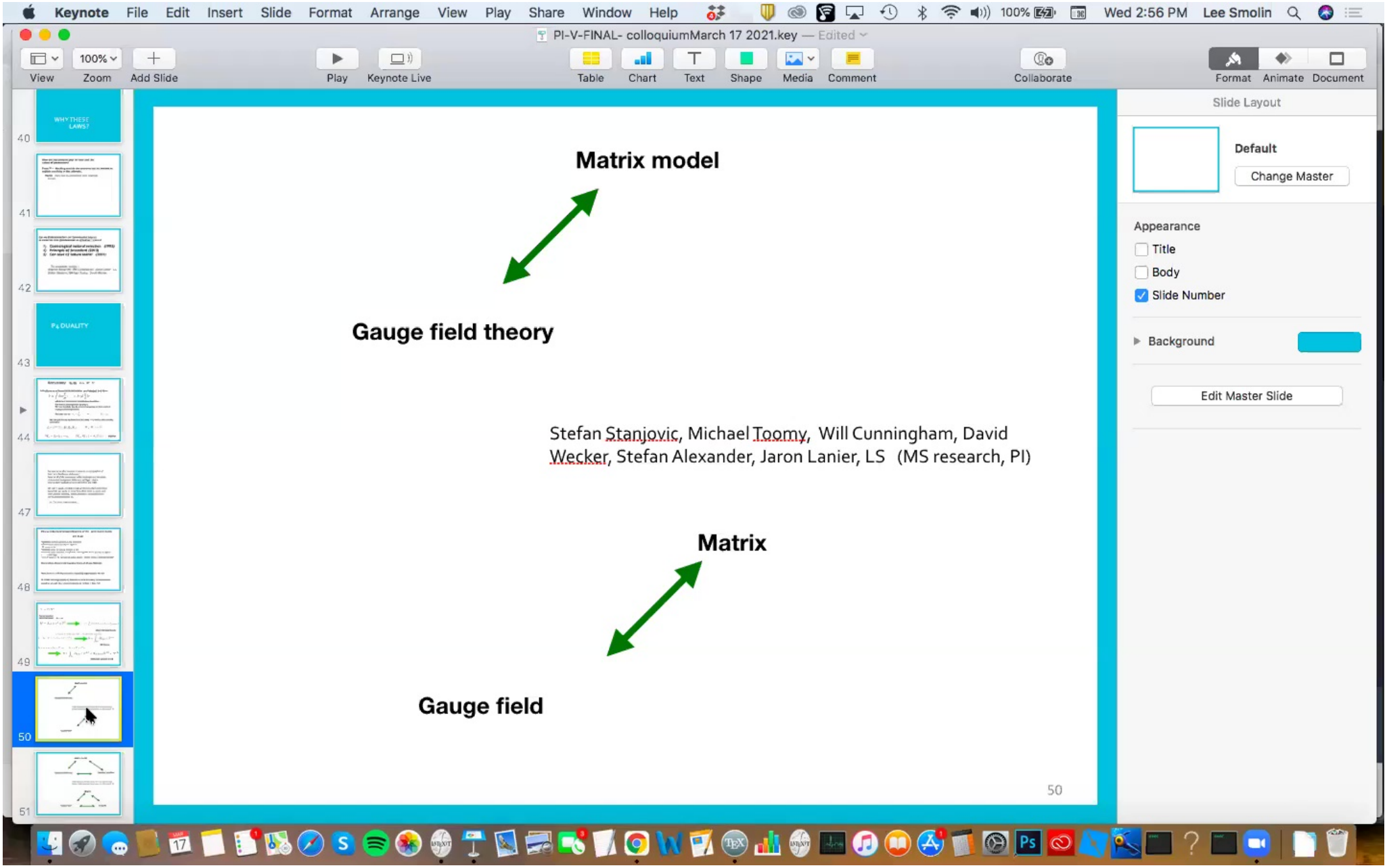
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Matrix model
Gauge field theory
Stefan Stanjovic, Michael Toomy, Will Cunningham, David Wecker, Stefan Alexander, Jaron Lanier, LS (MS research, PI)
Matrix
Gauge field
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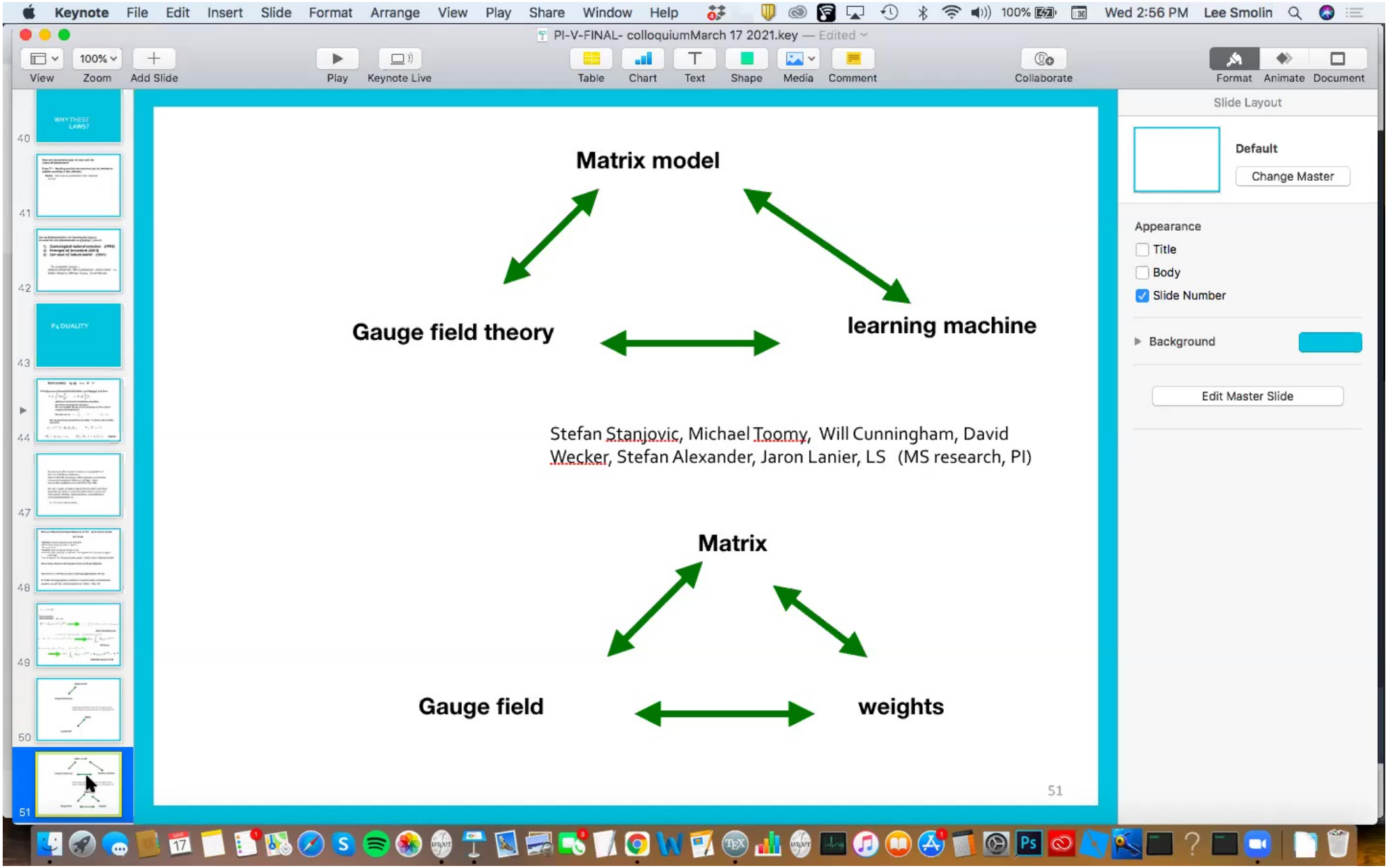
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Matrix model
Gauge field theory
learning machine
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Matrix
Gauge field
weights
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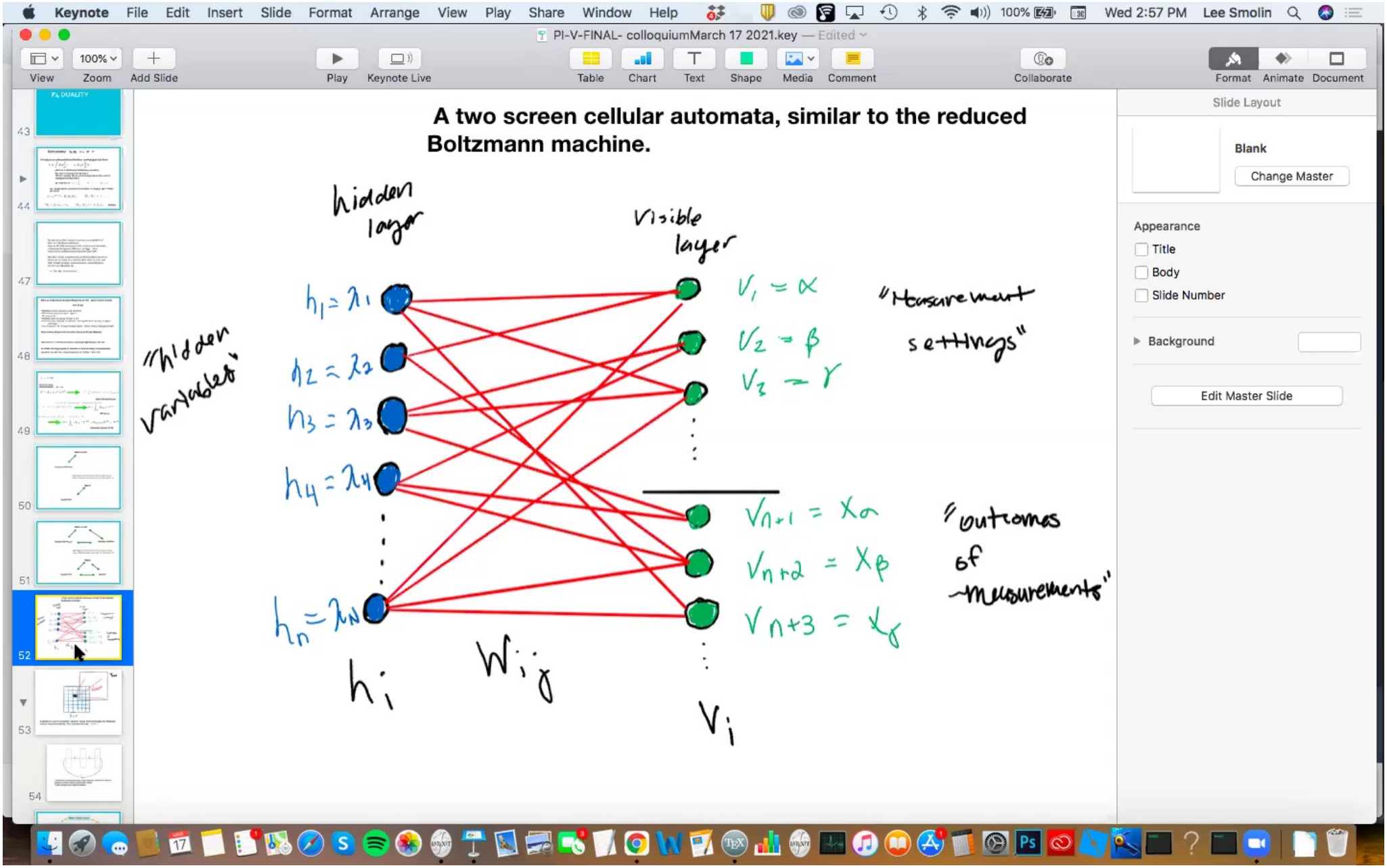
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A two screen cellular automata, similar to the reduced Boltzmann machine.
hidden layer
visible layer
"hidden variables"
"measurement settings"
"outcomes of measurements"
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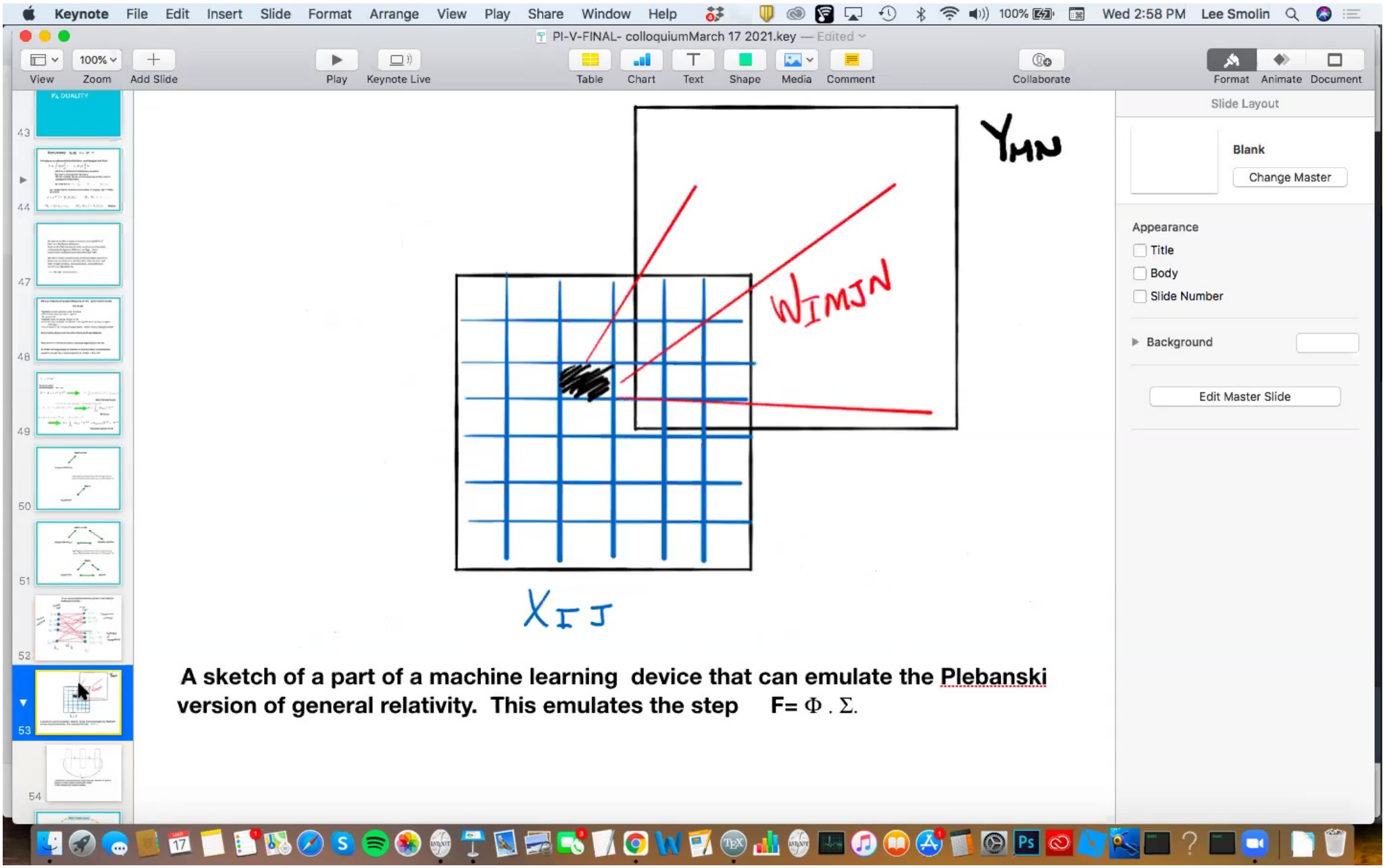
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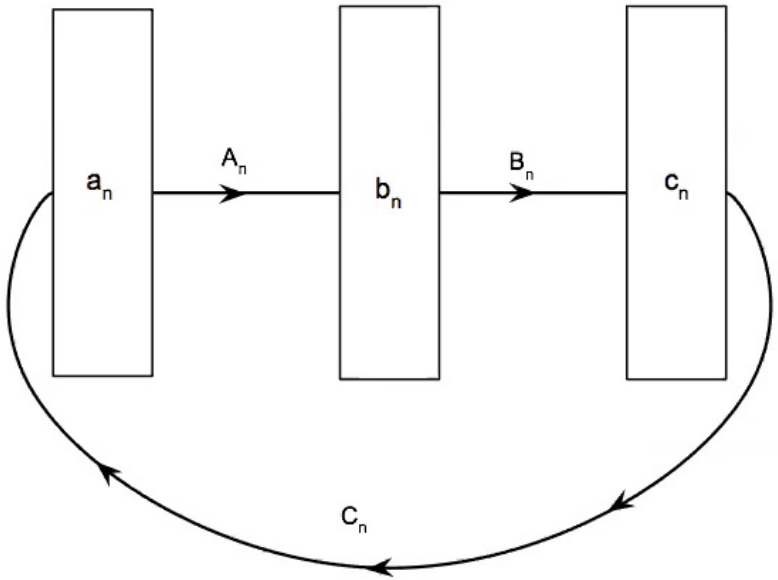
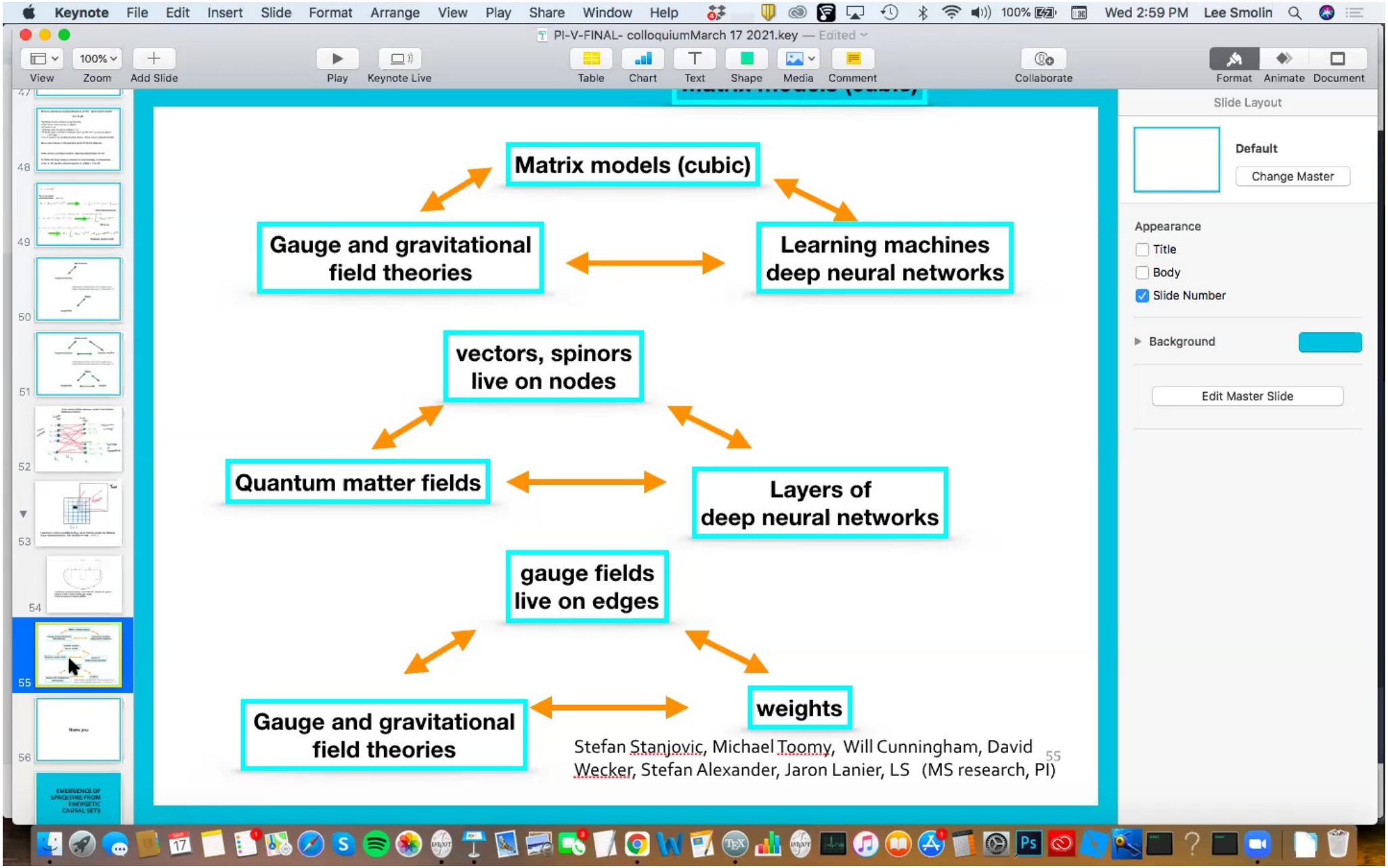
$Y_{MN}$
$W_{IMJN}$
$X_{IJ}$
A sketch of a part of a machine learning device that can emulate the Plebanski version of general relativity. This emulates the step F= Φ . Σ.




**A sketch of a machine learning device that can emulate the general solution of Chern-Simon's theory with matter;**
**it has 3 screens and 3 sets of weights.**


Matrix models (cubic)
Gauge and gravitational field theories
Learning machines deep neural networks
vectors, spinors live on nodes
Quantum matter fields
Layers of deep neural networks
gauge fields live on edges
Gauge and gravitational field theories
weights
Stefan Stanjovic, Michael Toomy, Will Cunningham, David Wecker, Stefan Alexander, Jaron Lanier, LS (MS research, PI)
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