

Title: Research Skills - Lecture 3D

Date: Aug 20, 2010 03:00 PM

URL: <http://pirsa.org/10080032>

Abstract:

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## Timetable

The timetable for these talks is now [available here](#). Please note, Friday is going to be a busy day, so the above timetable will be strictly enforced.



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# ***The Ruler-Fall***

**Babak Fotouhi**

**Perimeter Institute for Theoretical Physics**

**Aug. 2010**

# ***The Ruler-Fall***

**Babak Fotouhi**

**Perimeter Institute for Theoretical Physics**

**Aug. 2010**

# Observation...



# Observation...

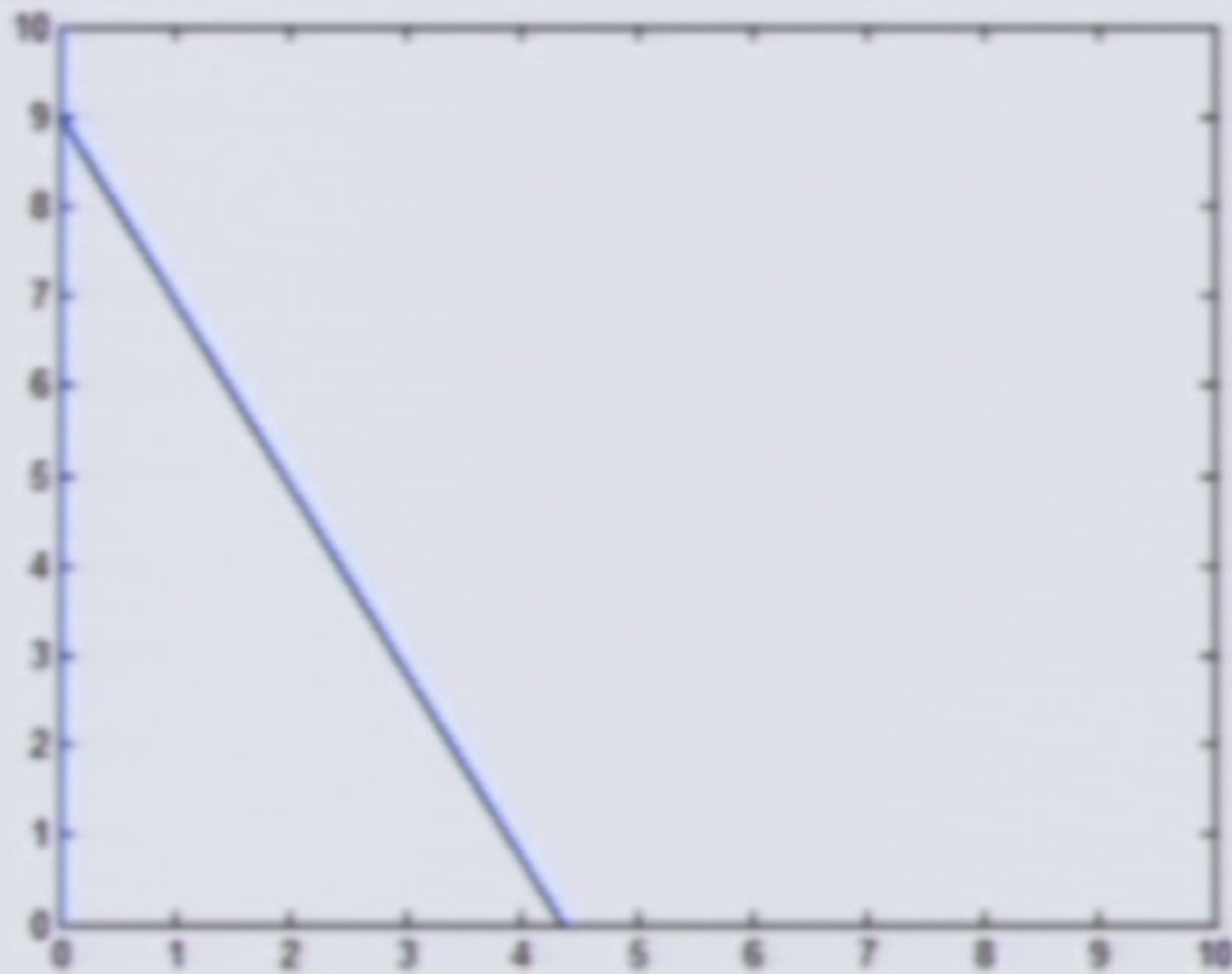




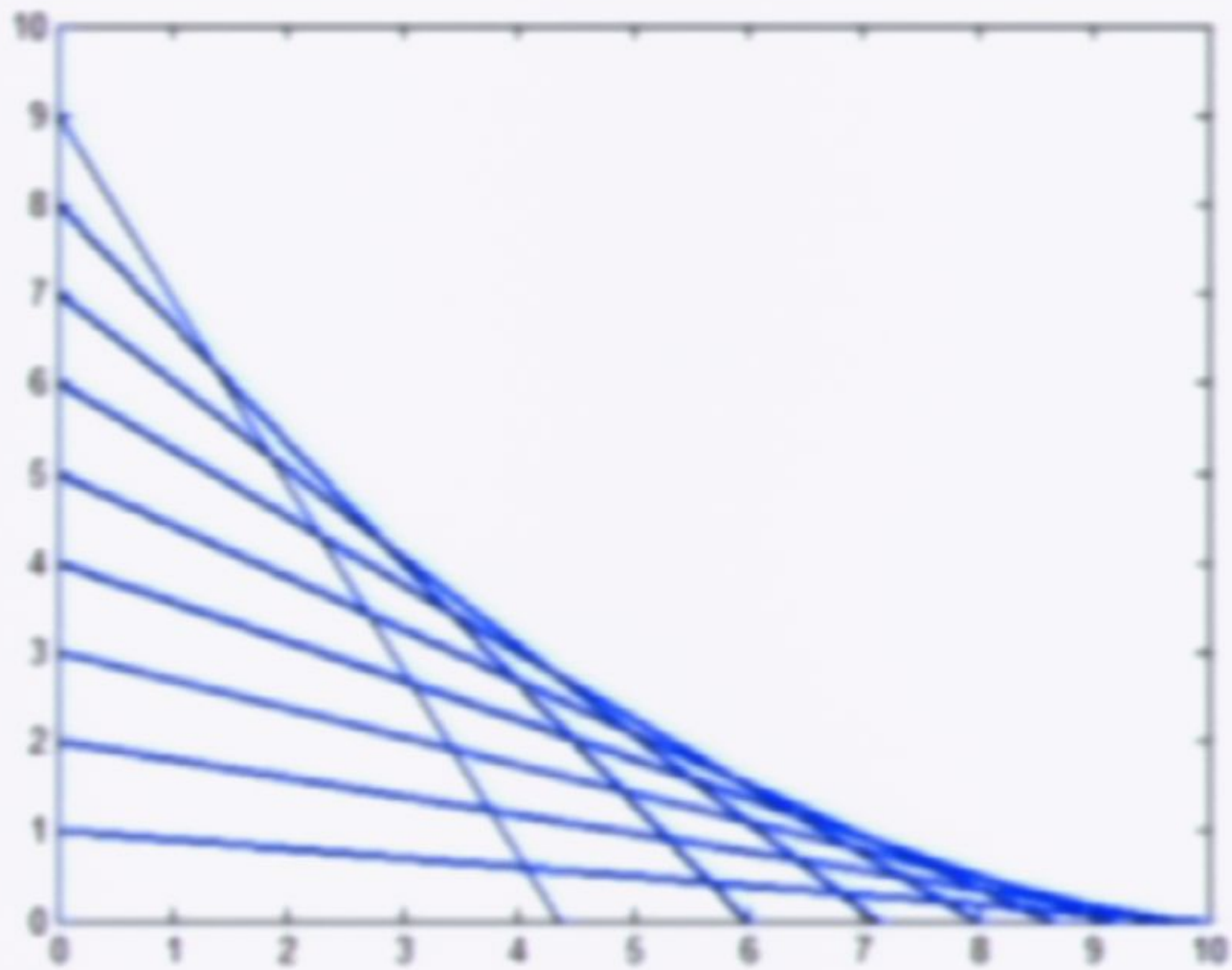




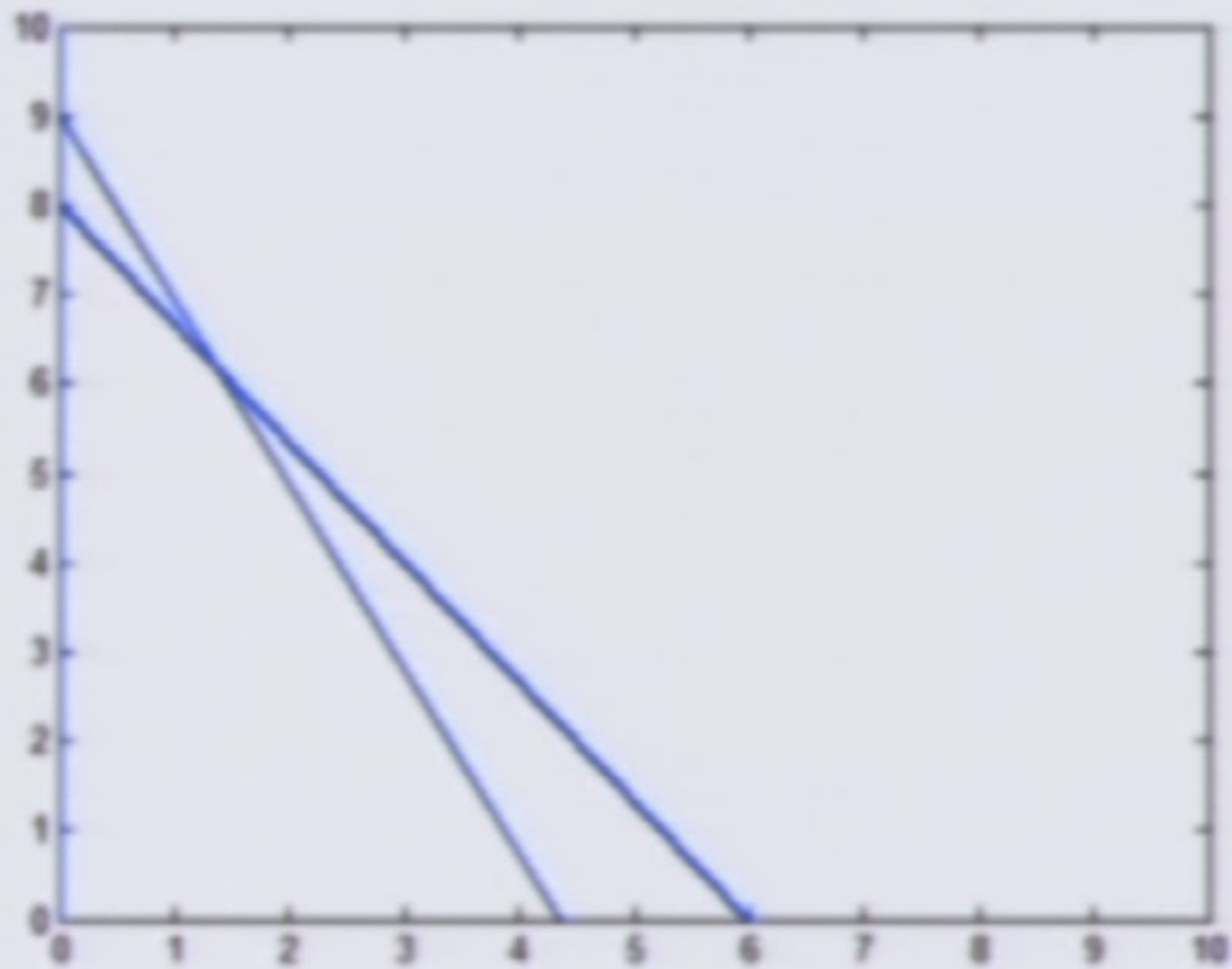


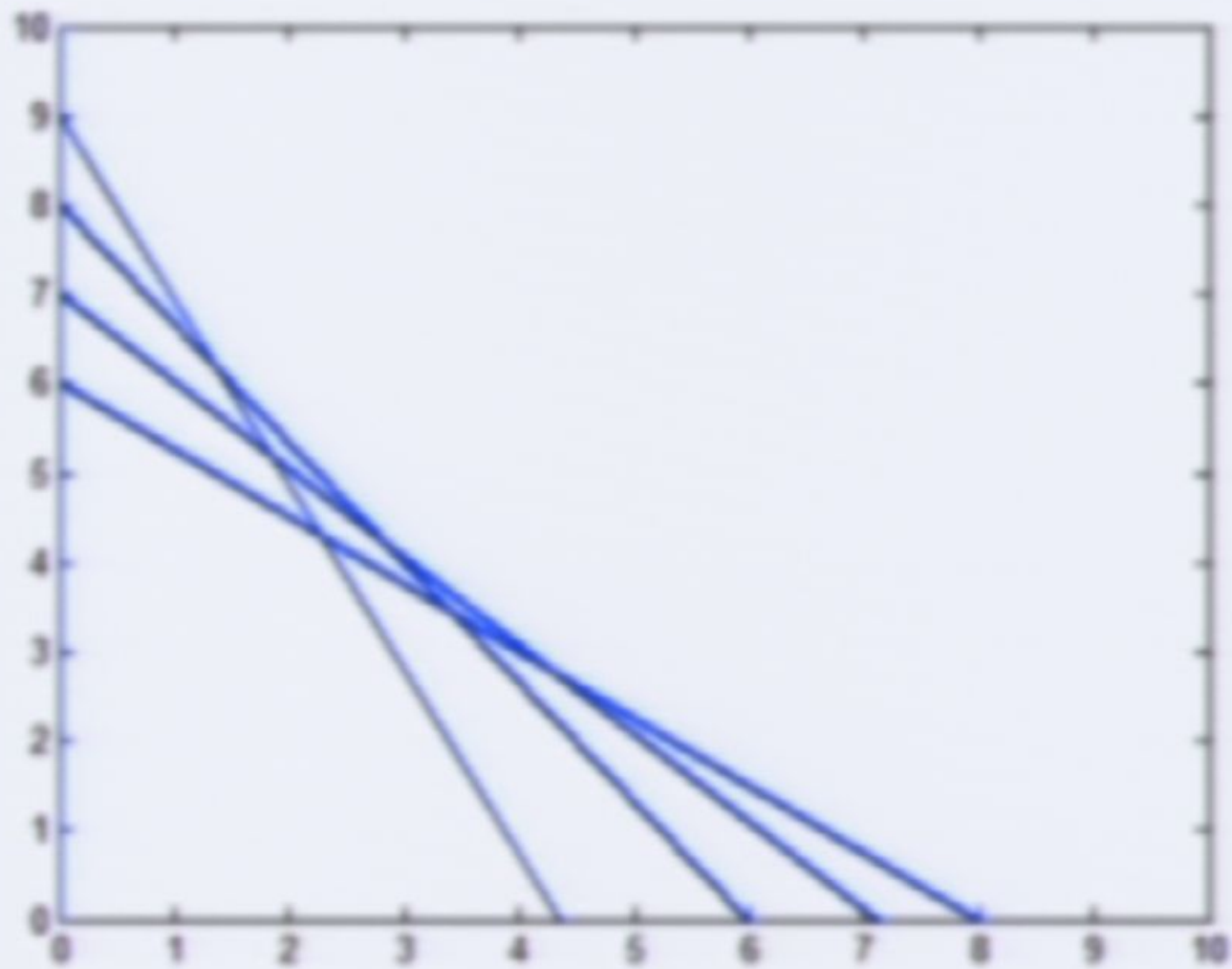


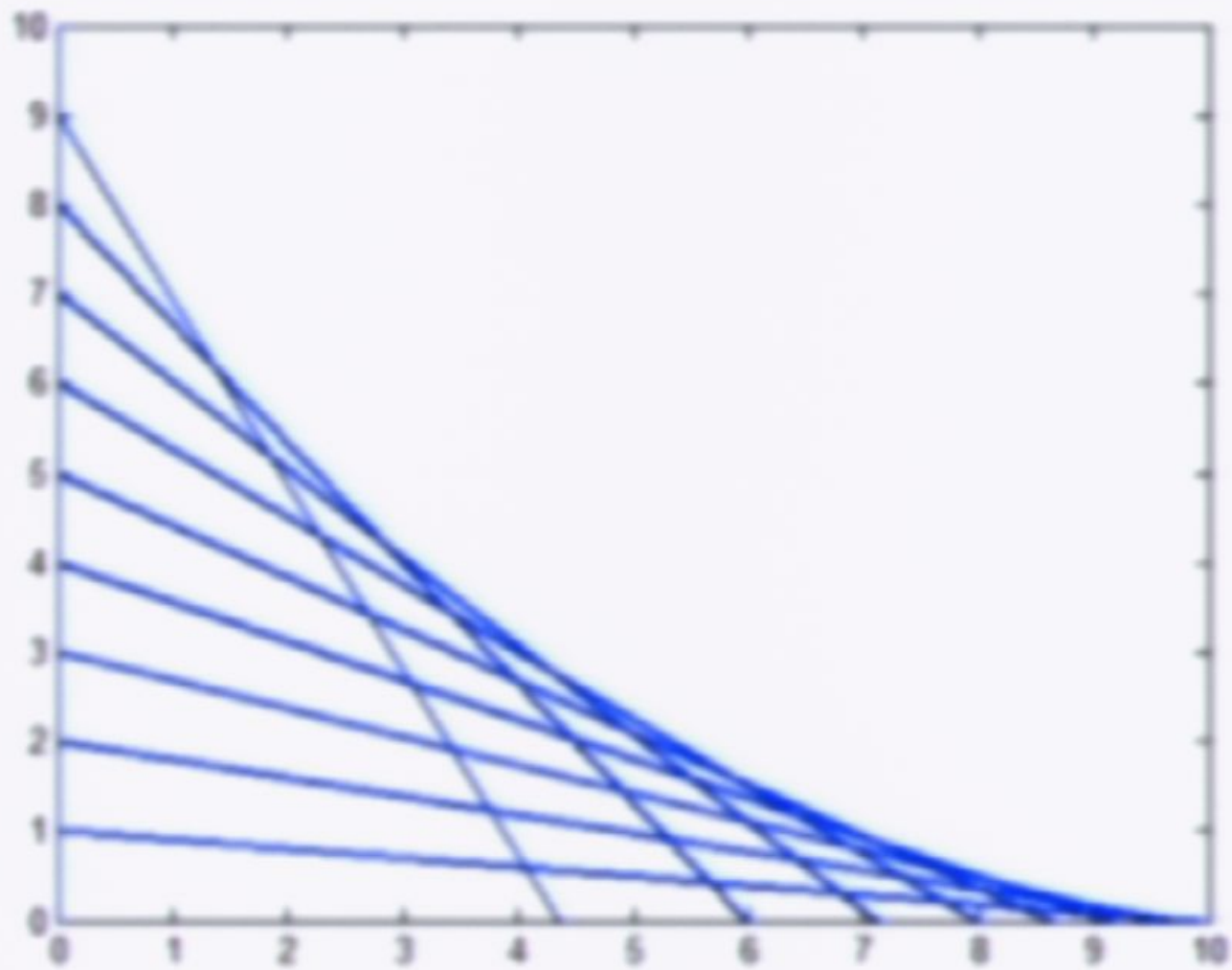


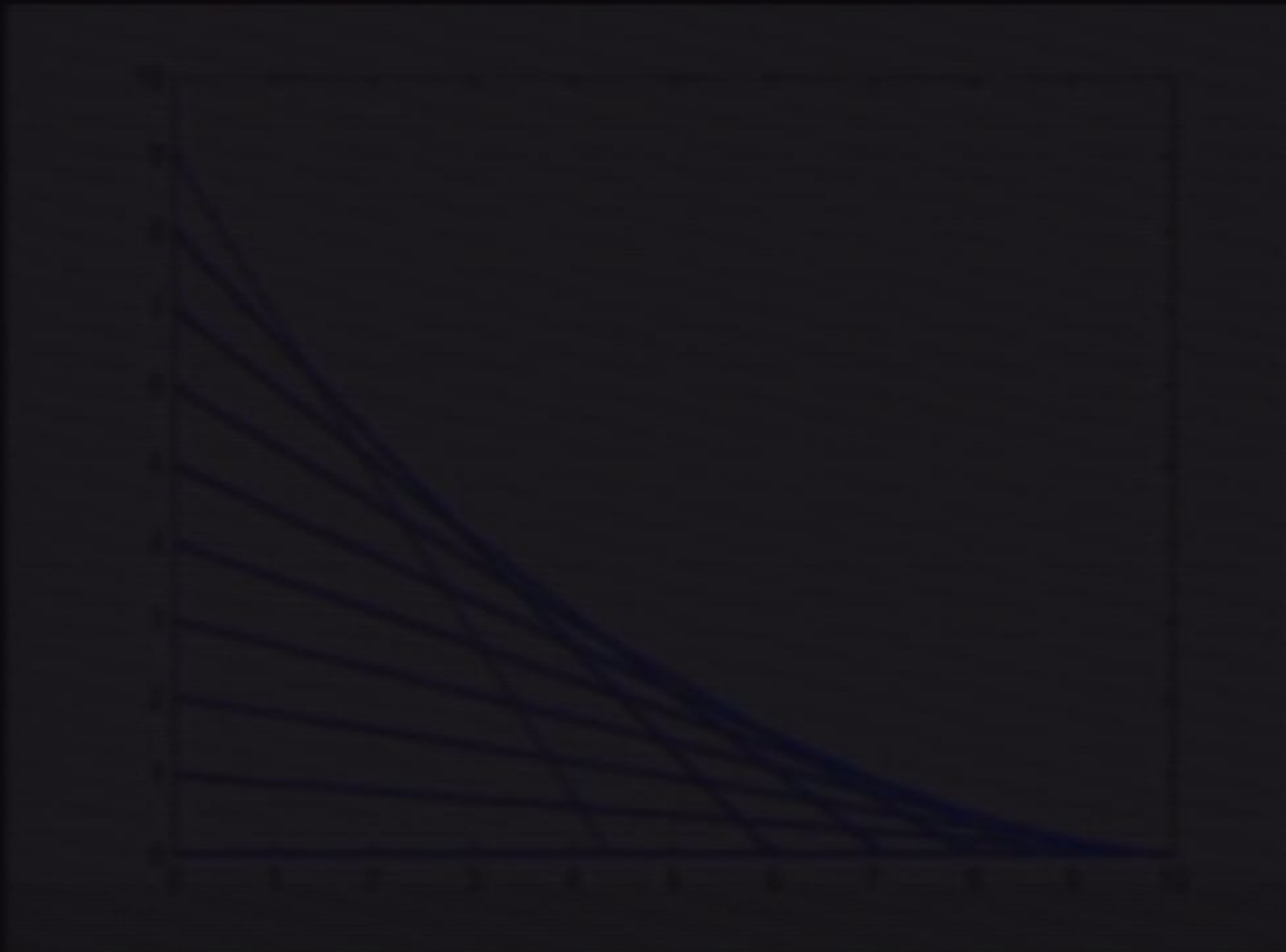






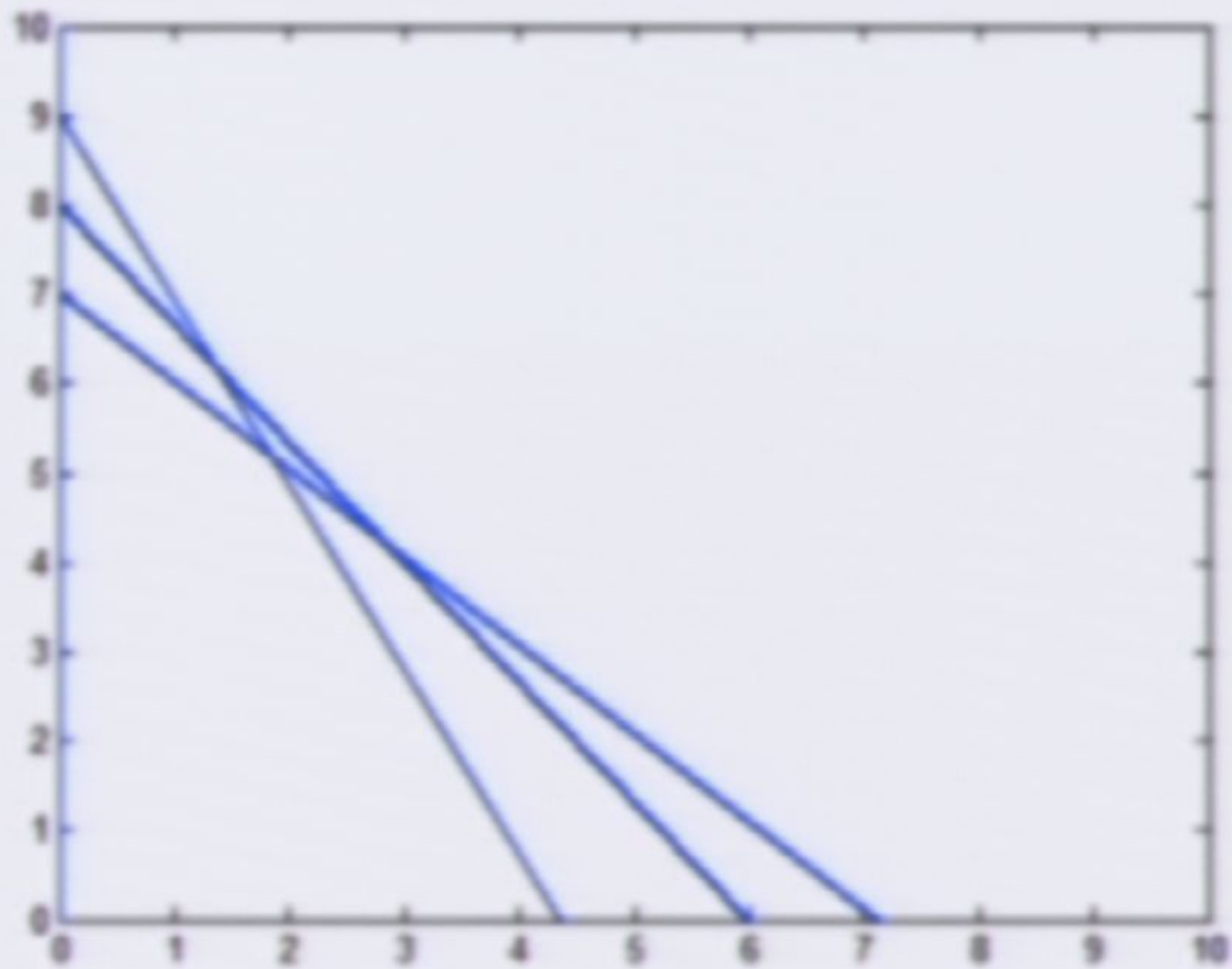


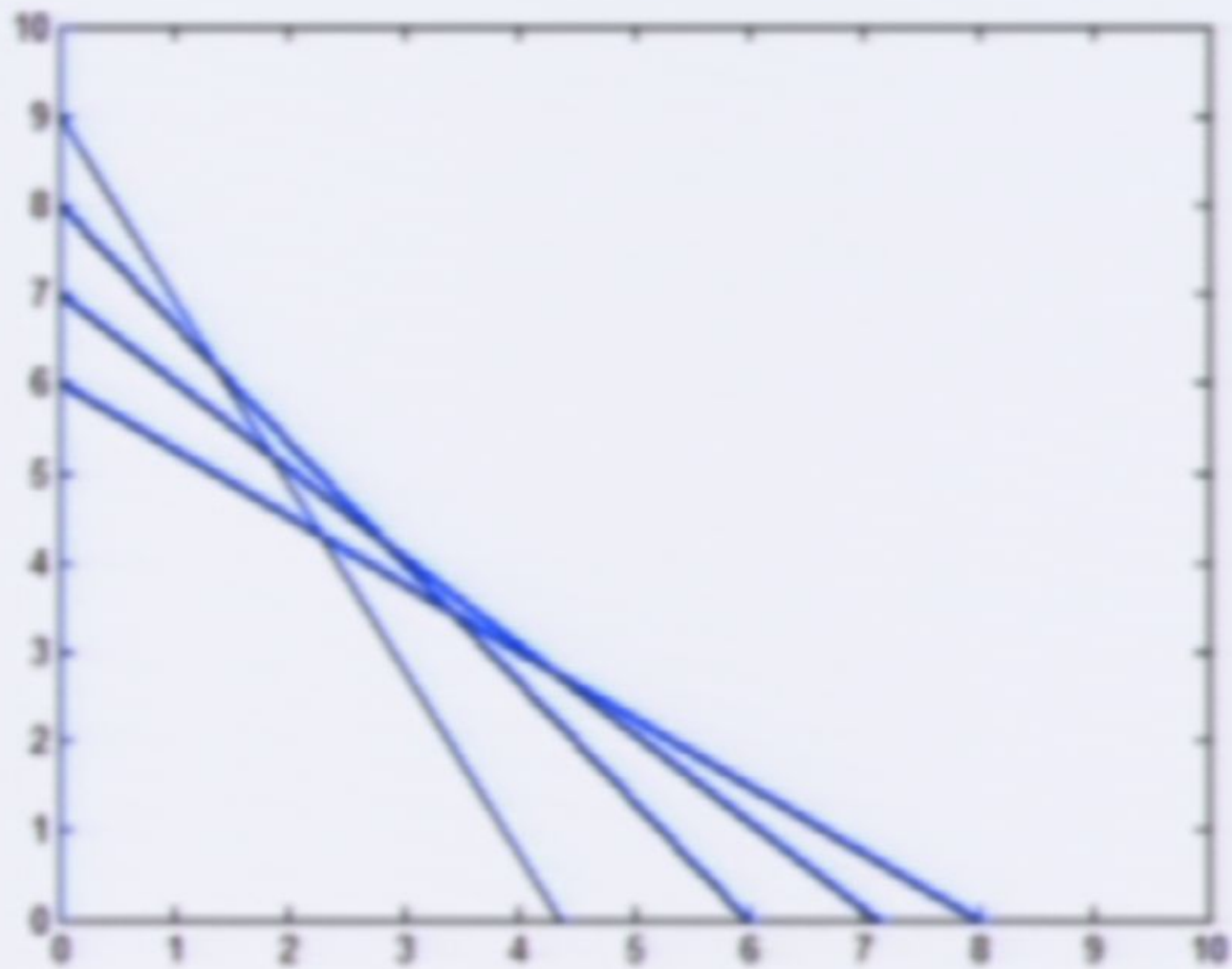


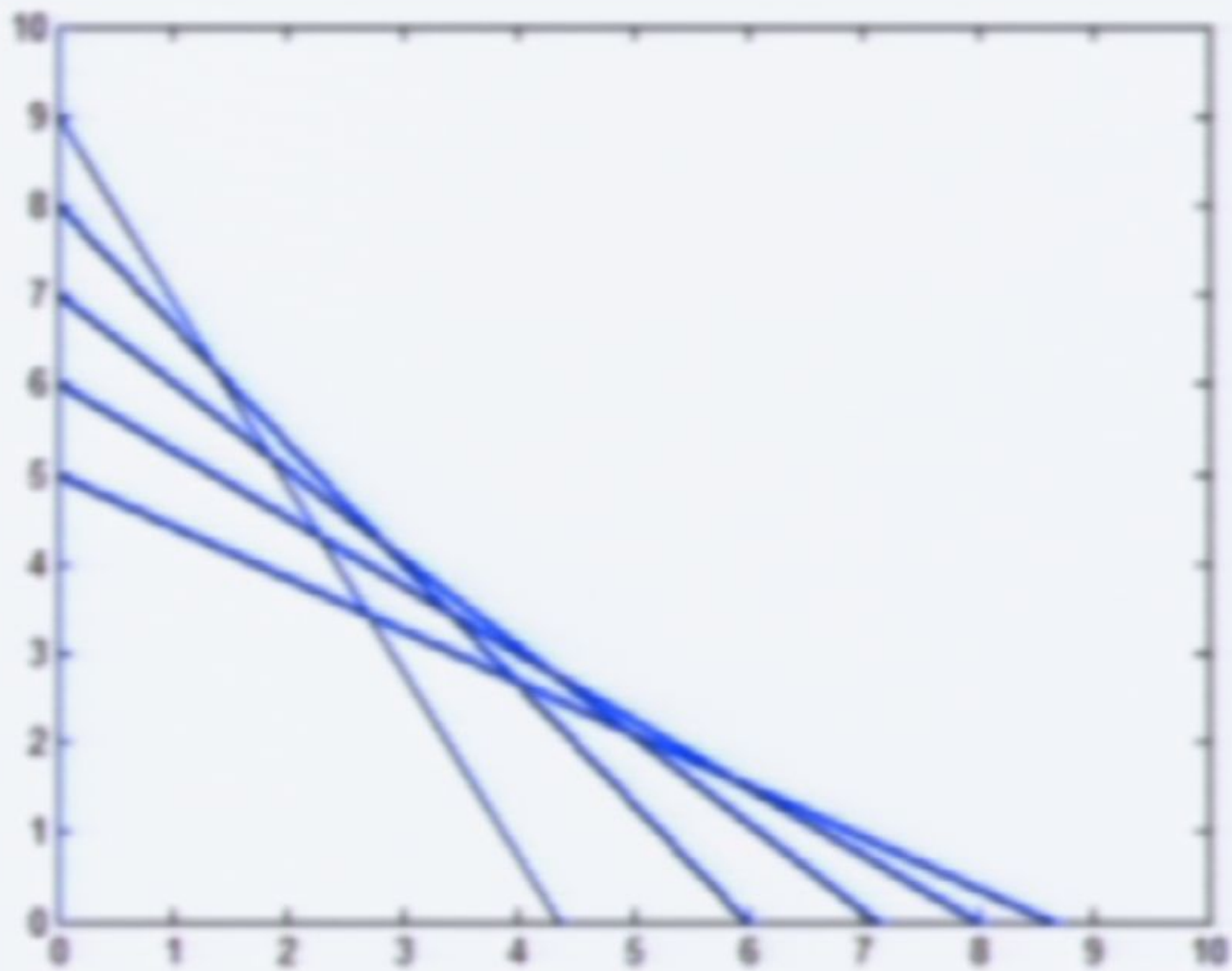


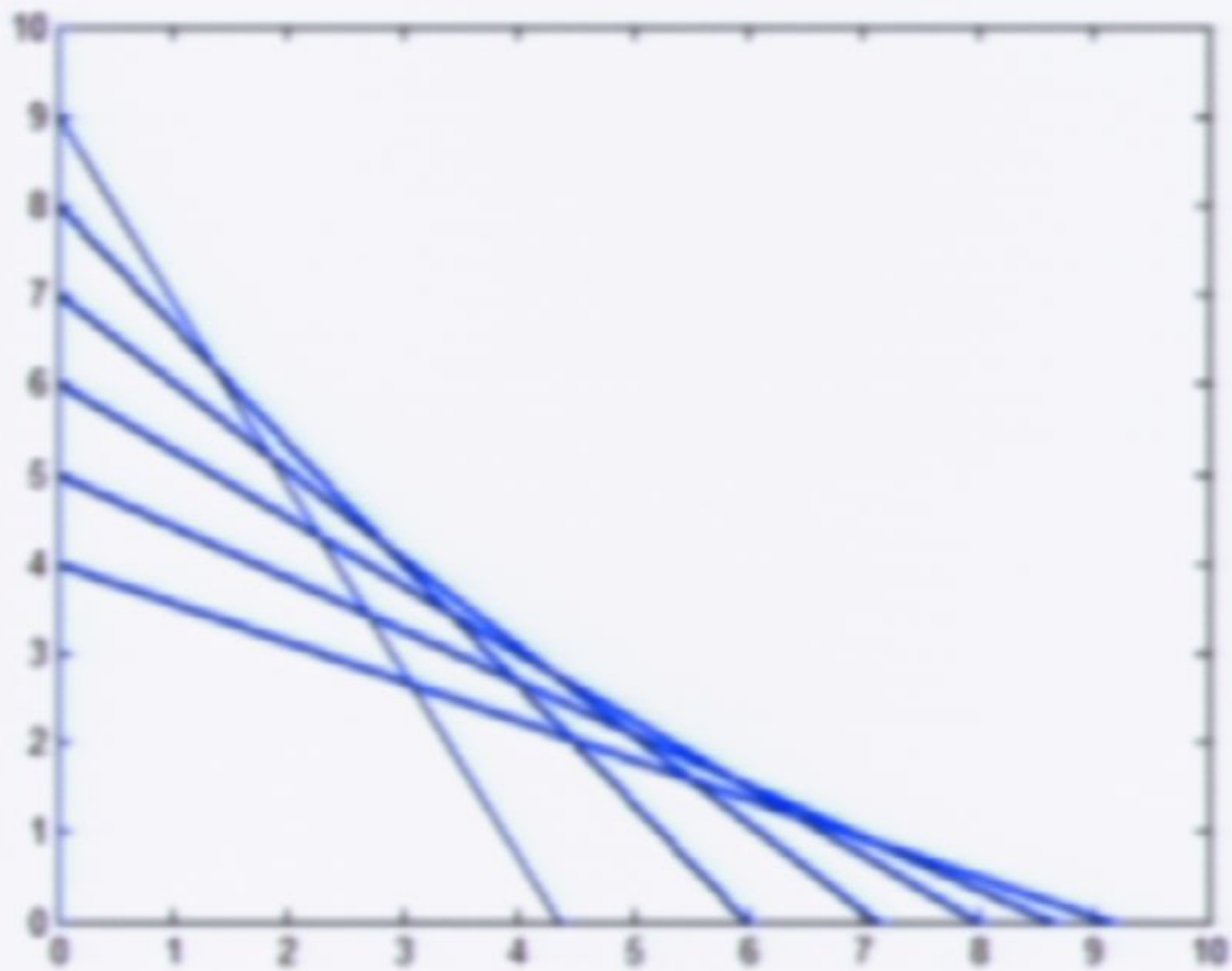


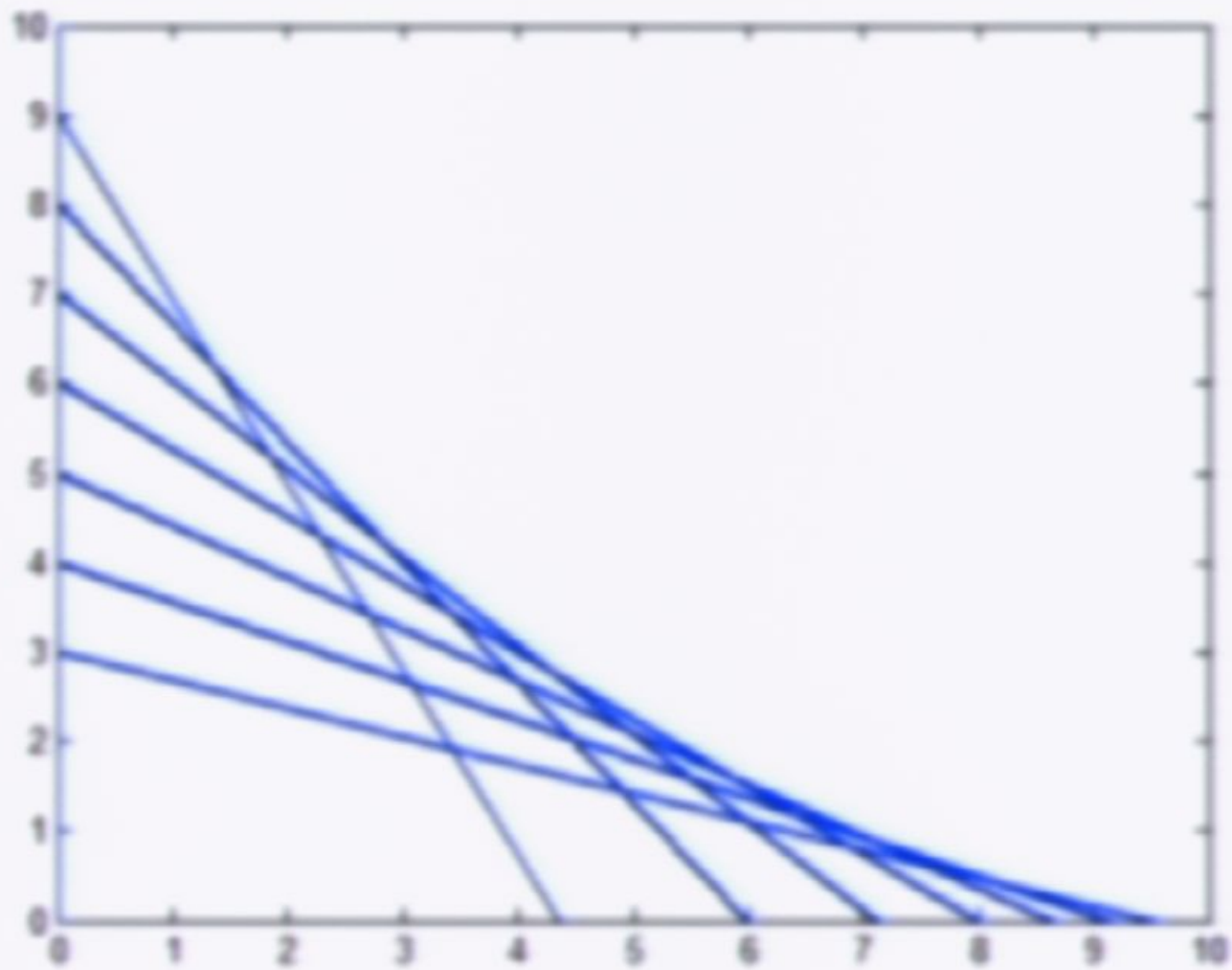


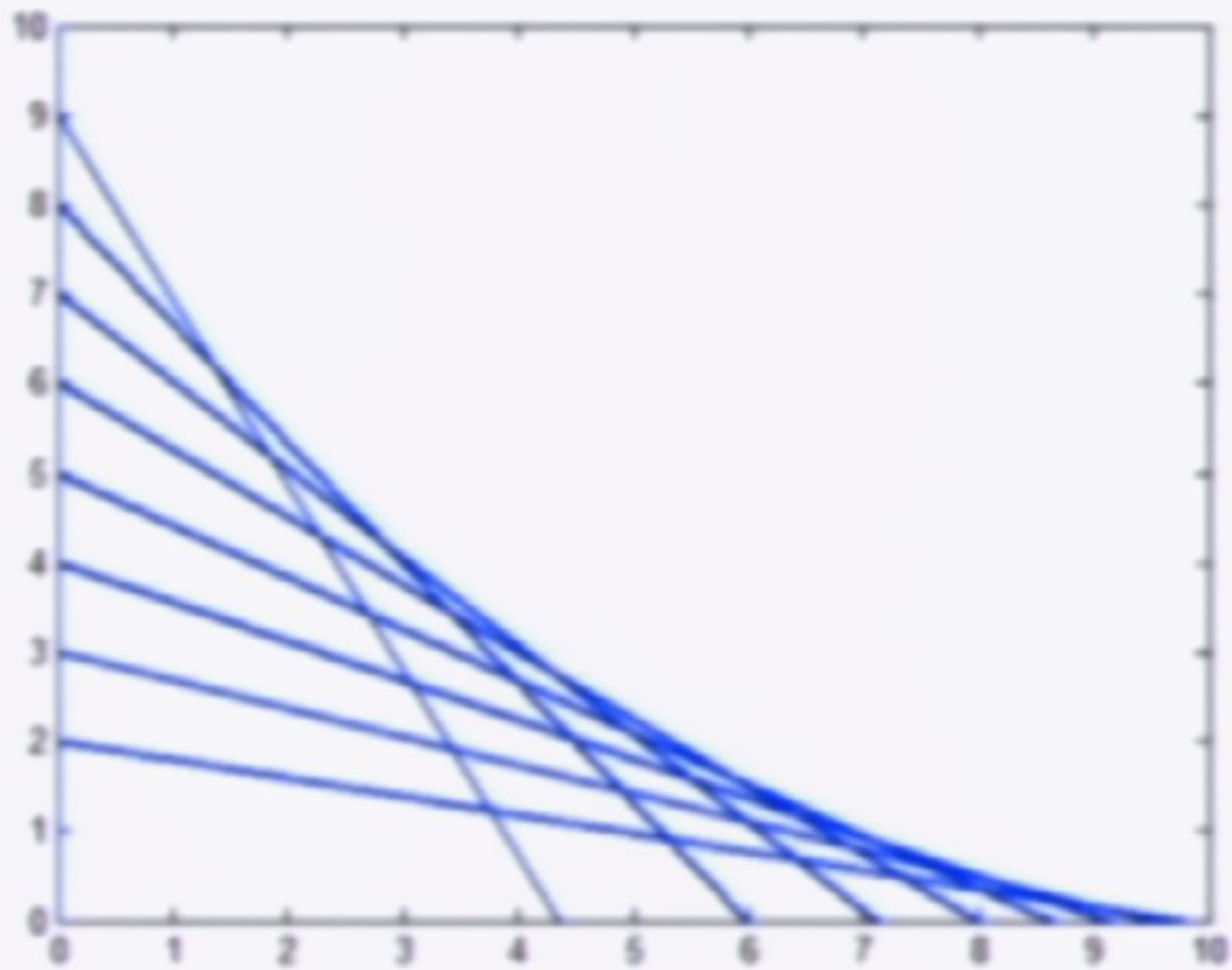


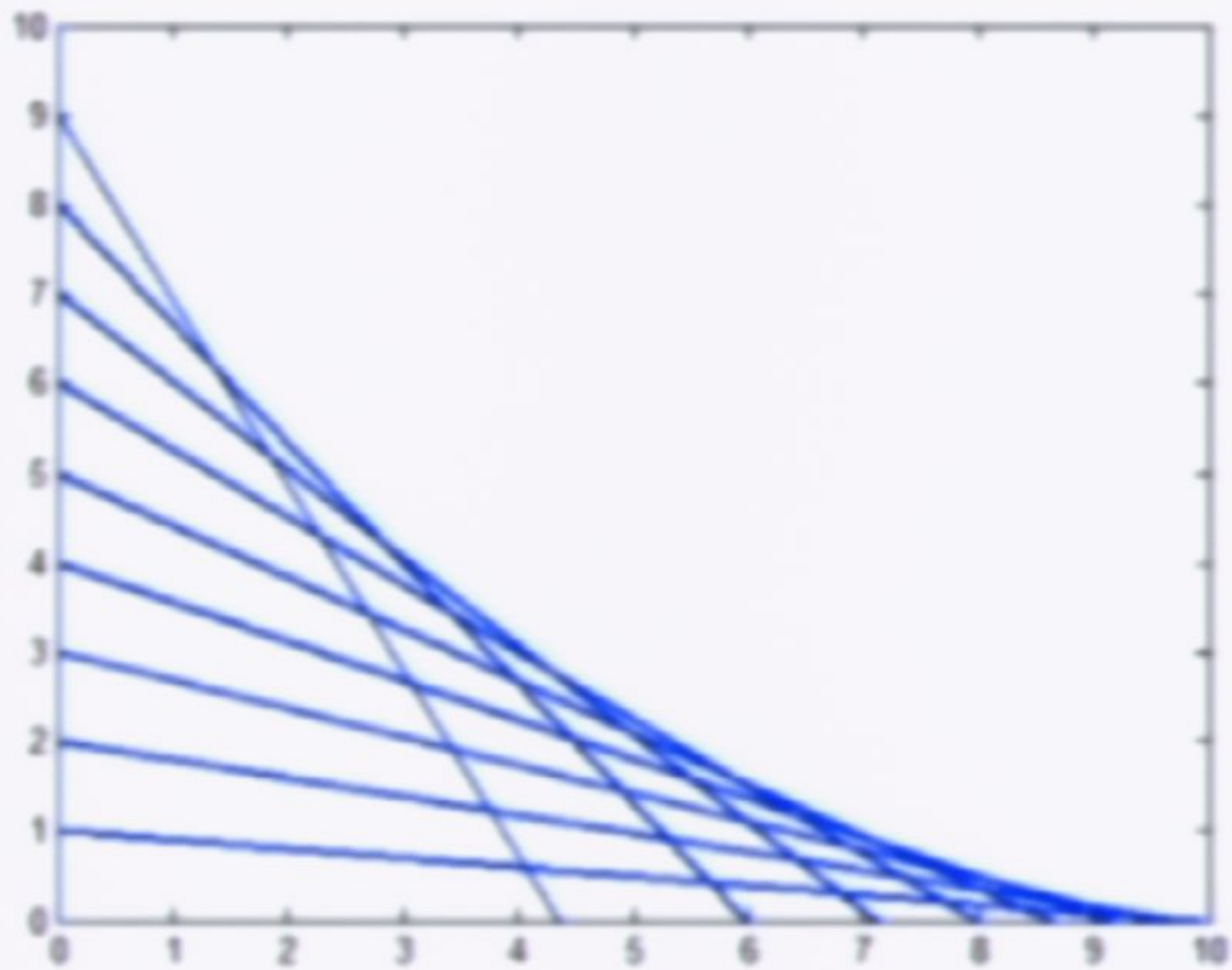




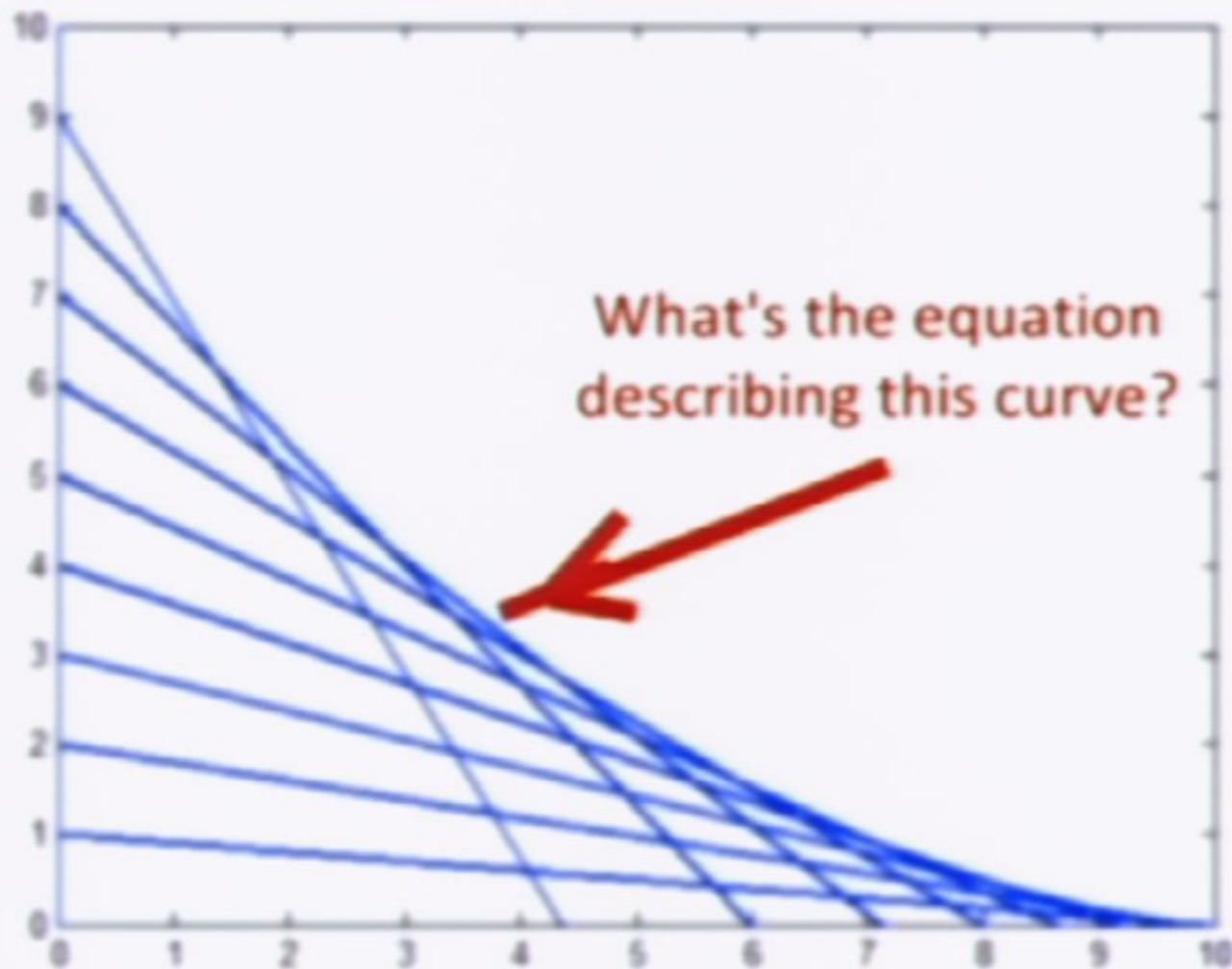










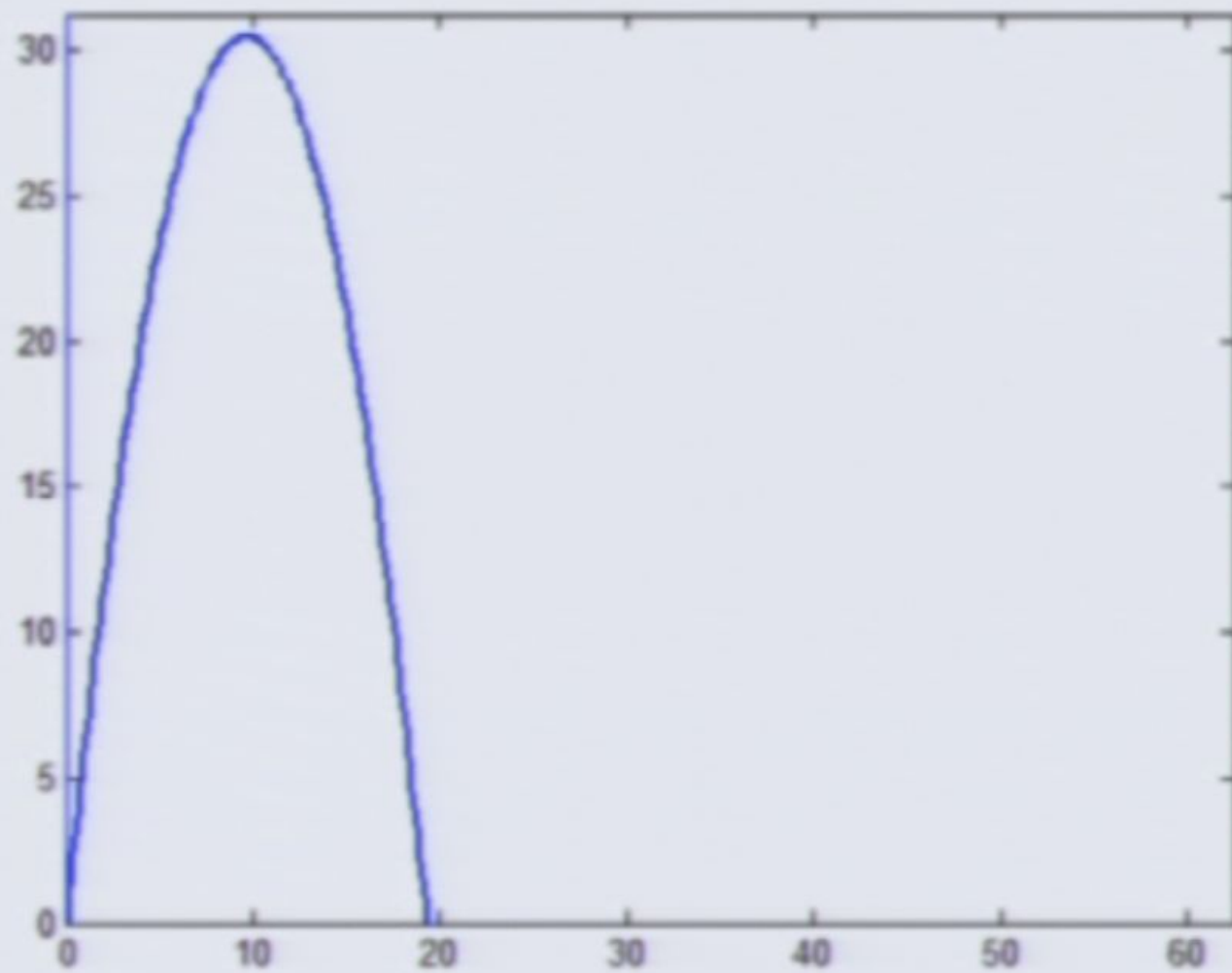


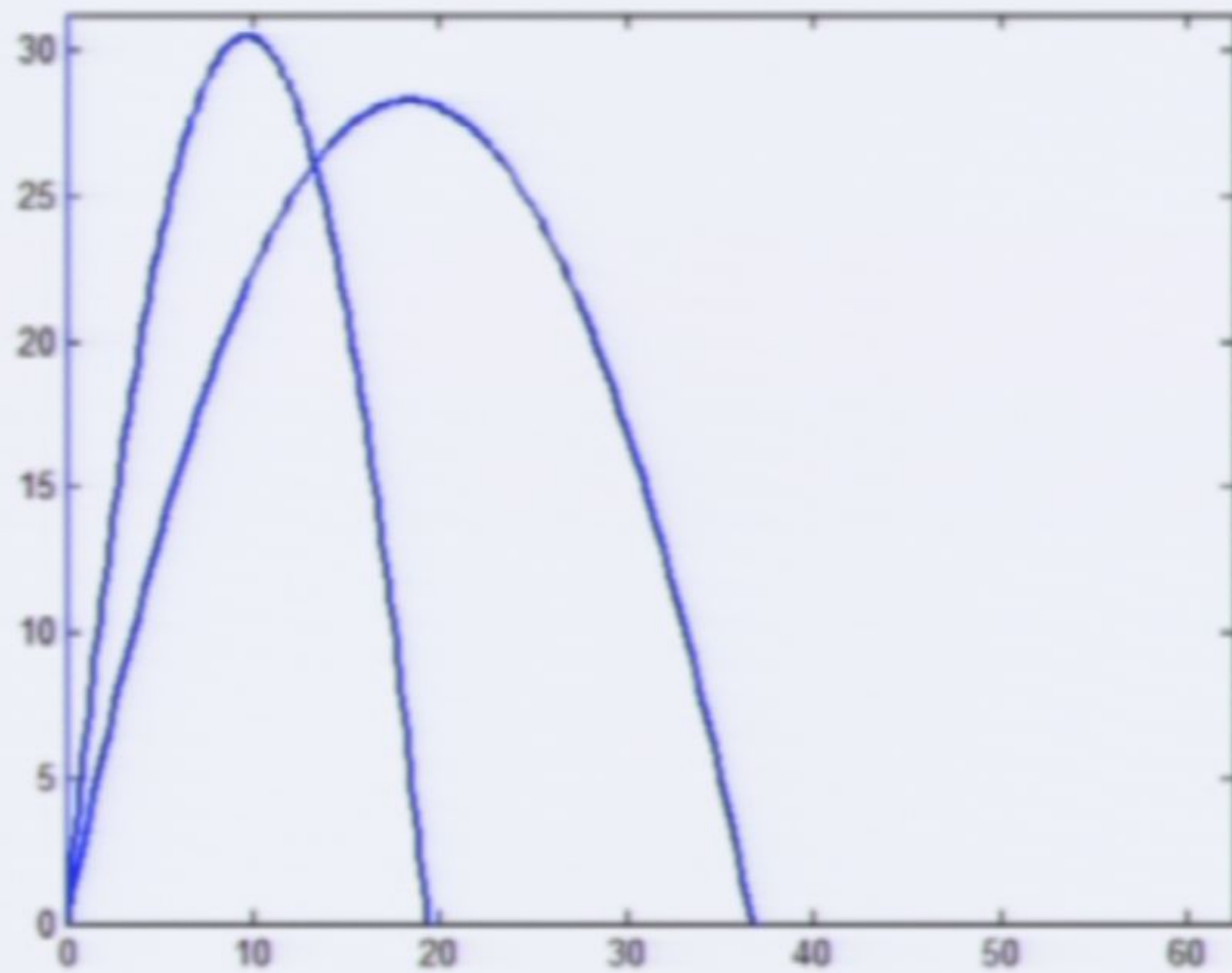


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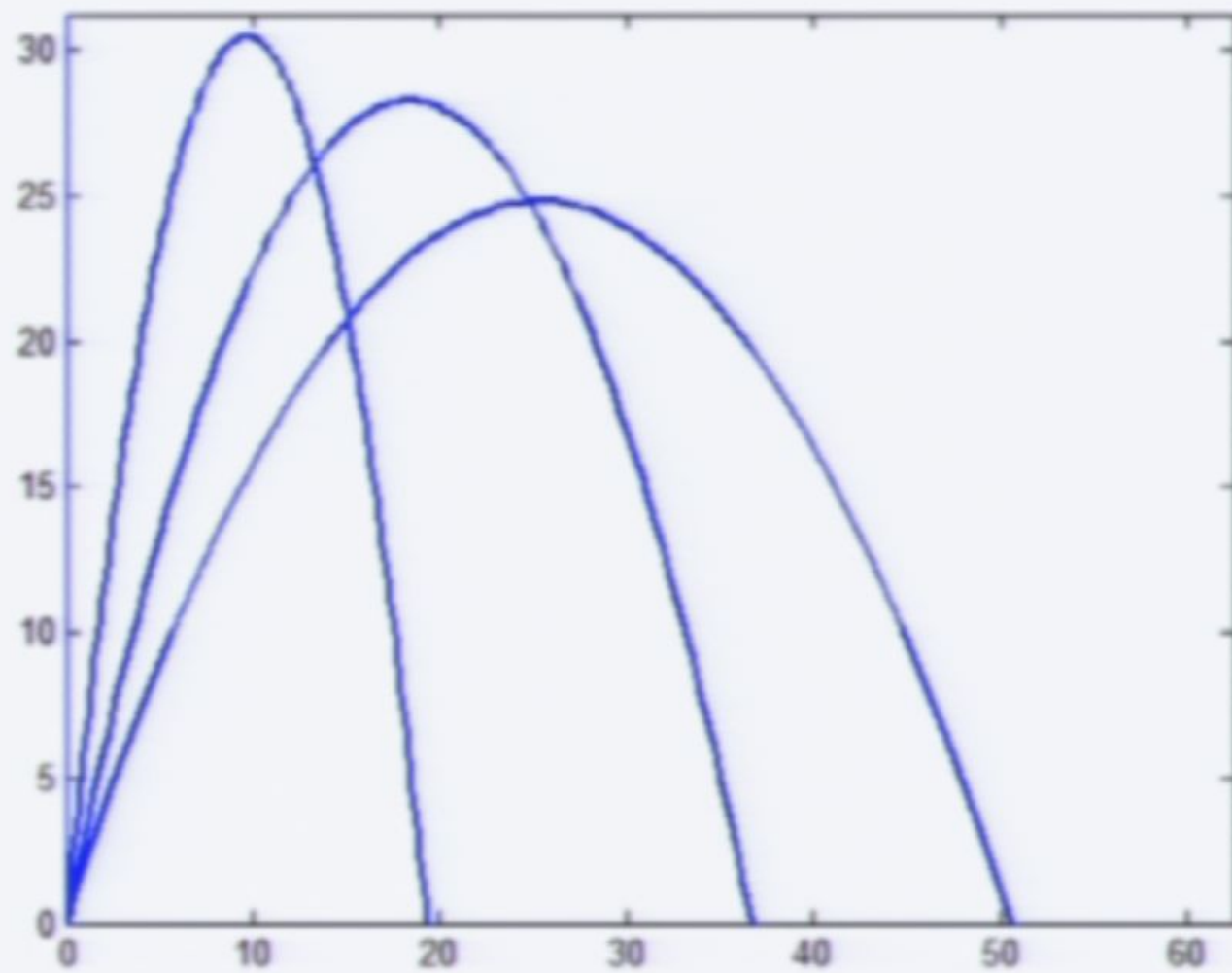
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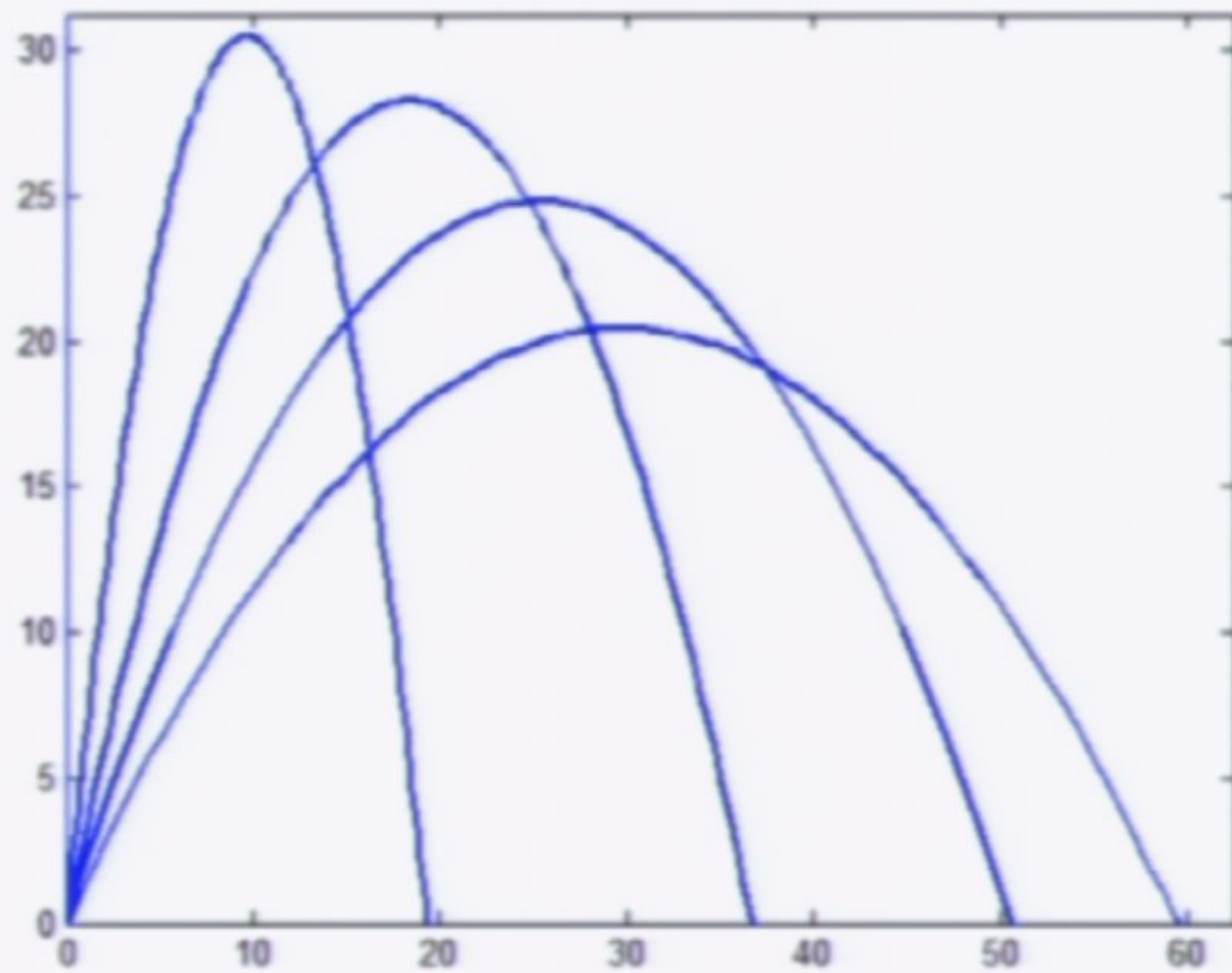
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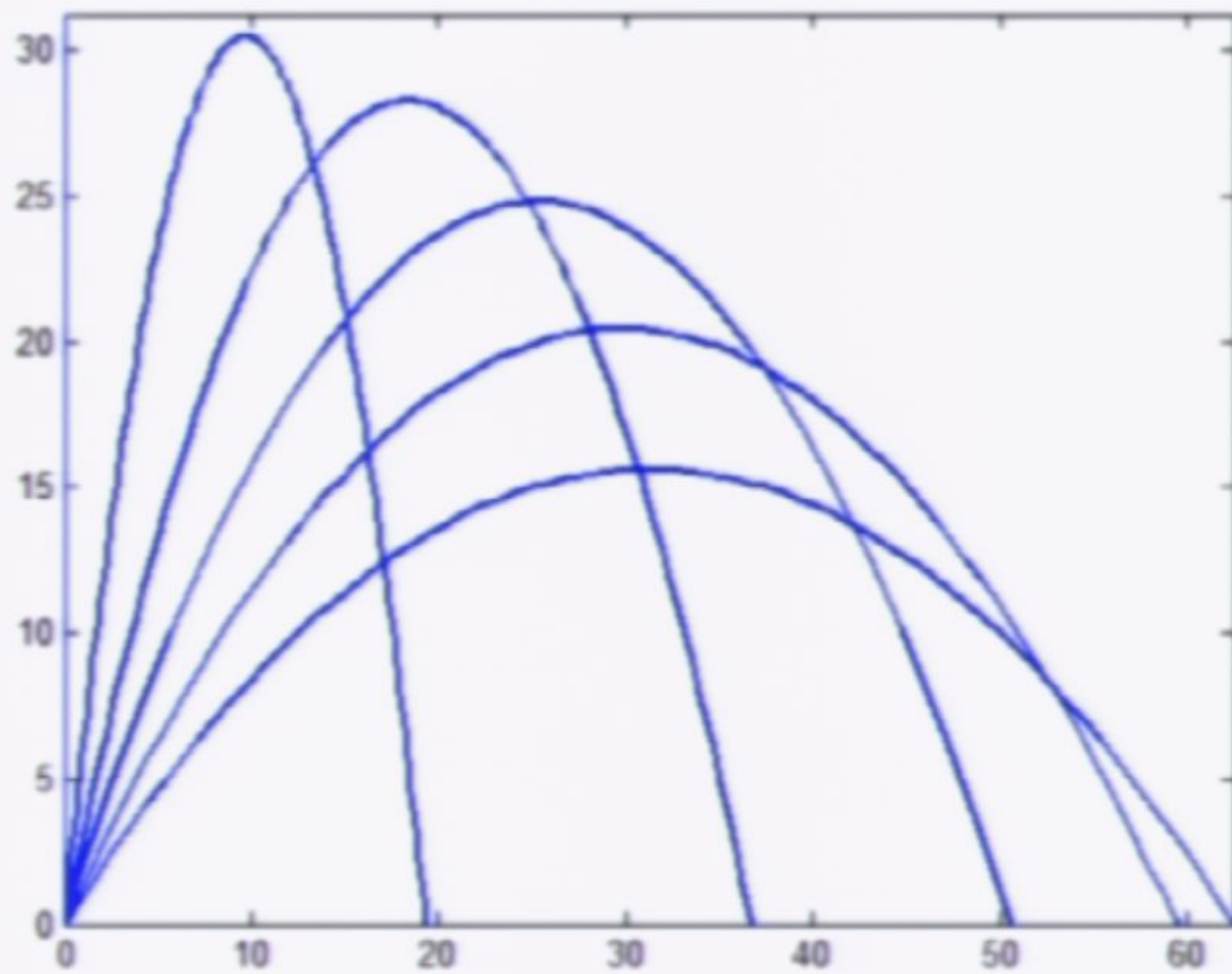


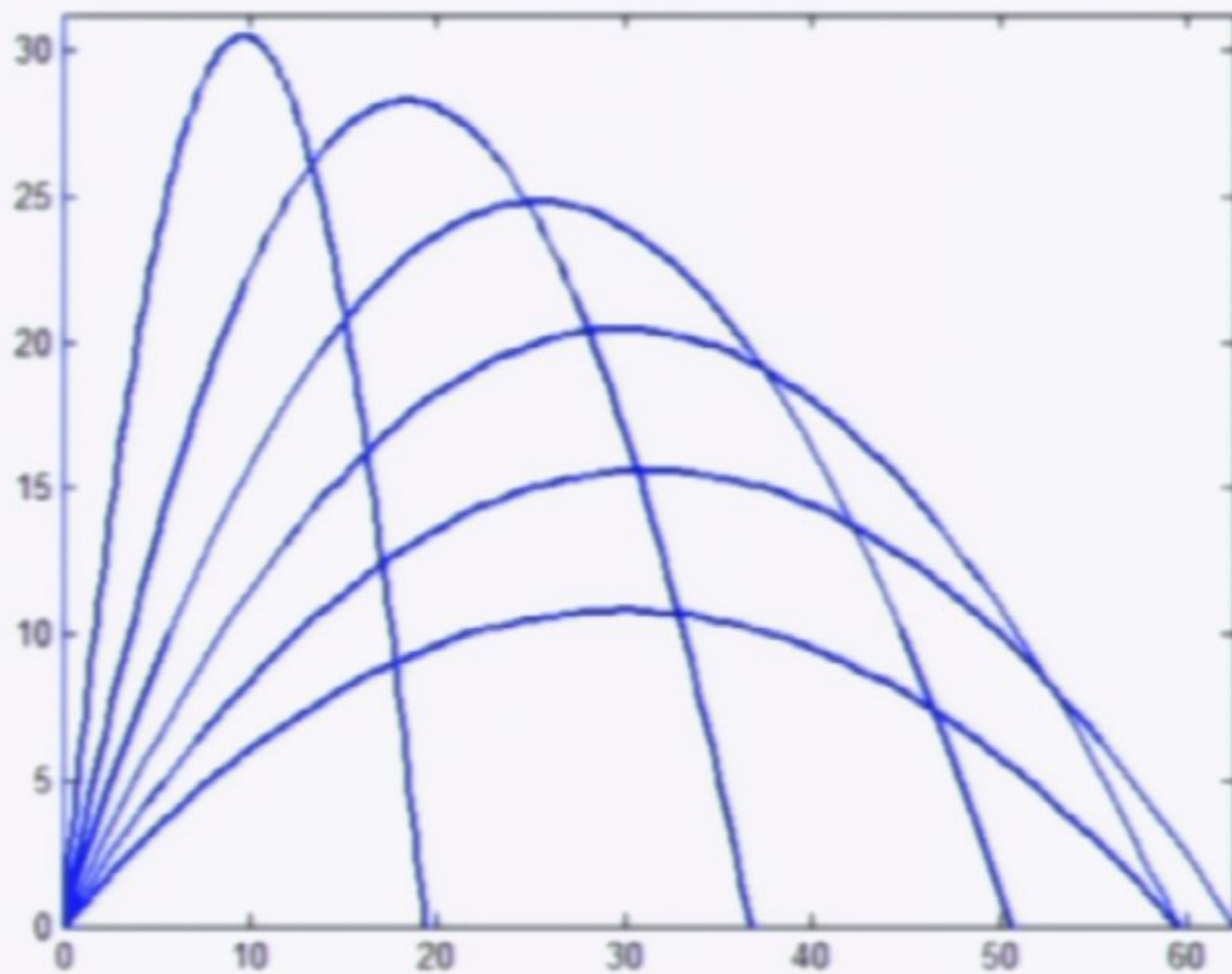


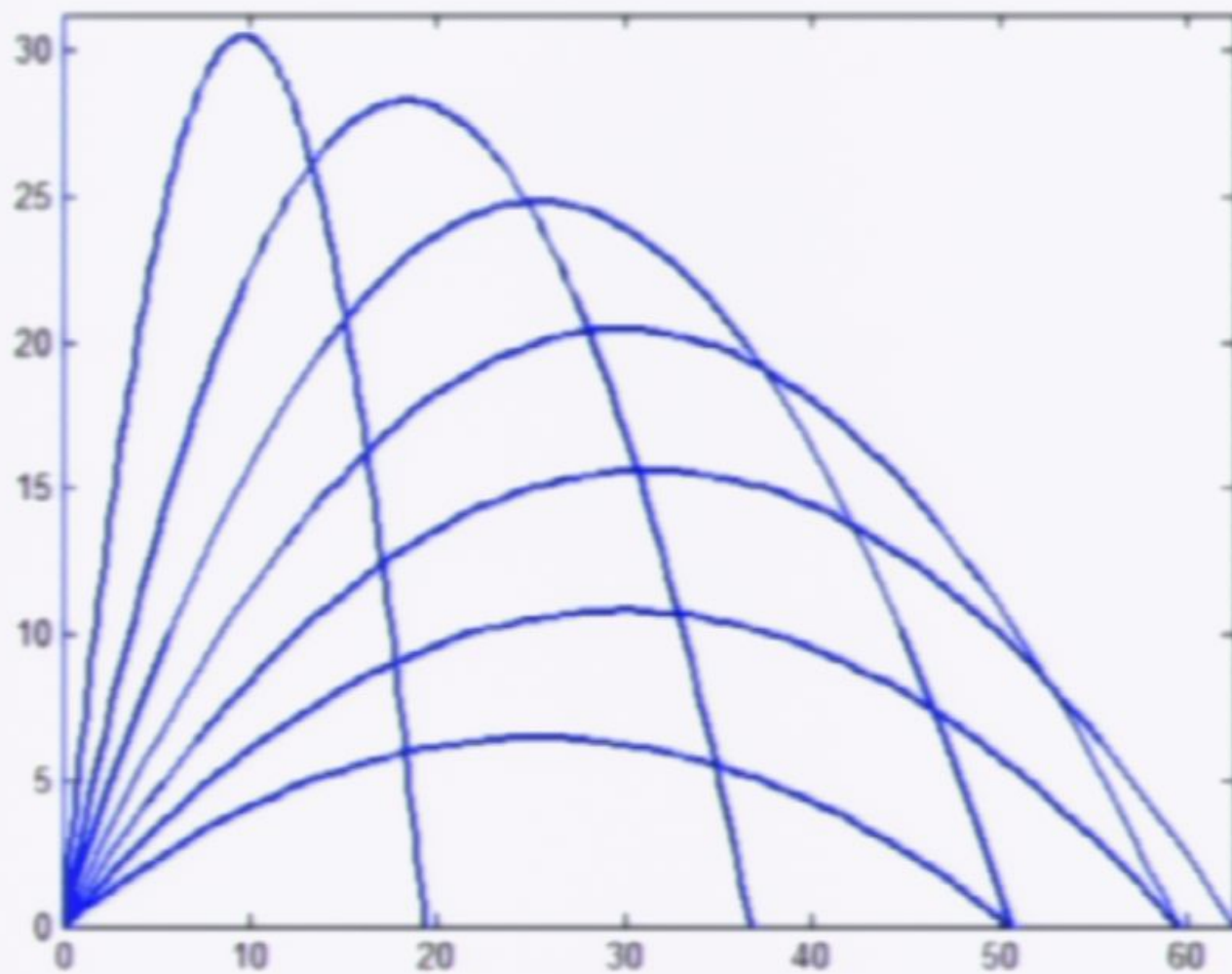




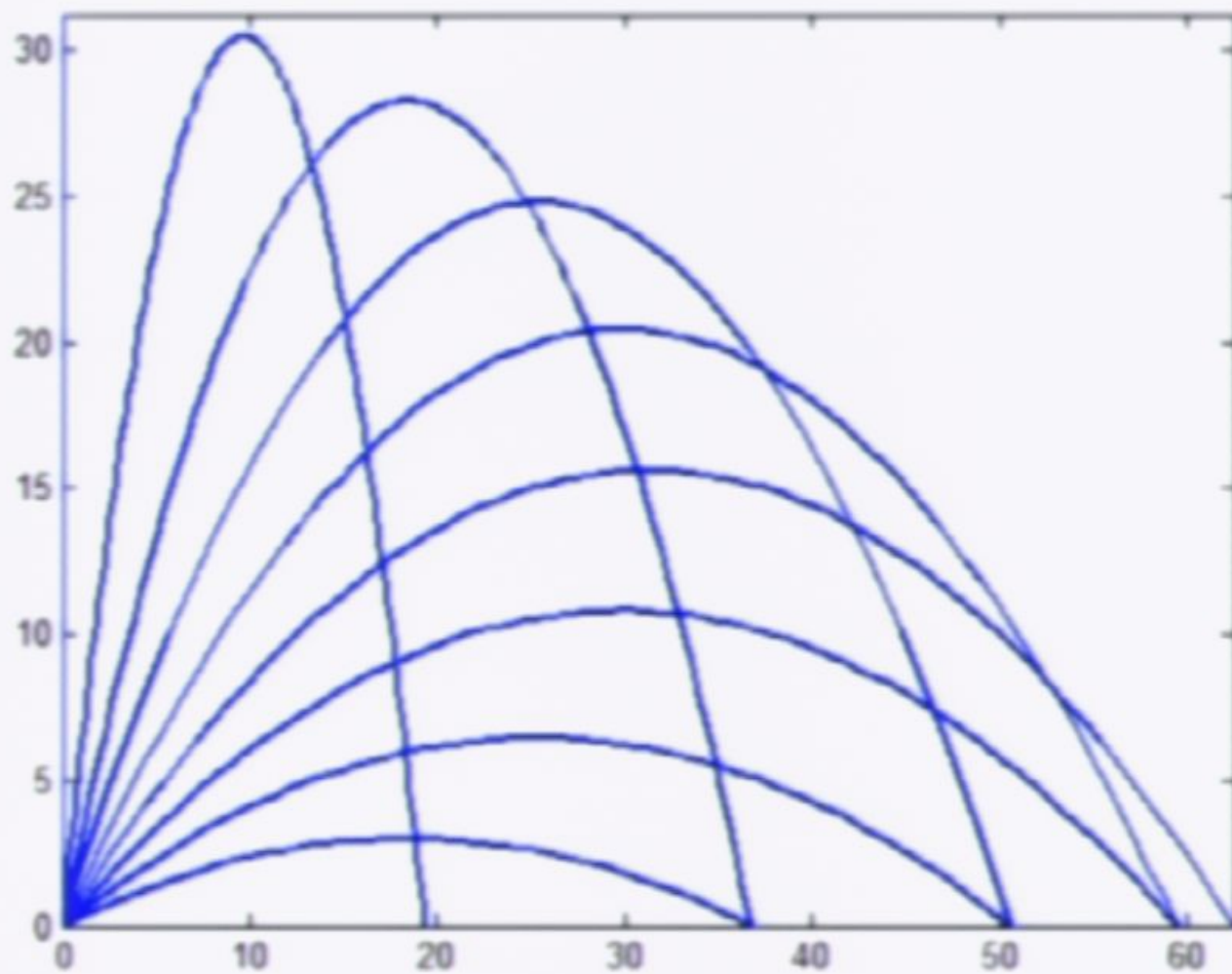














# Envelopes, Example 1

1- Choose an arbitrary  $X_0$ .

# Envelopes, Example 1

- 1- Choose an arbitrary  $X_0$ .
- 2- Choose a parameter uniquely determining each curve

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- 3- Express  $Y(X_0)$  in terms of your parameter.



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$$Y = X_0 \tan\theta - \frac{1}{2} g \frac{x^2}{v_0^2 \cos^2(\theta)}$$

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$$\theta = \tan^{-1}\left(\frac{v_0^2}{g x_0}\right)$$

- 5- Put it in the equation of part 3

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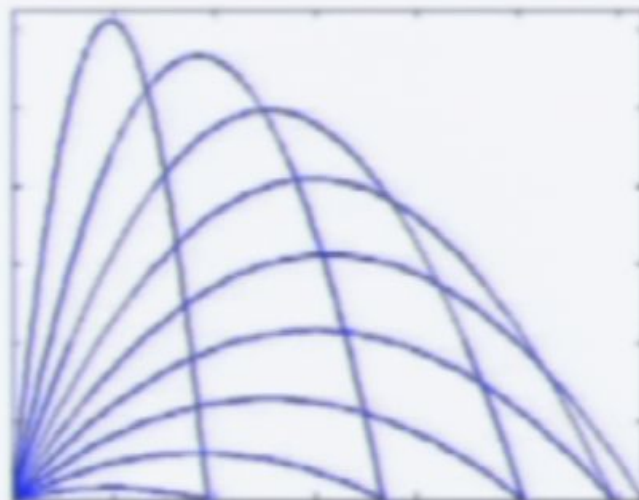
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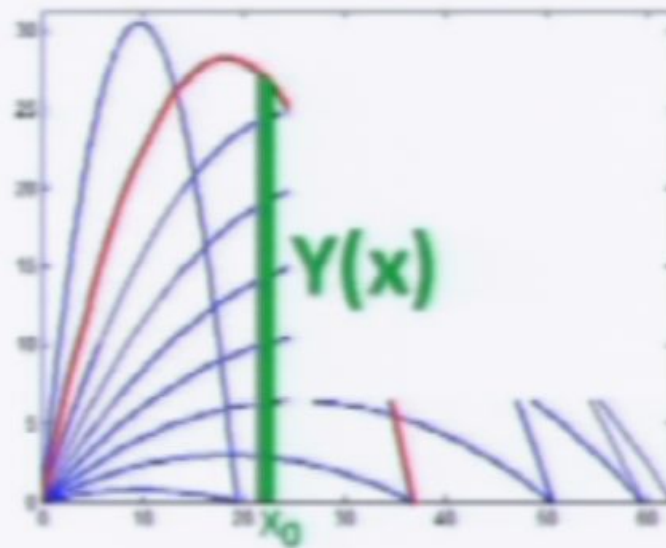




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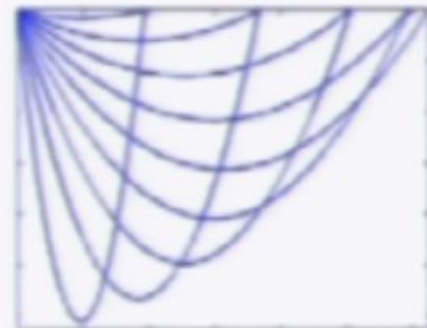
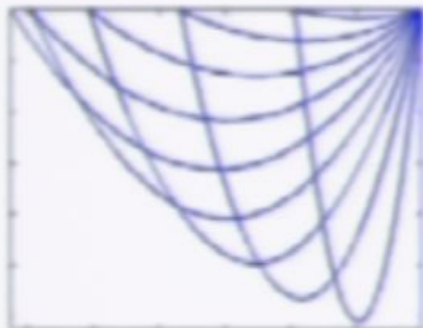
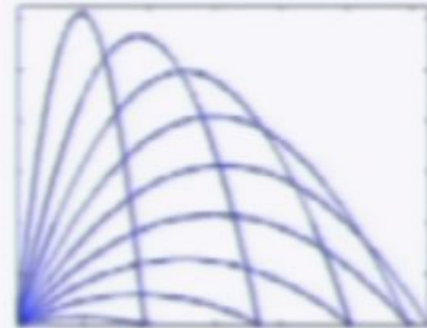


# Envelopes, Example 1





## Envelopes, Example 1

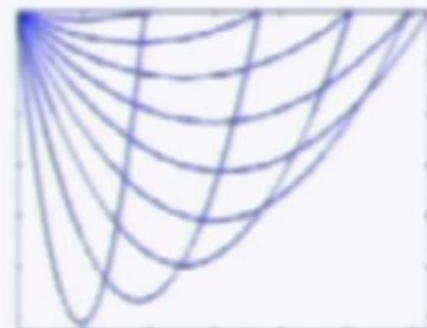
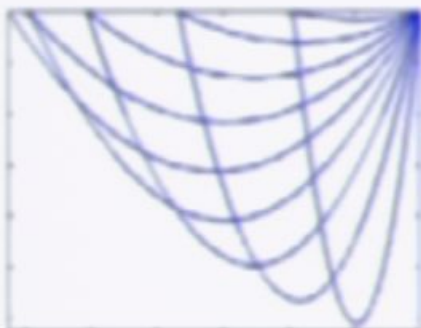




## Envelopes, Example 1



$$Y = \frac{v_0^2}{2g} - \frac{1}{2} g \frac{x^2}{v_0^2}$$

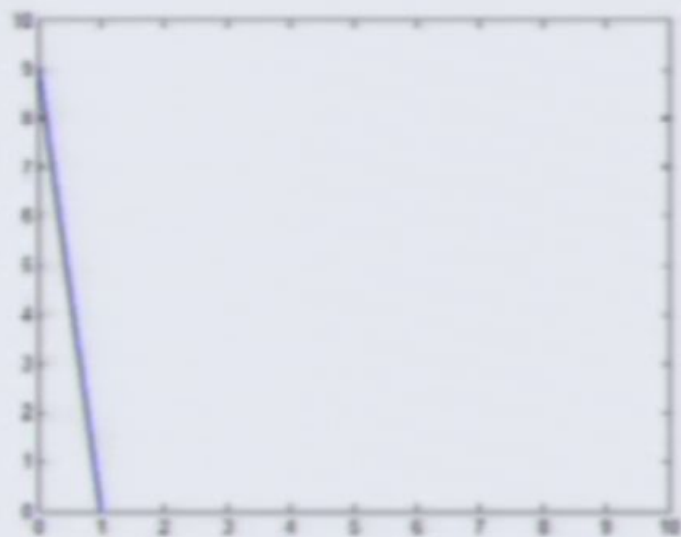




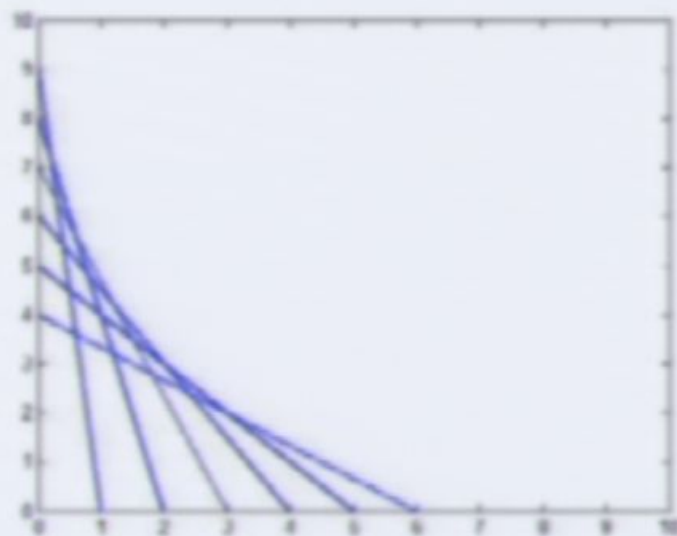
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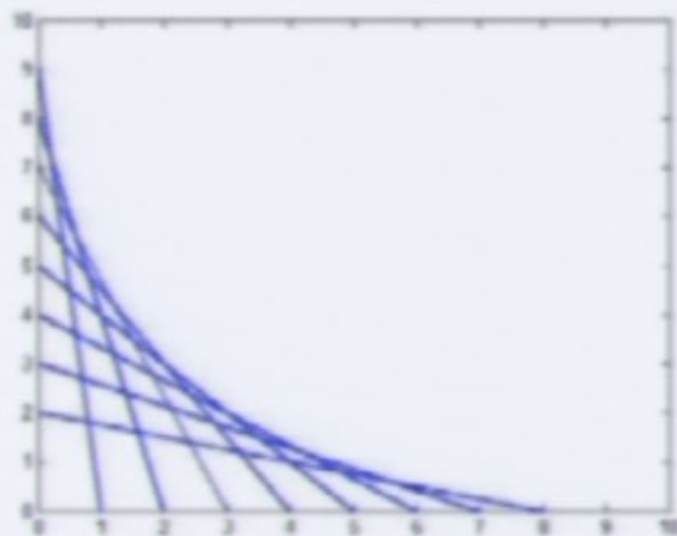
## Envelopes, Example 2



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## Envelopes, Example 2

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1- Choose an arbitrary  $X_0$ .

## Envelopes, Example 2

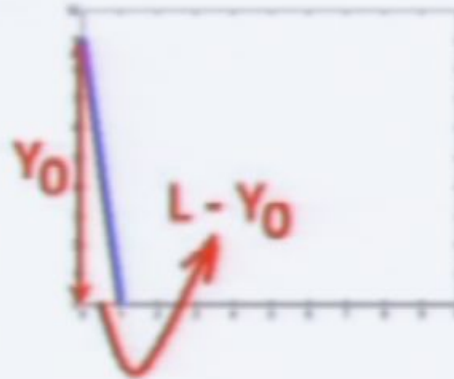
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## Envelopes, Example 2

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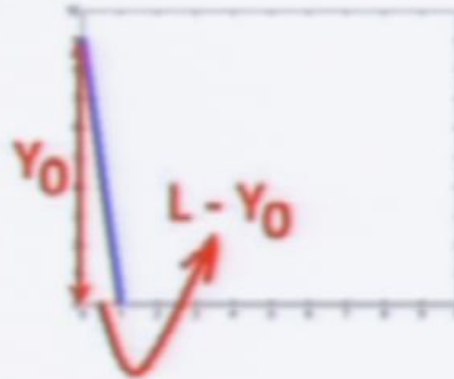
This parameter is " $Y_0$ "



## Envelopes, Example 2

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This parameter is " $Y_0$ "



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## Envelopes, Example 2

- 1- Choose an arbitrary  $x_0$ .
- 2- Choose a parameter uniquely determining each curve

**This parameter is " $y_0$ "**

- 3- Express  $Y(x_0)$  in terms of your parameter.

$$Y = y_0 \left( 1 - \frac{x_0}{L - y_0} \right)$$

## Envelopes, Example 2

- 1- Choose an arbitrary  $x_0$ .
- 2- Choose a parameter uniquely determining each curve

**This parameter is " $y_0$ "**

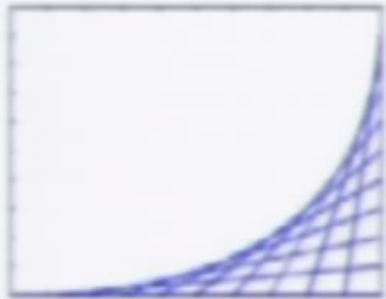
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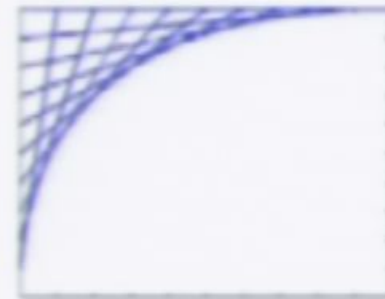
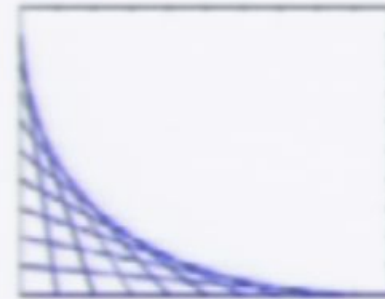
- 4- Find the value of the parameter maximizing  $Y(x_0)$

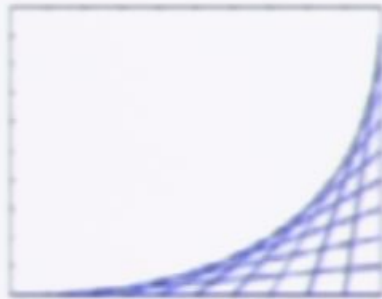




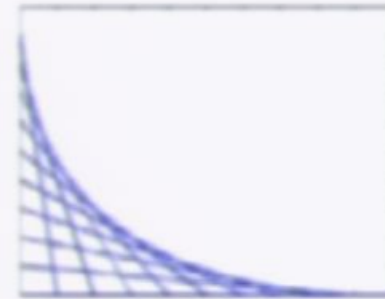


## Envelopes, Example 2

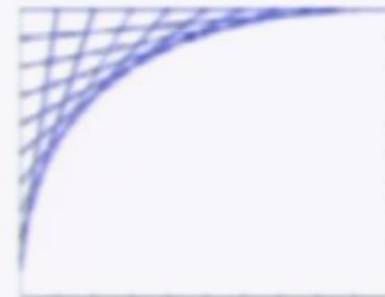




Envelopes,  
Example 2



$$y = (\sqrt{L} - \sqrt{x})^2$$





# The original problem

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$$\theta = \cos^{-1} \left( \left( \frac{x_0}{L} \right)^{\frac{1}{3}} \right)$$

## Final Solution

The original problem

1. Choose an arbitrary  $x_0$ .
2. Choose a parameter uniquely determining each curve.

This parameter is  $\theta$  for this problem.

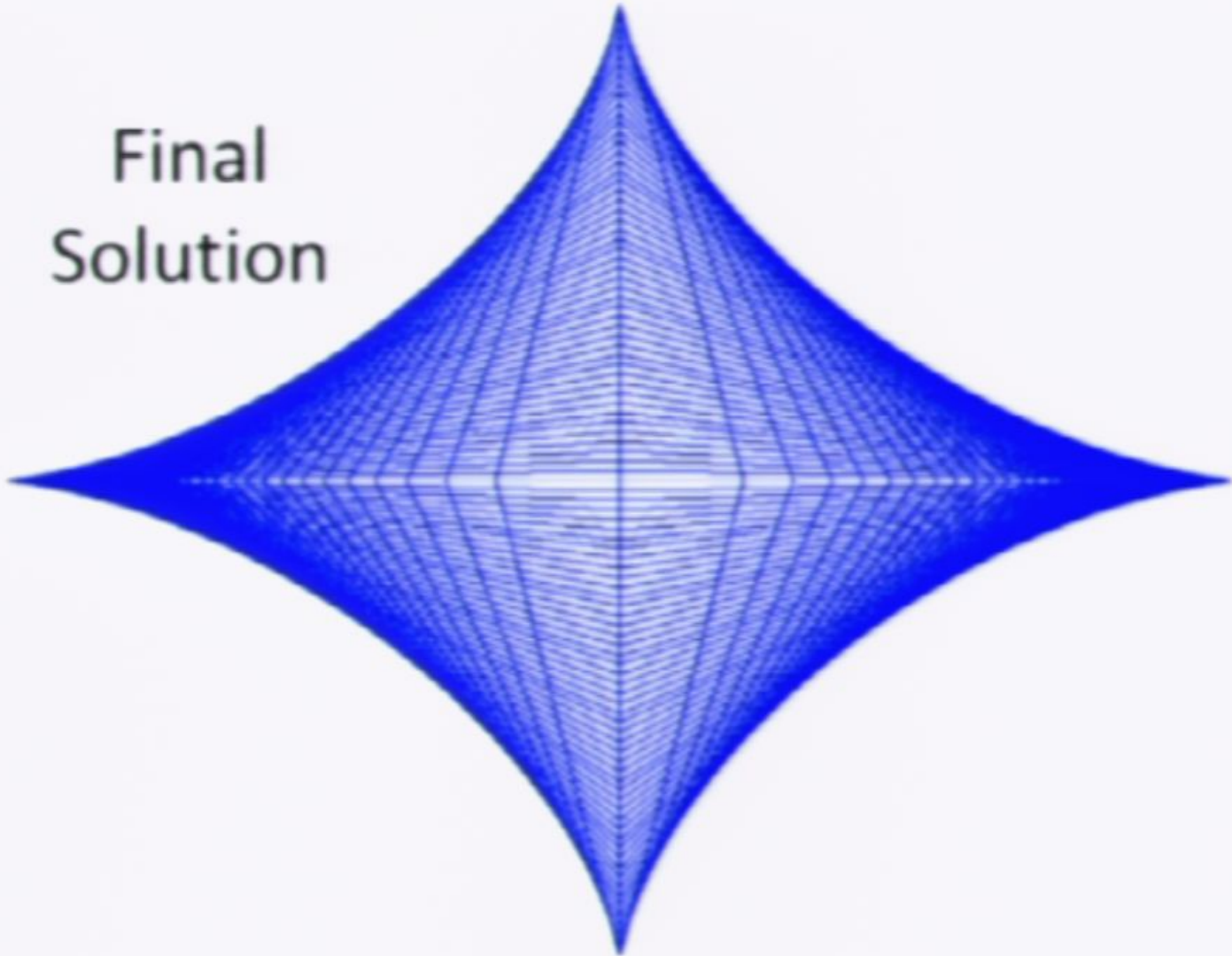
3. Express  $y(x)$  in terms of your parameter.

$$y = -x \tan \theta + L \sin \theta$$

4. Find the value of the parameter maximizing  $y(x)$ .

$$\theta = \cos^{-1} \left( \frac{x_0 \sqrt{3}}{L} \right)$$

Final  
Solution



Final  
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$$y = \left( L^{\frac{2}{3}} - x^{\frac{2}{3}} \right)^{\frac{3}{2}}$$

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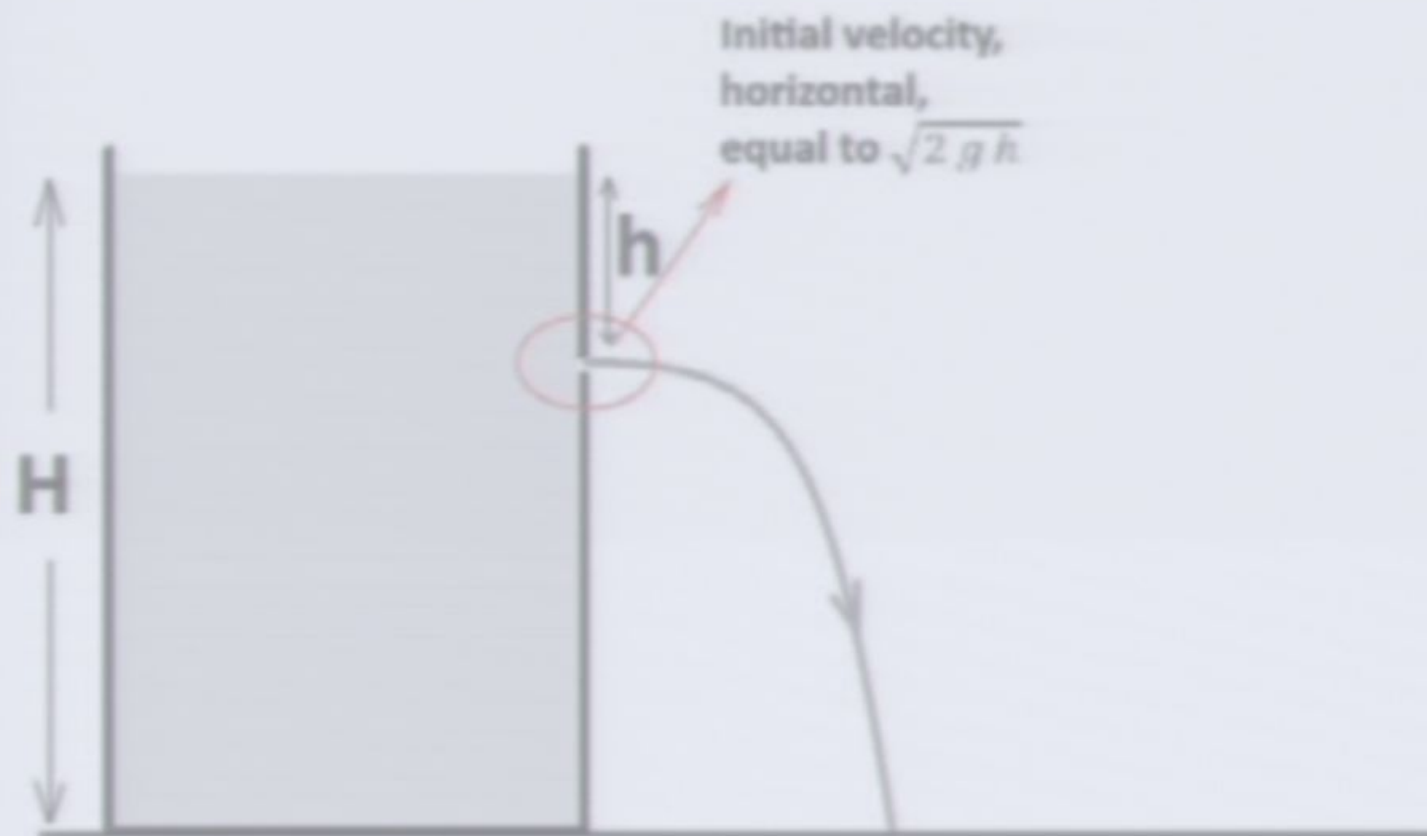


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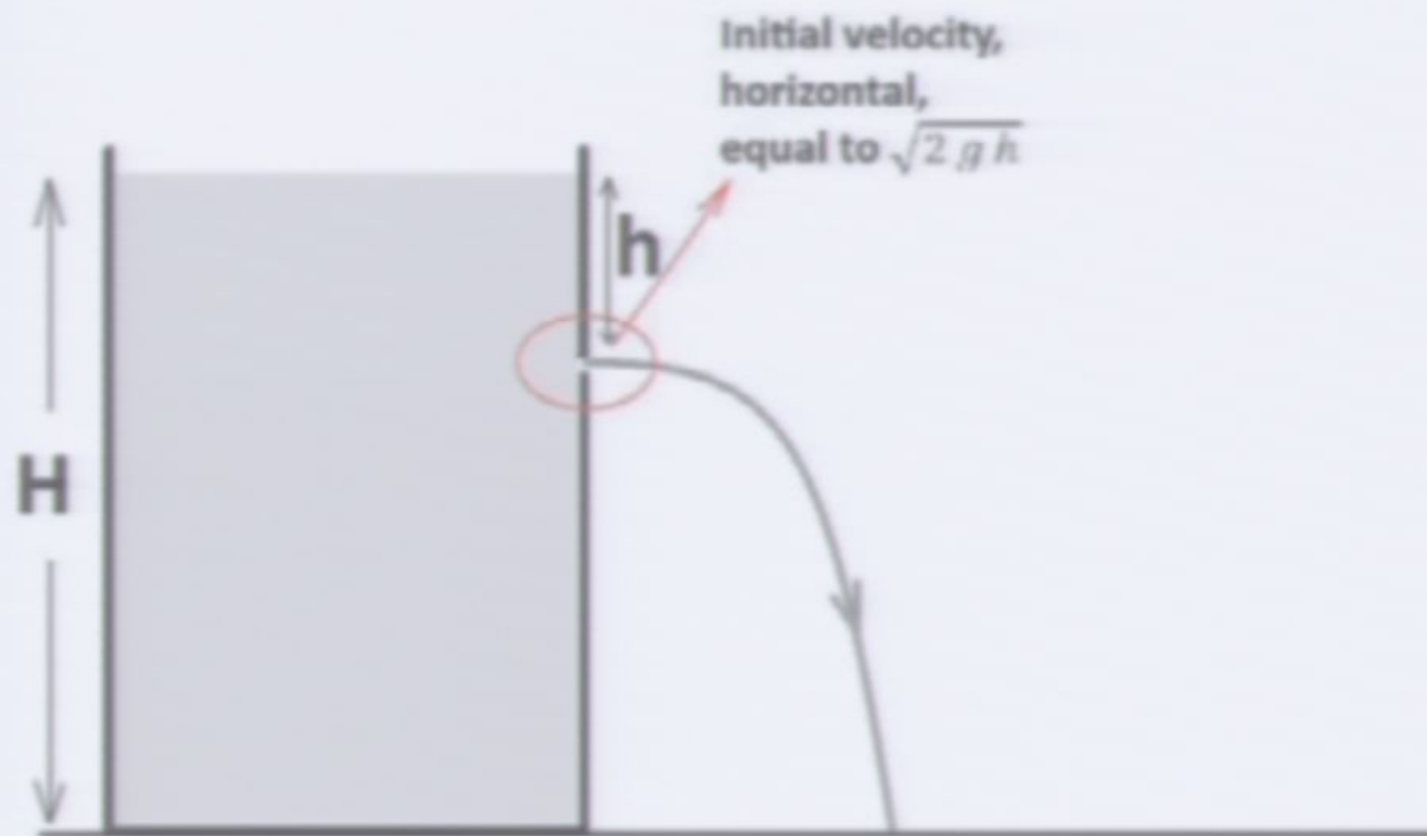


# Excercise

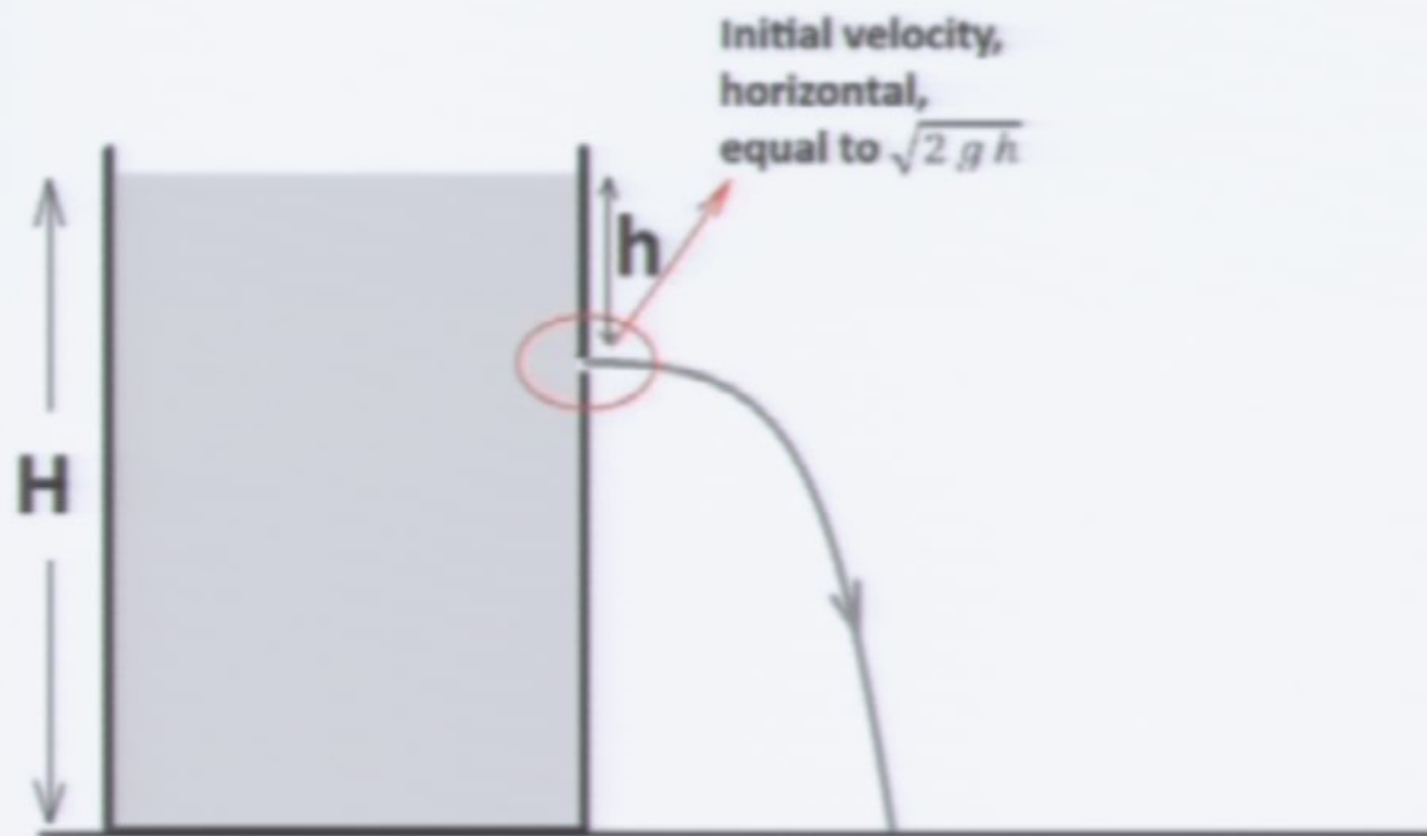
# Excercise



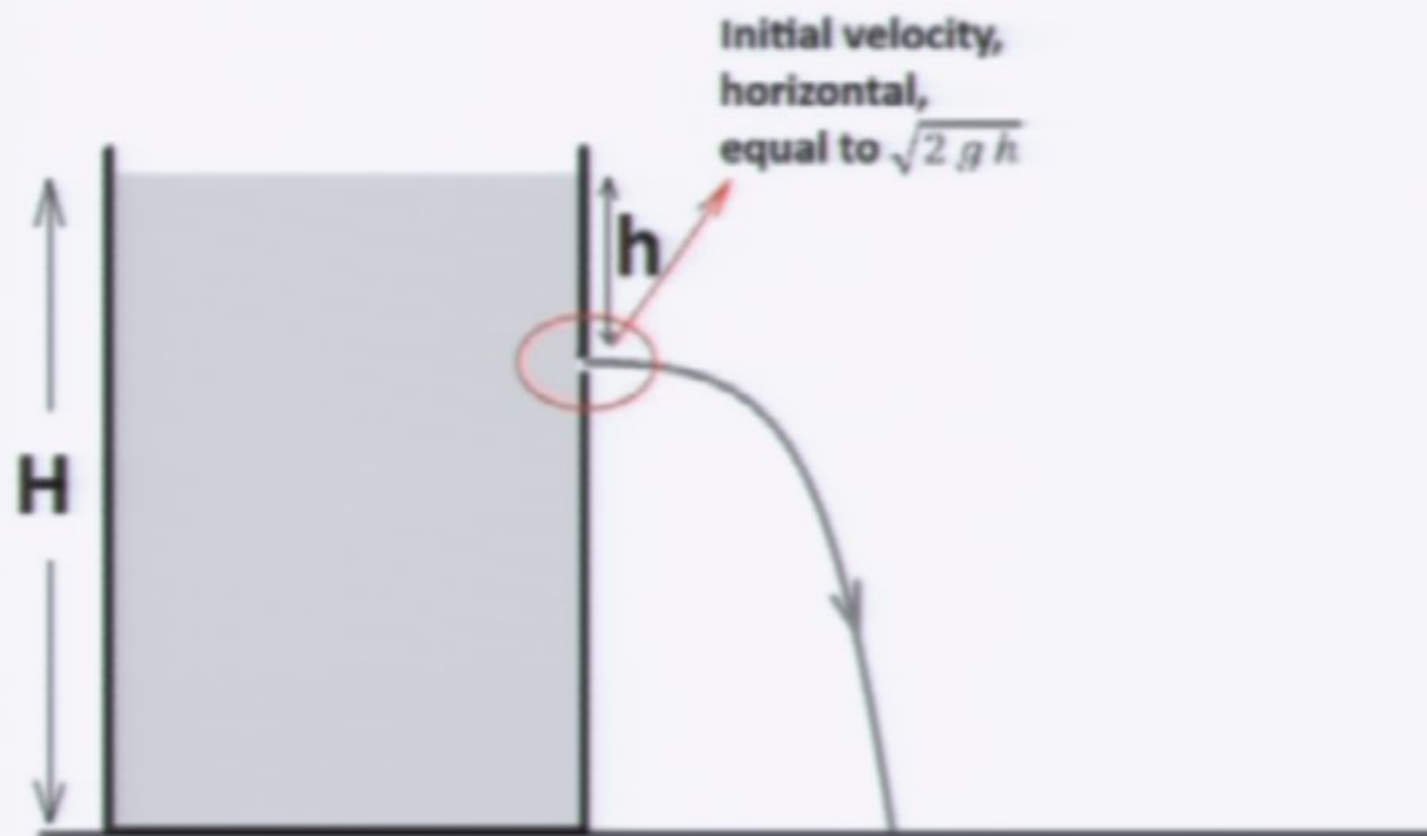
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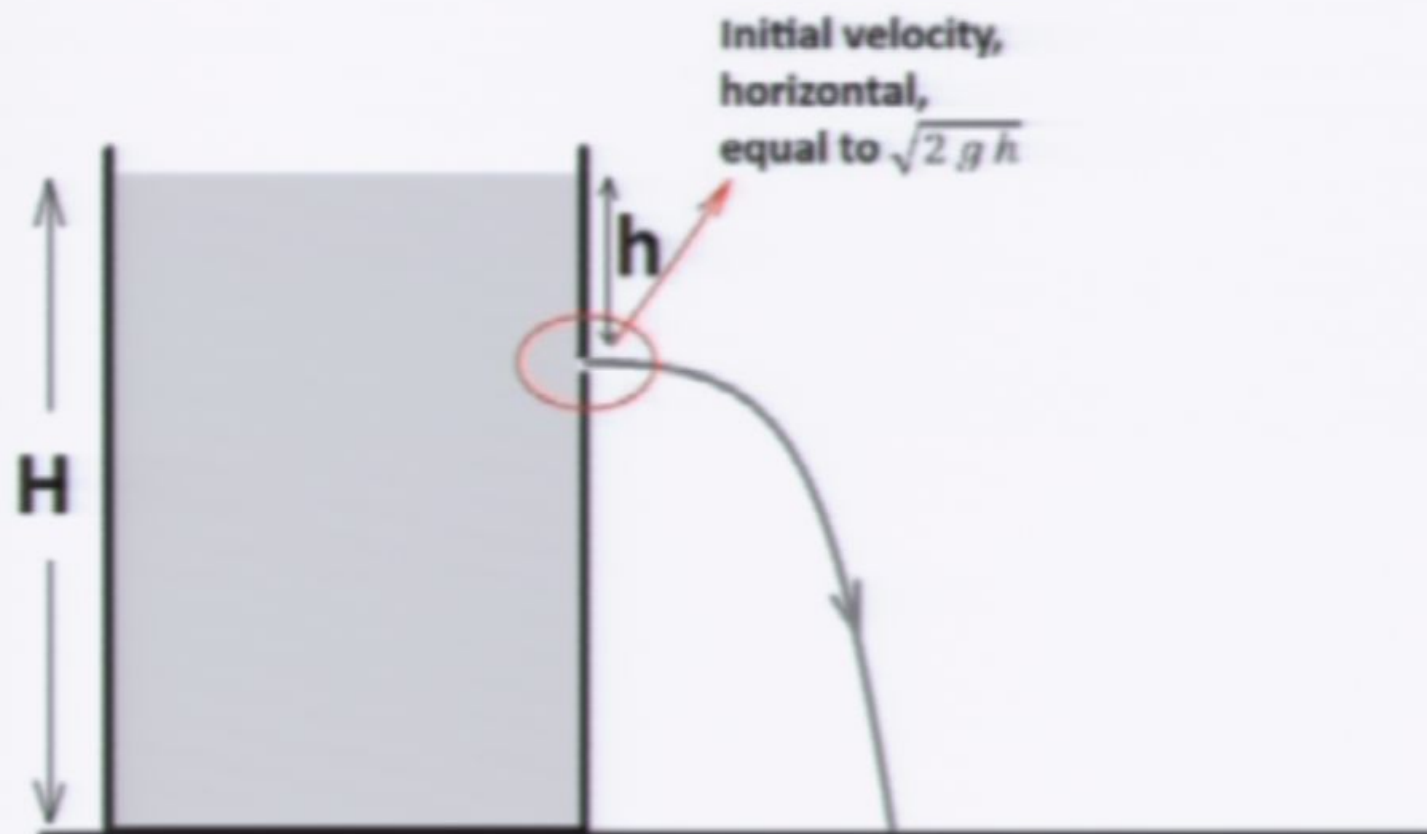


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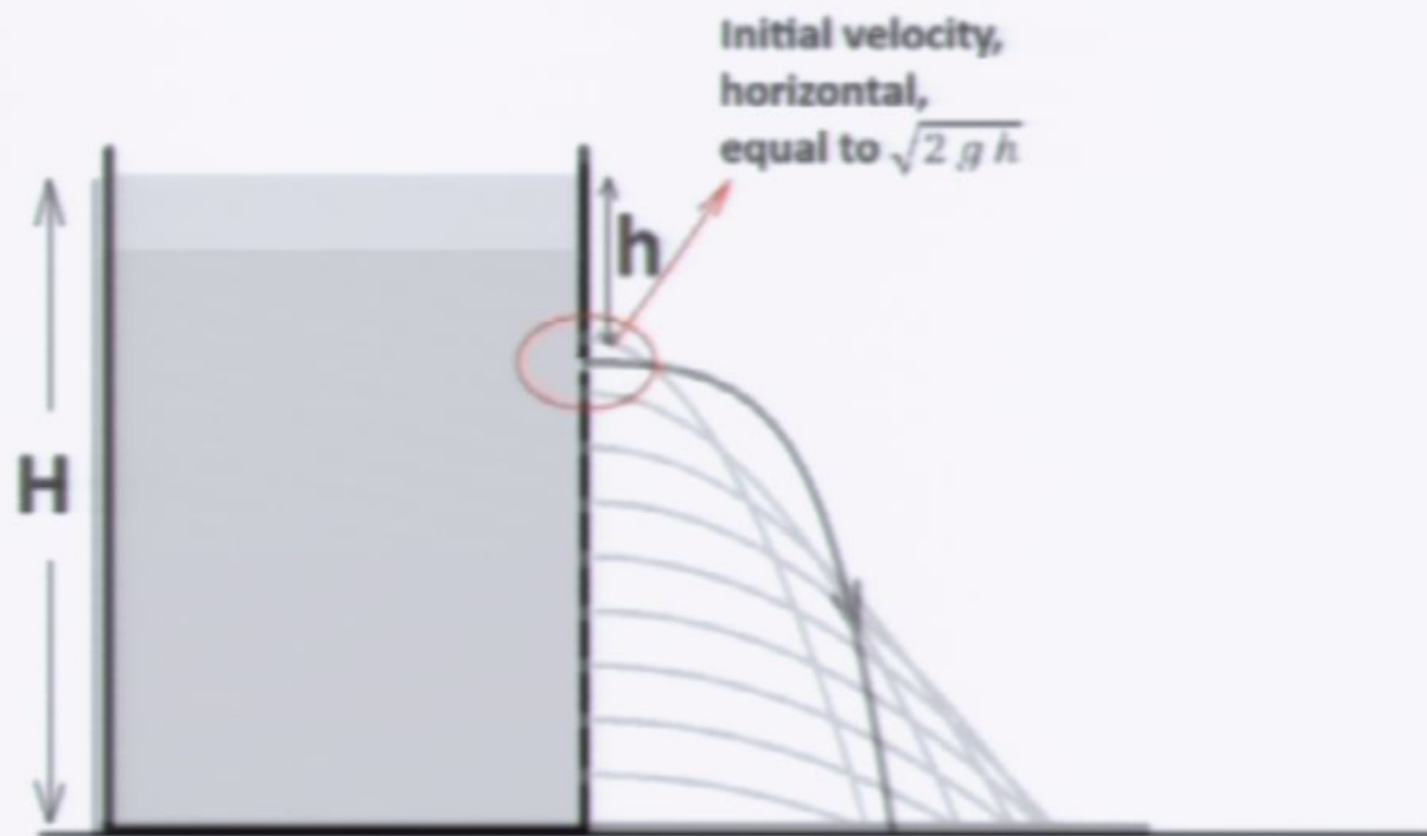




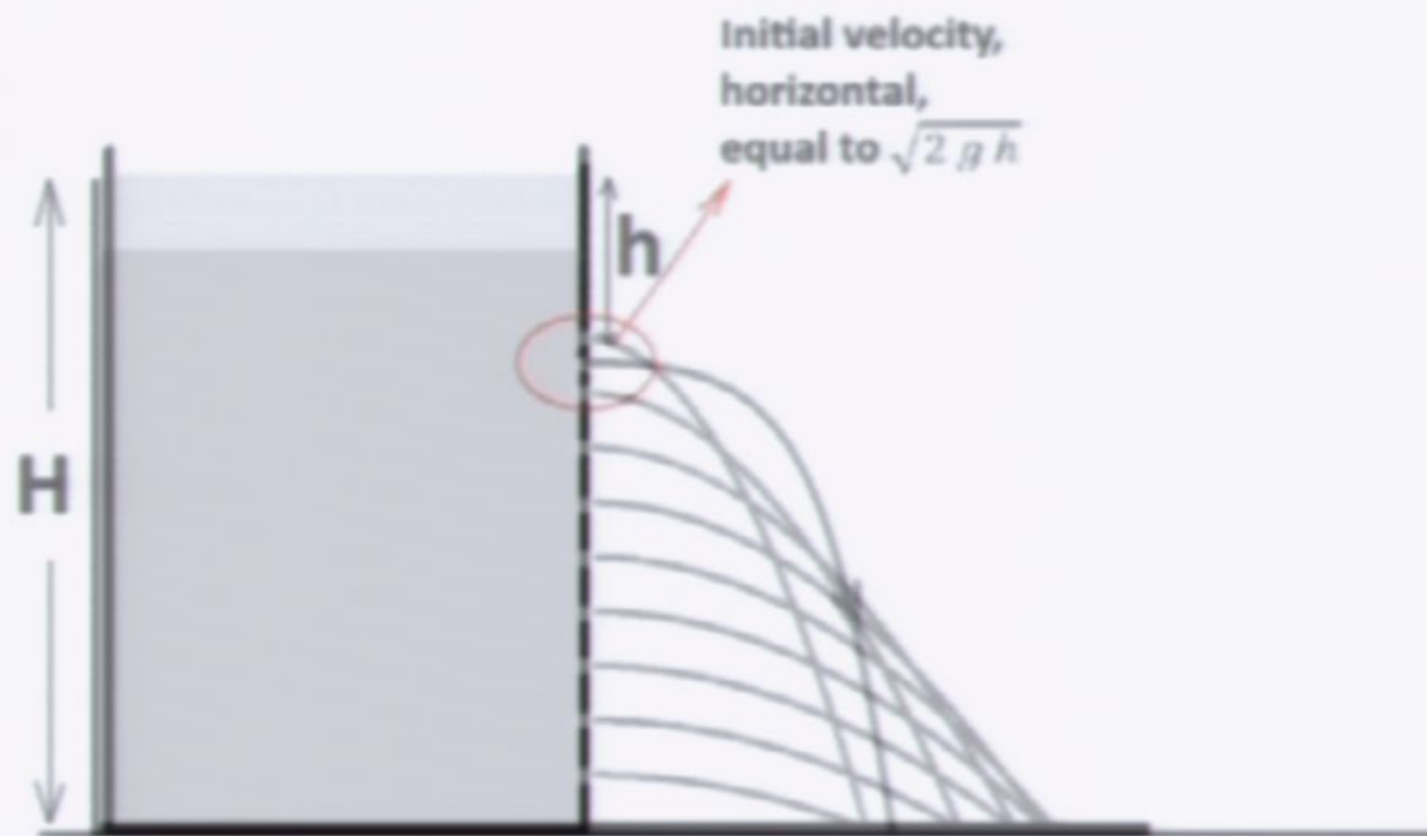
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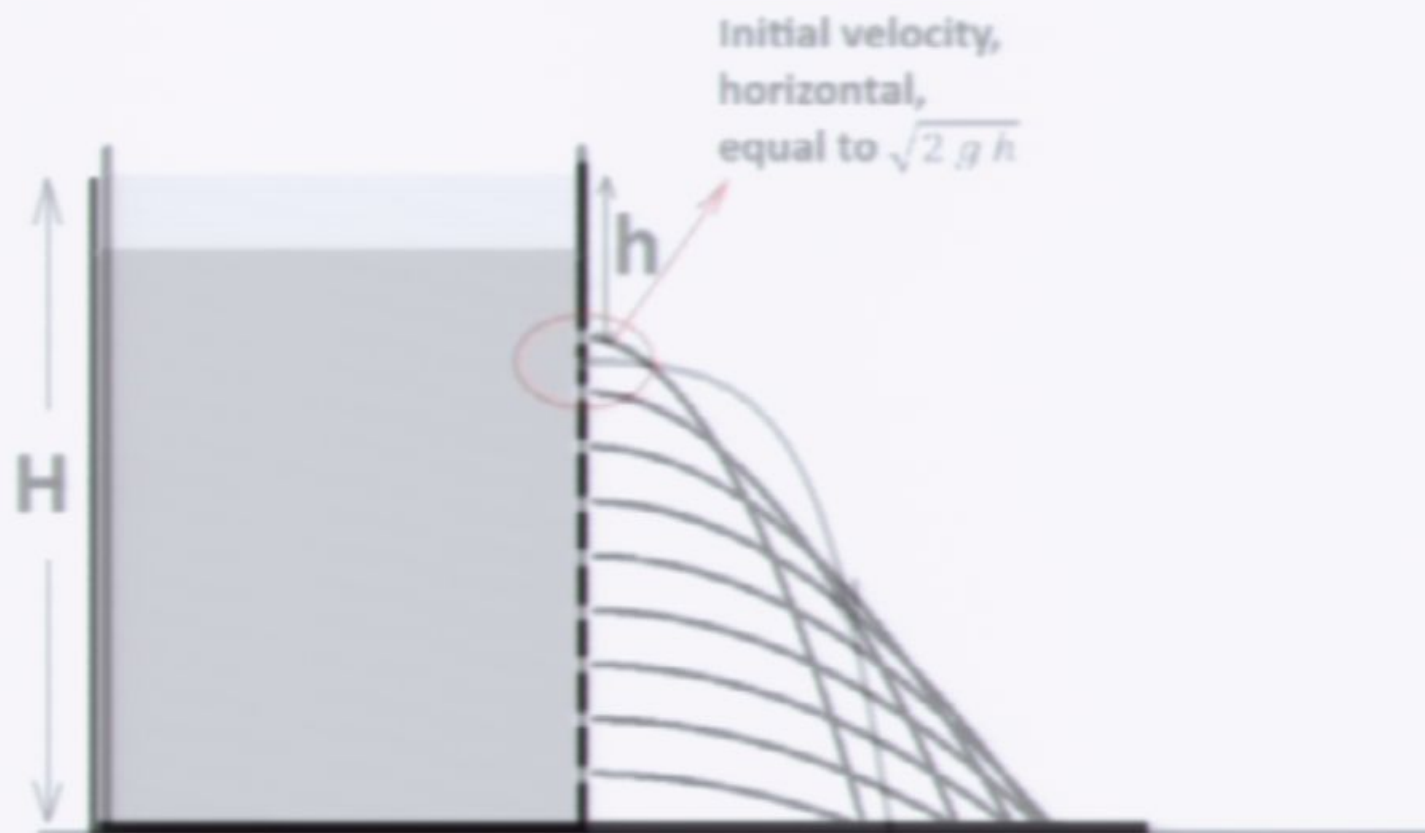
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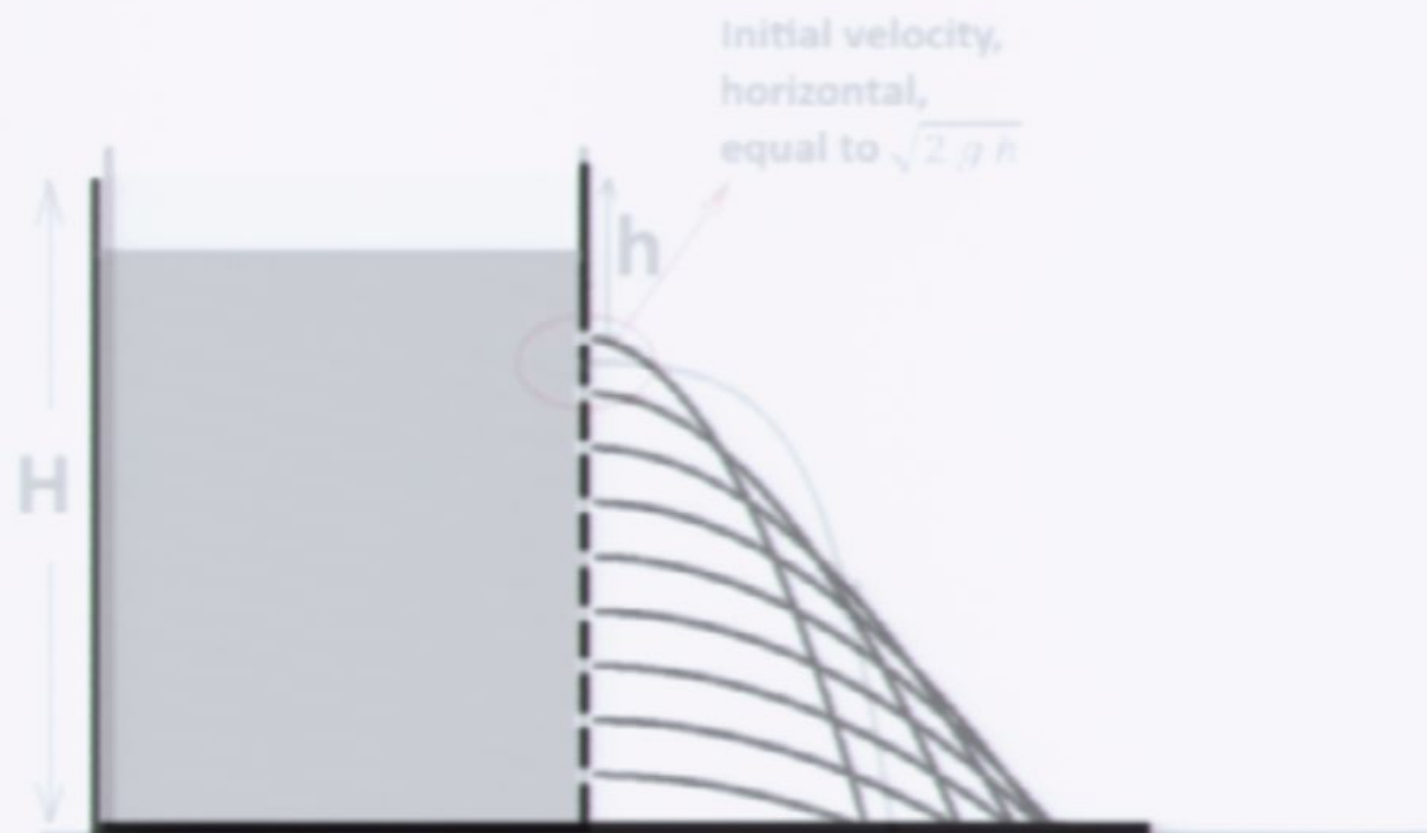
# Excercise



# Excercise



# Exercise



# Excercise



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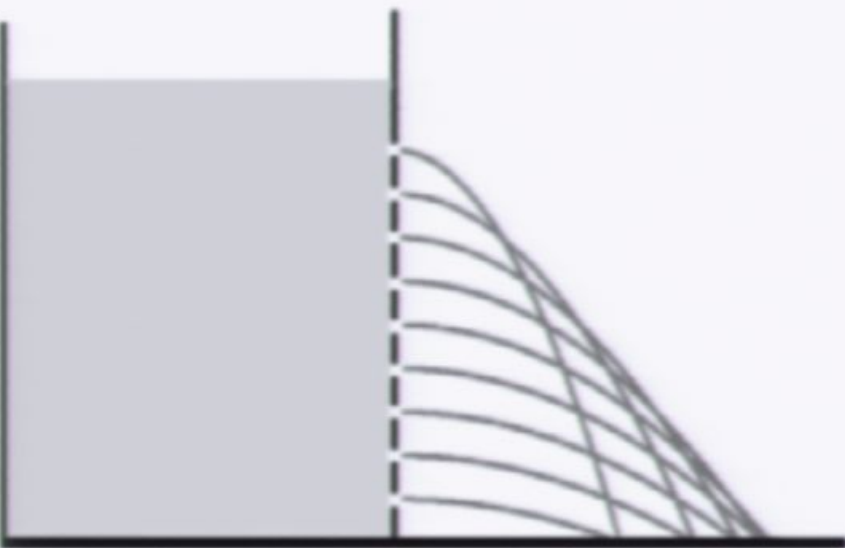
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# Excercise



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- Permanent link

Details

Yihong Wang -upload Power Point OR upload PDF OR upload OpenOffice Impress

Tibra Ali -upload Power Point OR upload PDF OR upload OpenOffice Impress

## Timetable

The timetable for these talks is now available

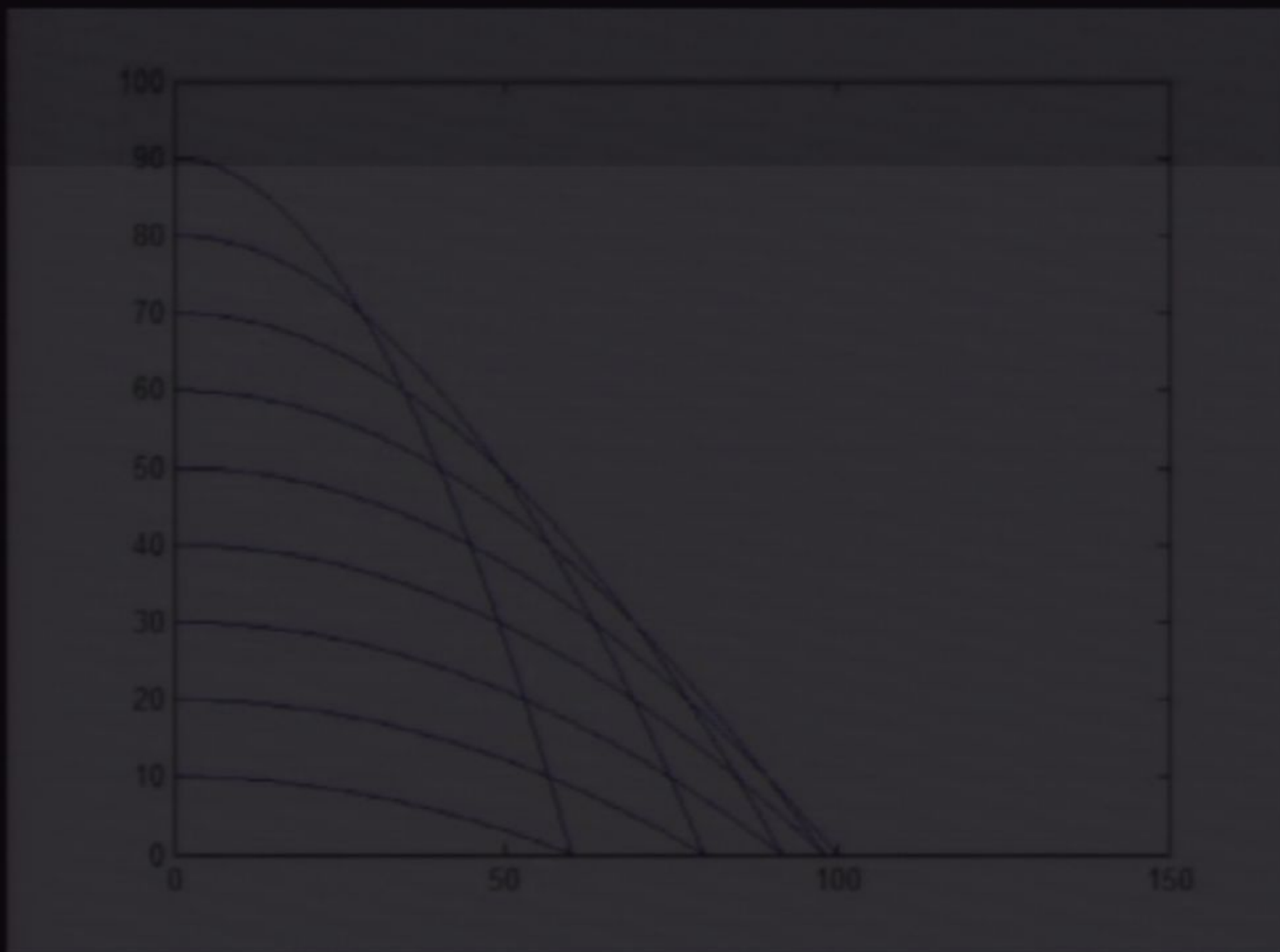
timetable will be strictly enforced.

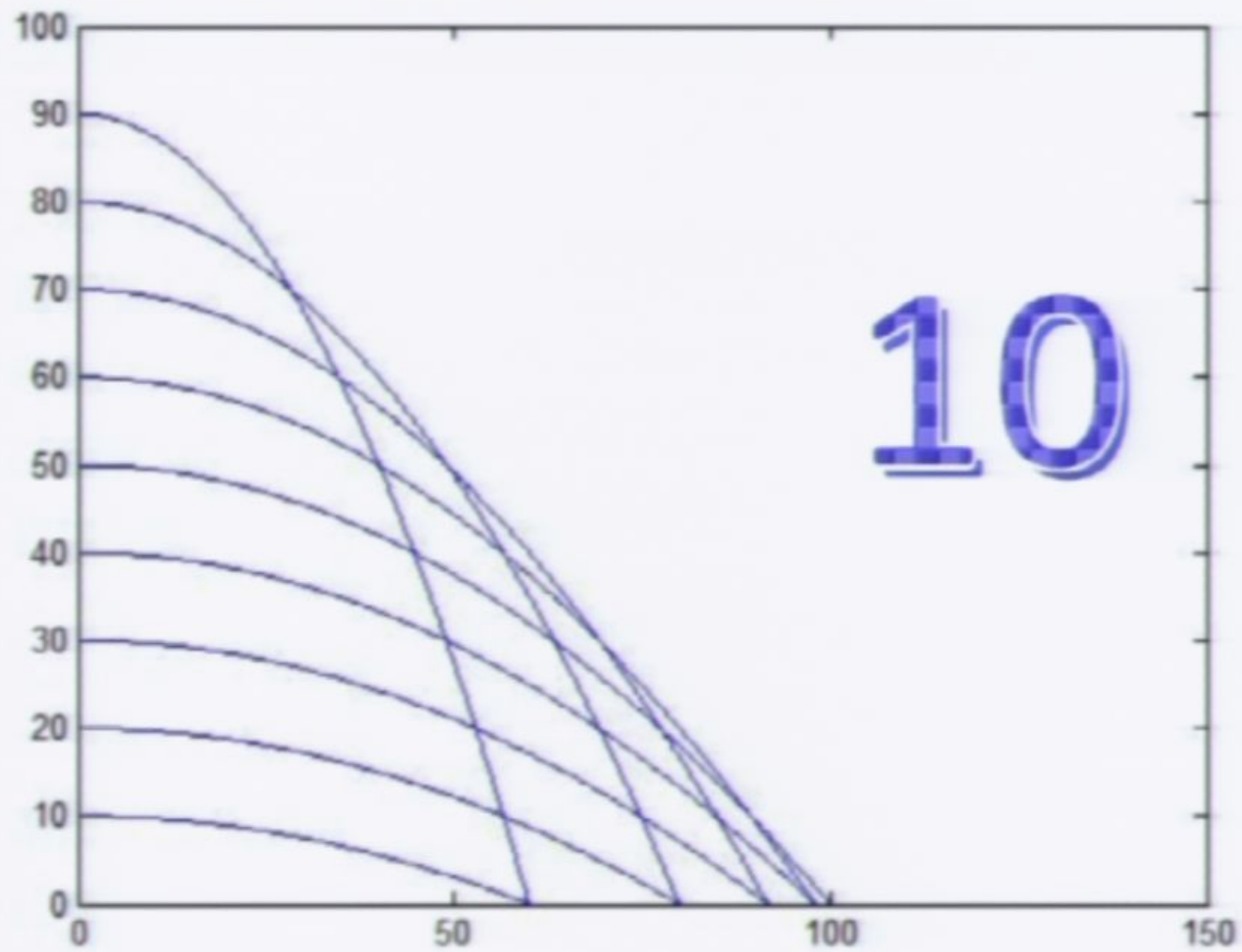
Page 113/1202 [edit]

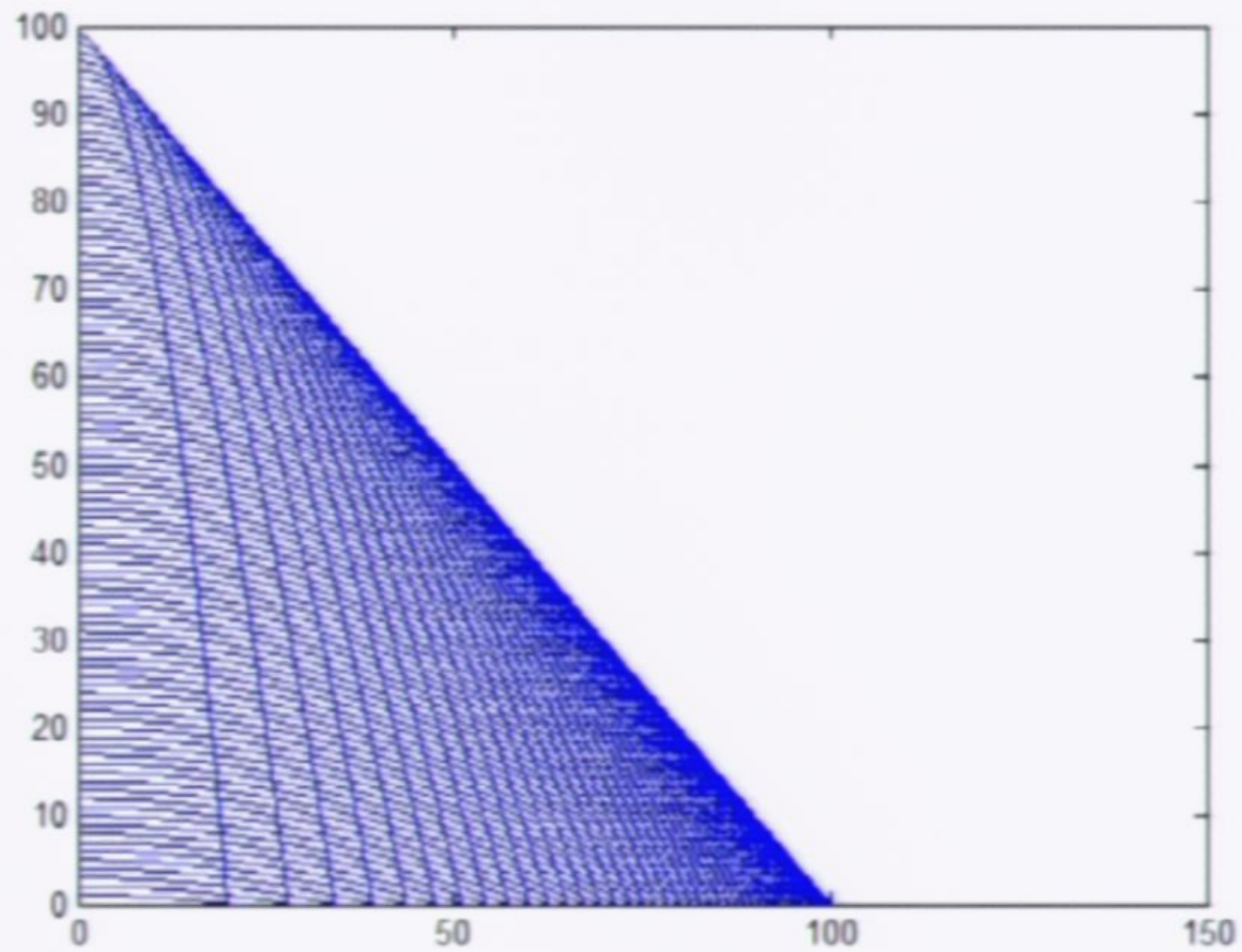


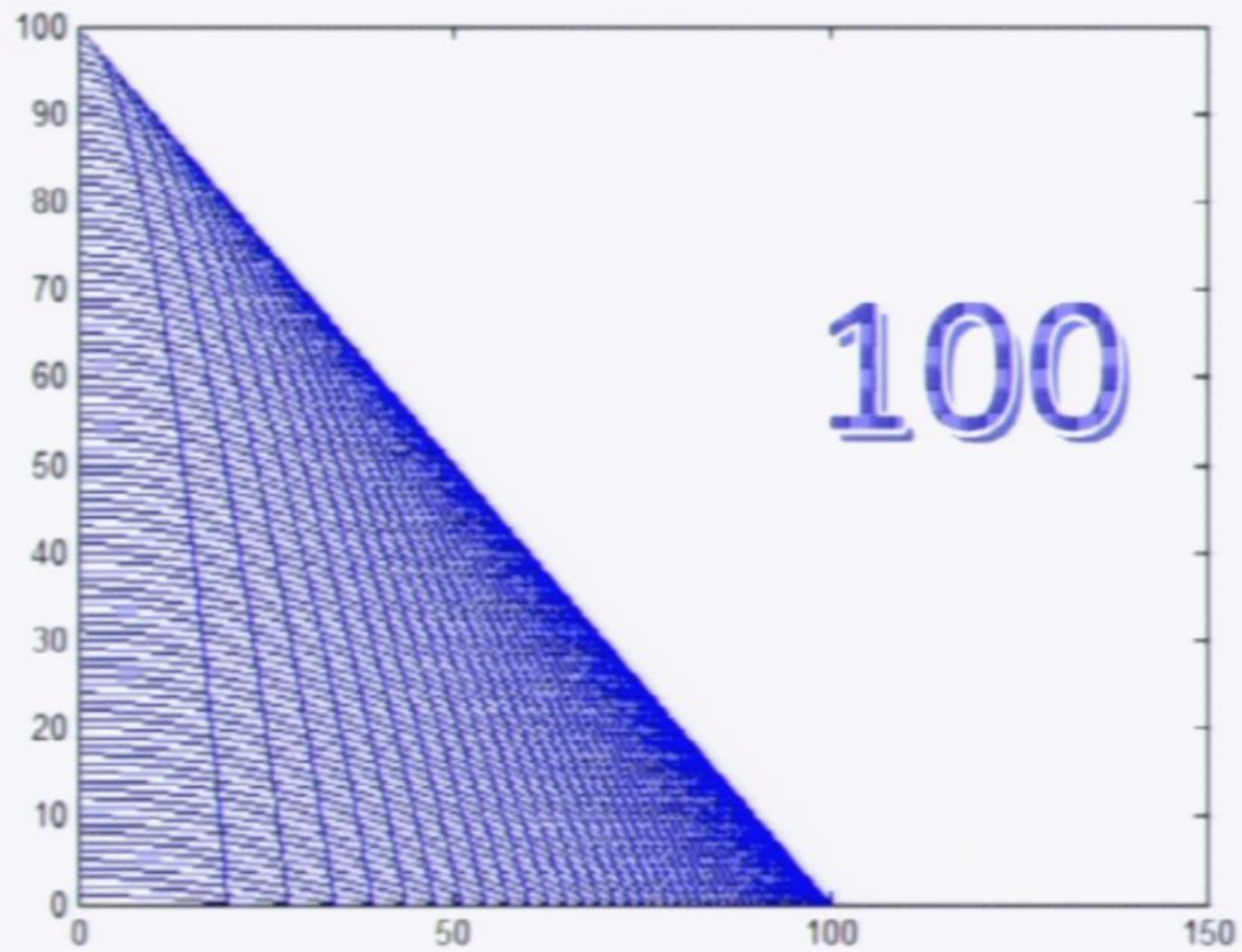


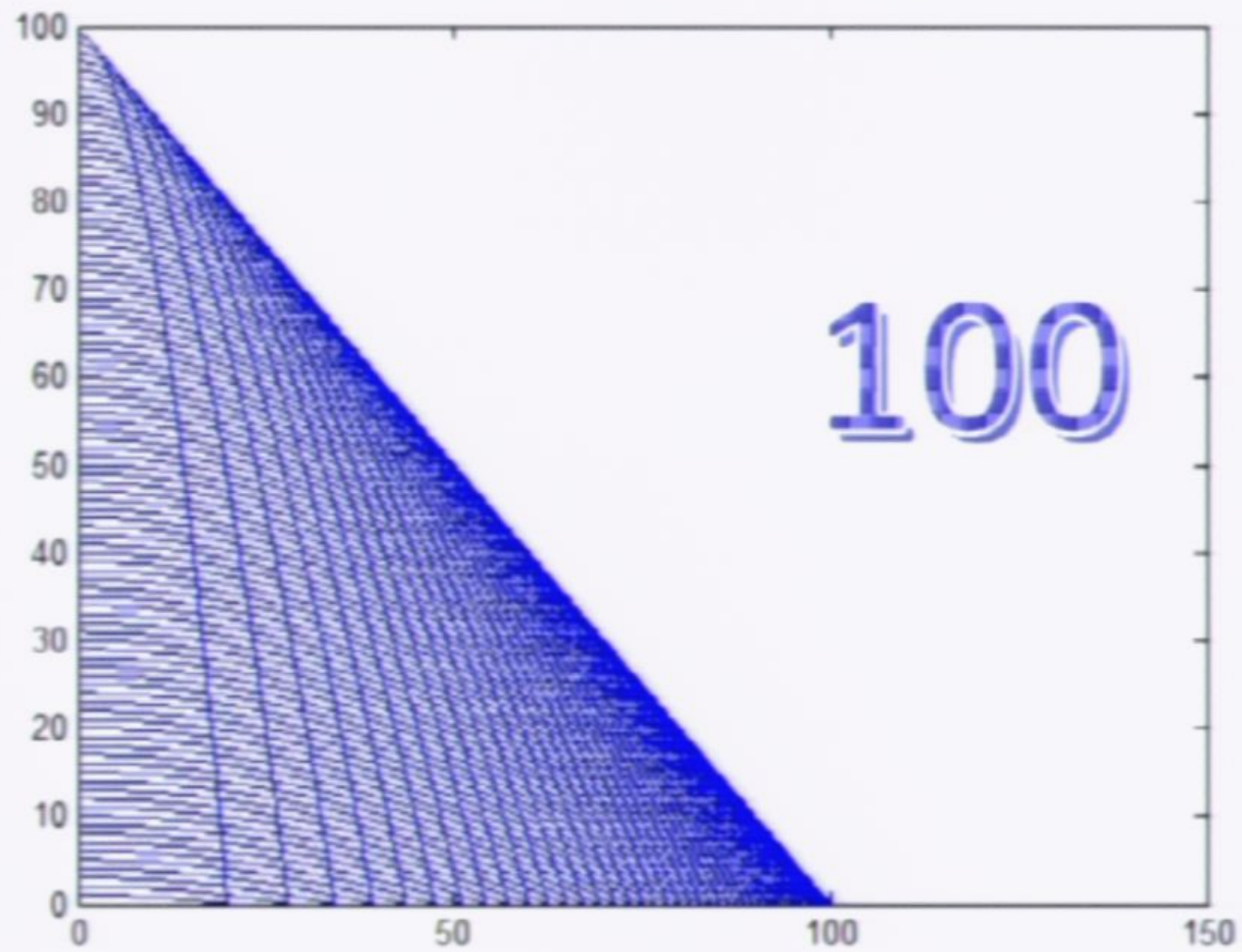


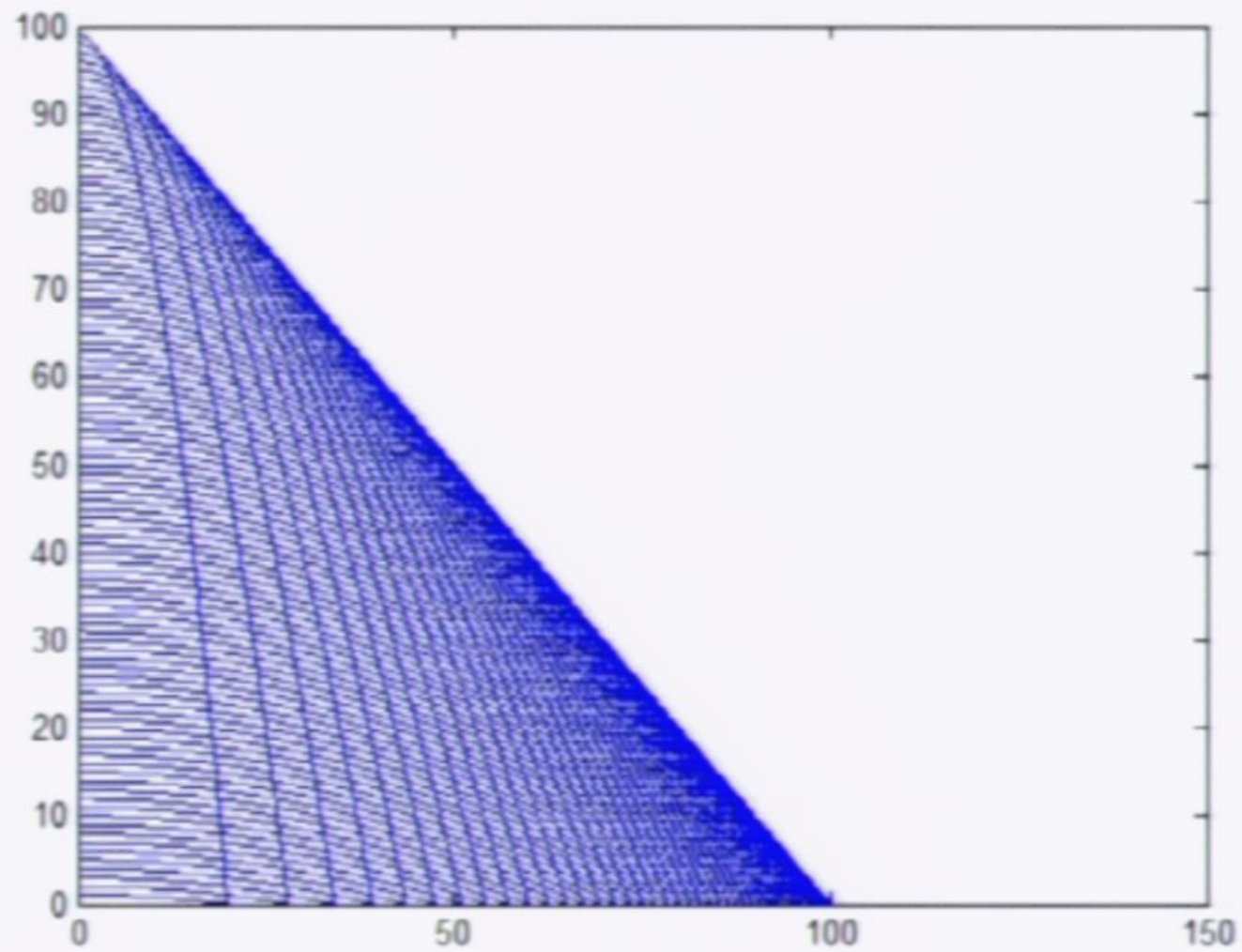




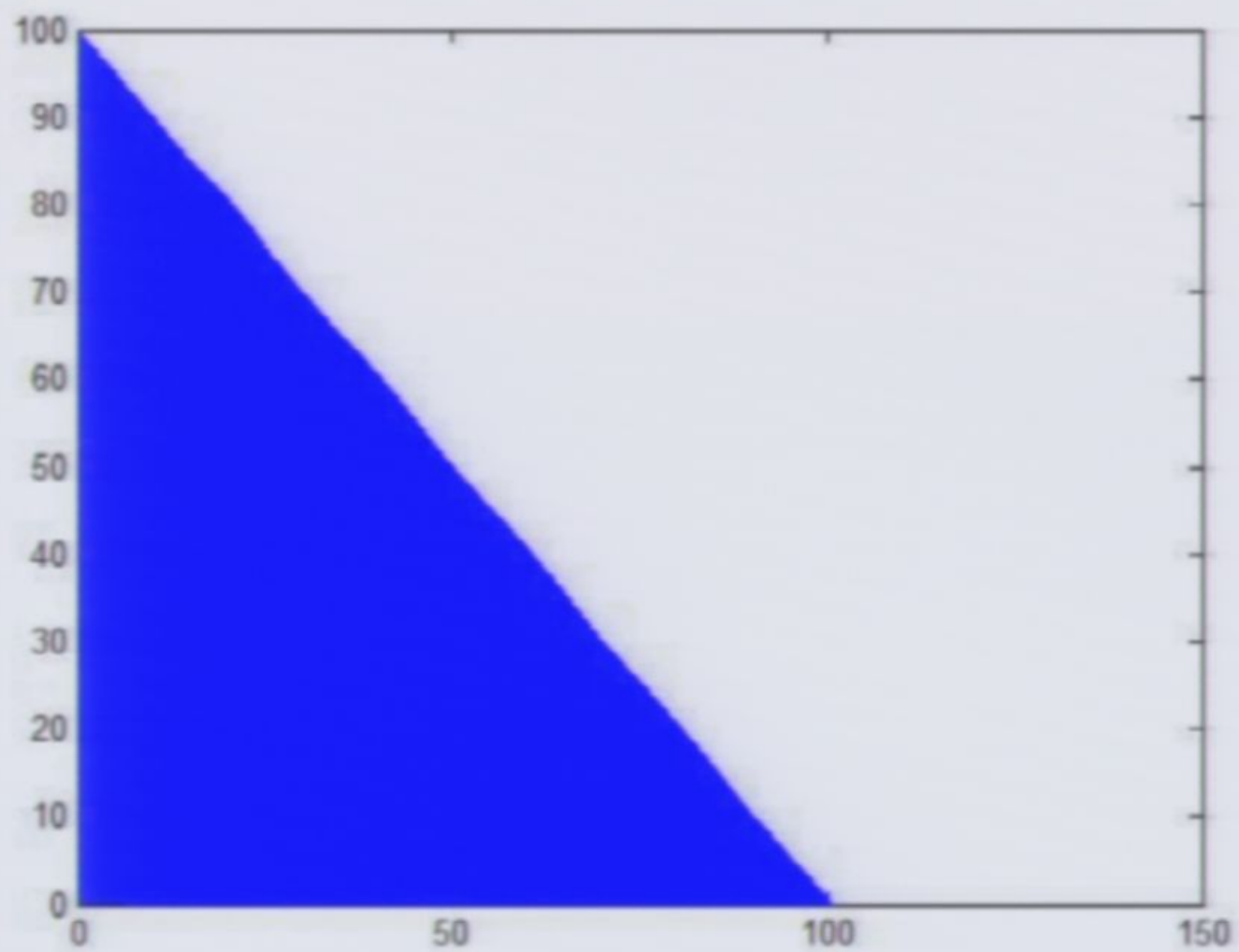


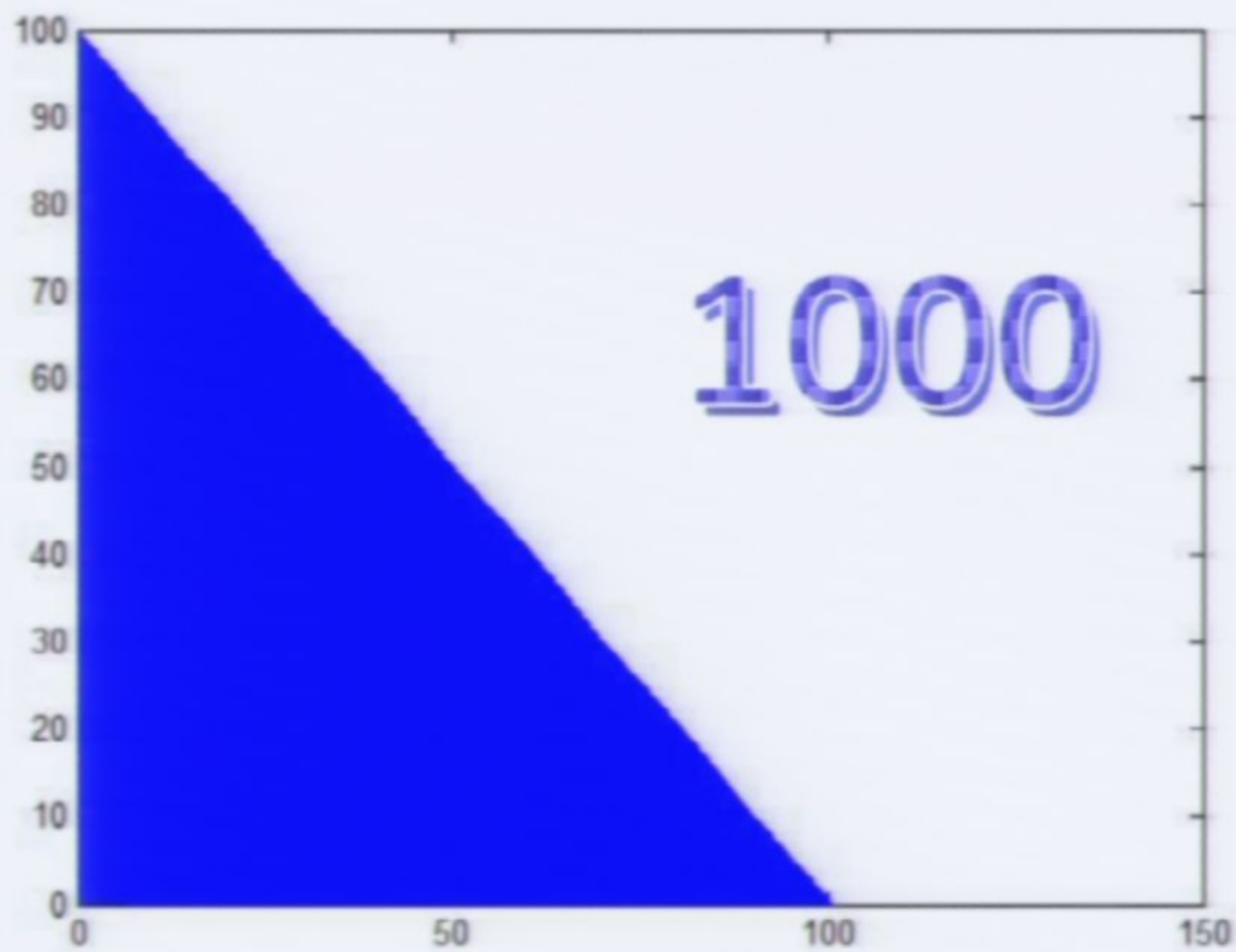




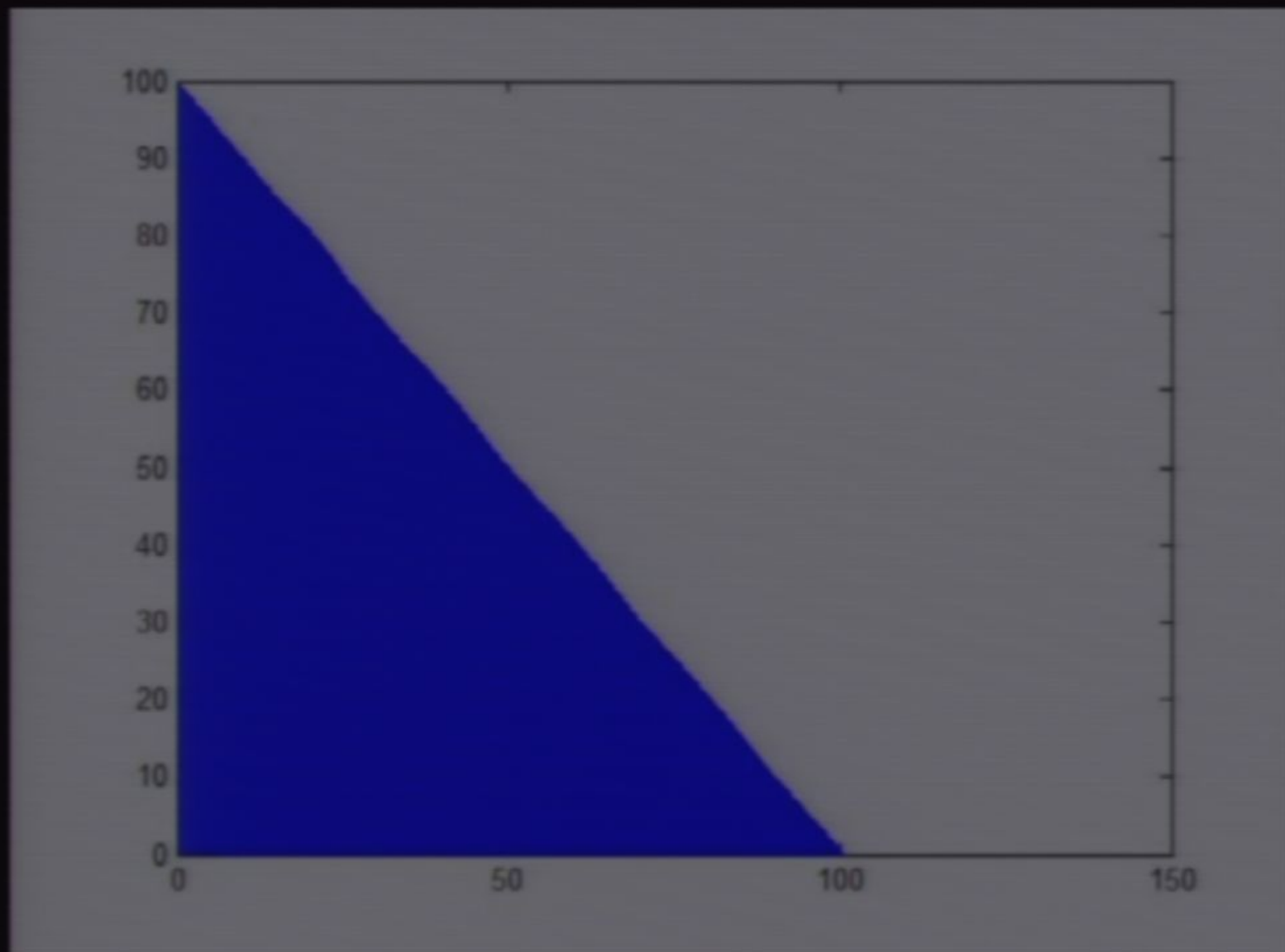












**Thanks  
for your attention/...**

**You may now wake up ;)**

**Thanks  
for your attention/...**

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Thanks  
for your attention!  
You may now wake up!

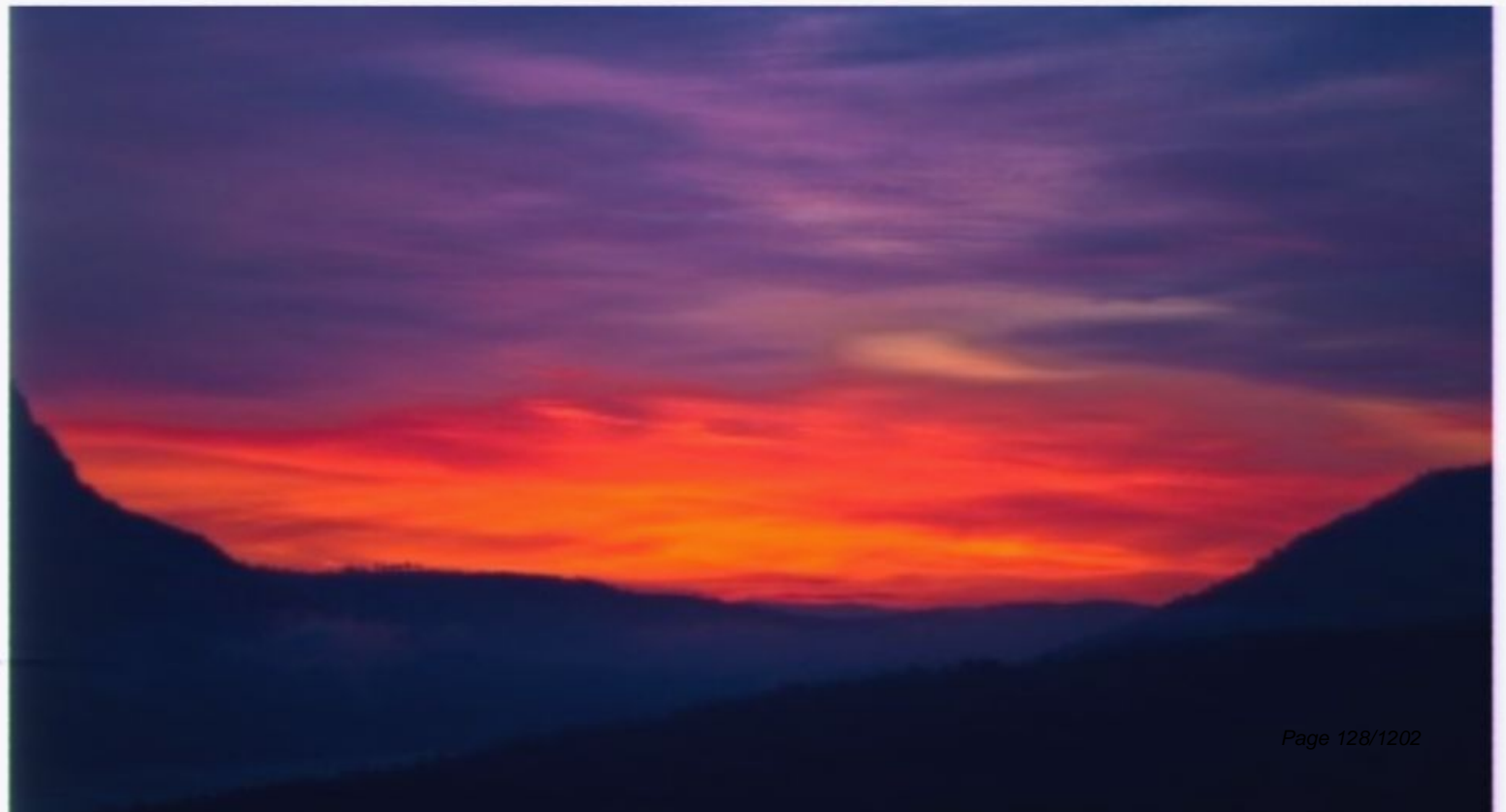
# red sky in morning

an exploration of the colours of the sky



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an exploration of the colours of the sky



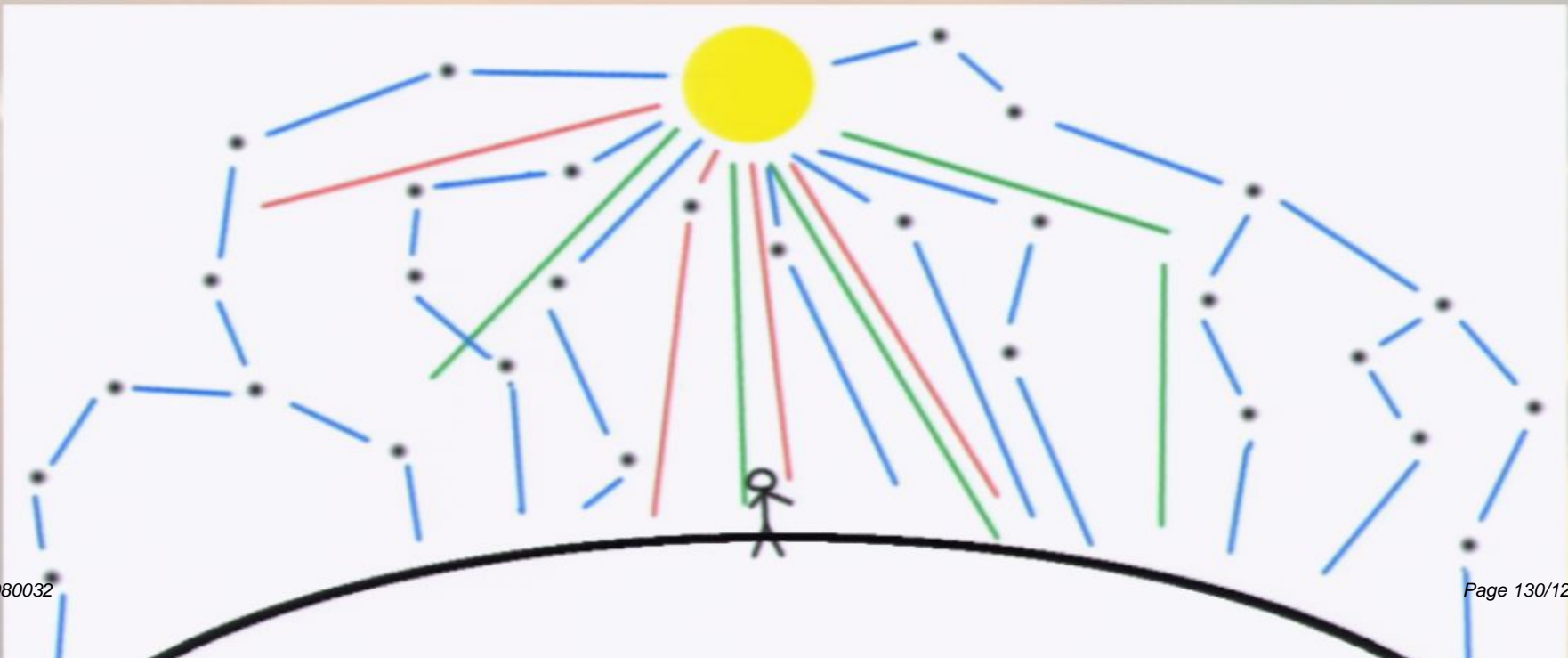
# Outline

1. Why is the sky coloured?
2. Why does the colour change at sunrise and sunset?
3. What can affect the colour of the sky?



# Why isn't the sky white?

- Rayleigh scattering:  $I \propto \frac{1}{\lambda^4}$
- Given  $\lambda_{red} = 750 \text{ nm}$  and  $\lambda_{blue} = 450 \text{ nm}$ ,  $I_{red} : I_{blue}$  is approximately 1:8



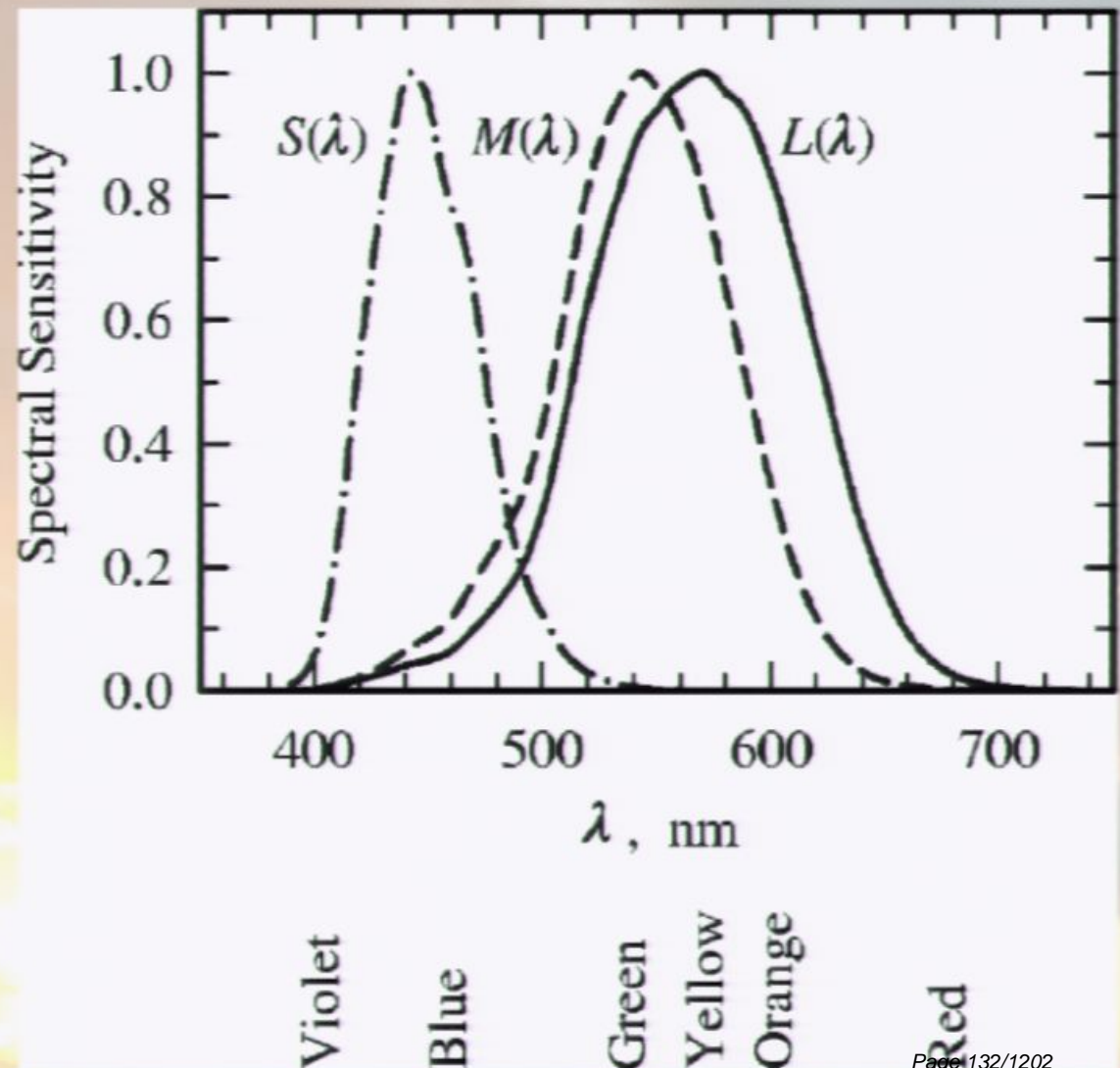




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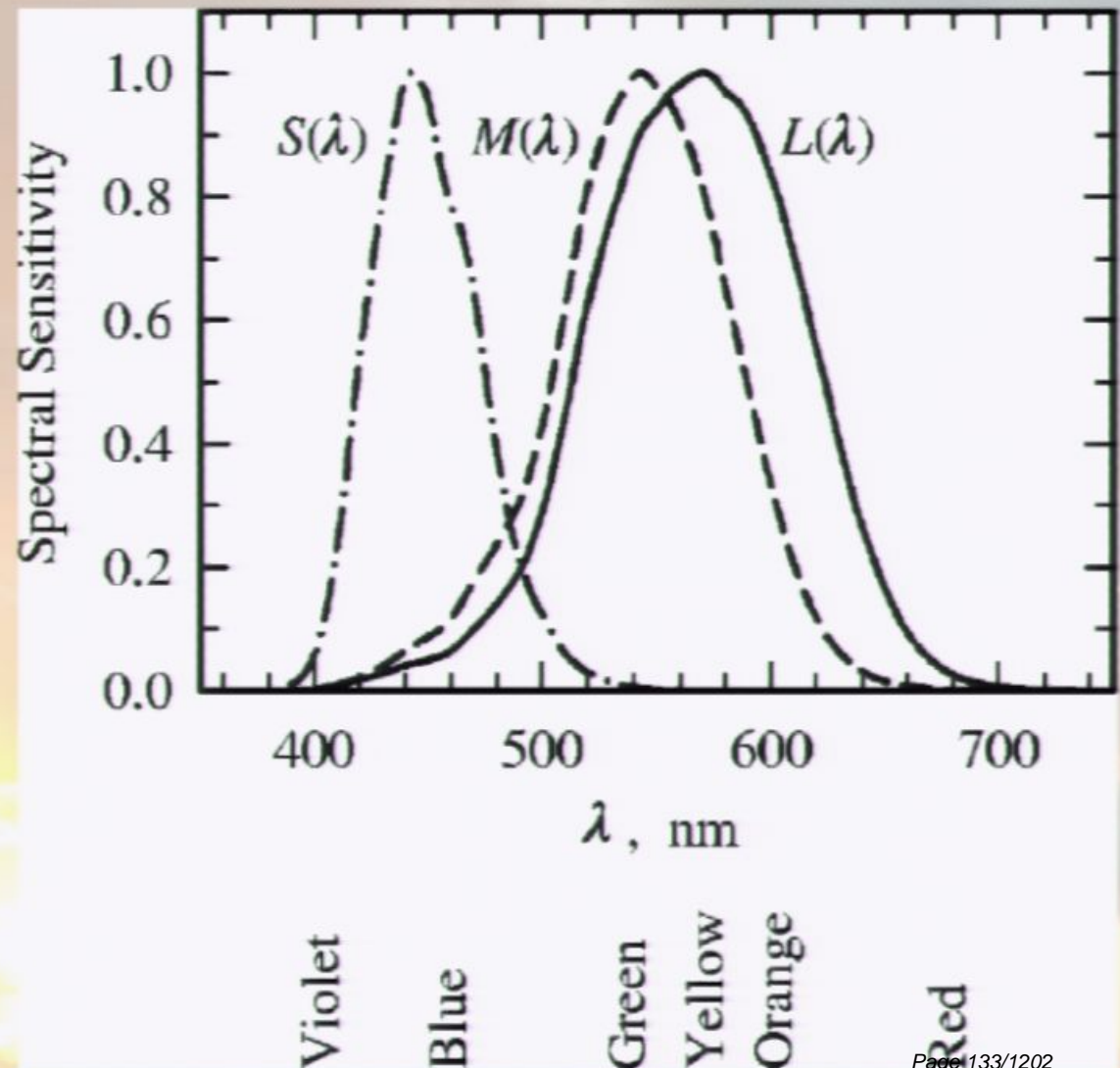
→ eye sensitivity



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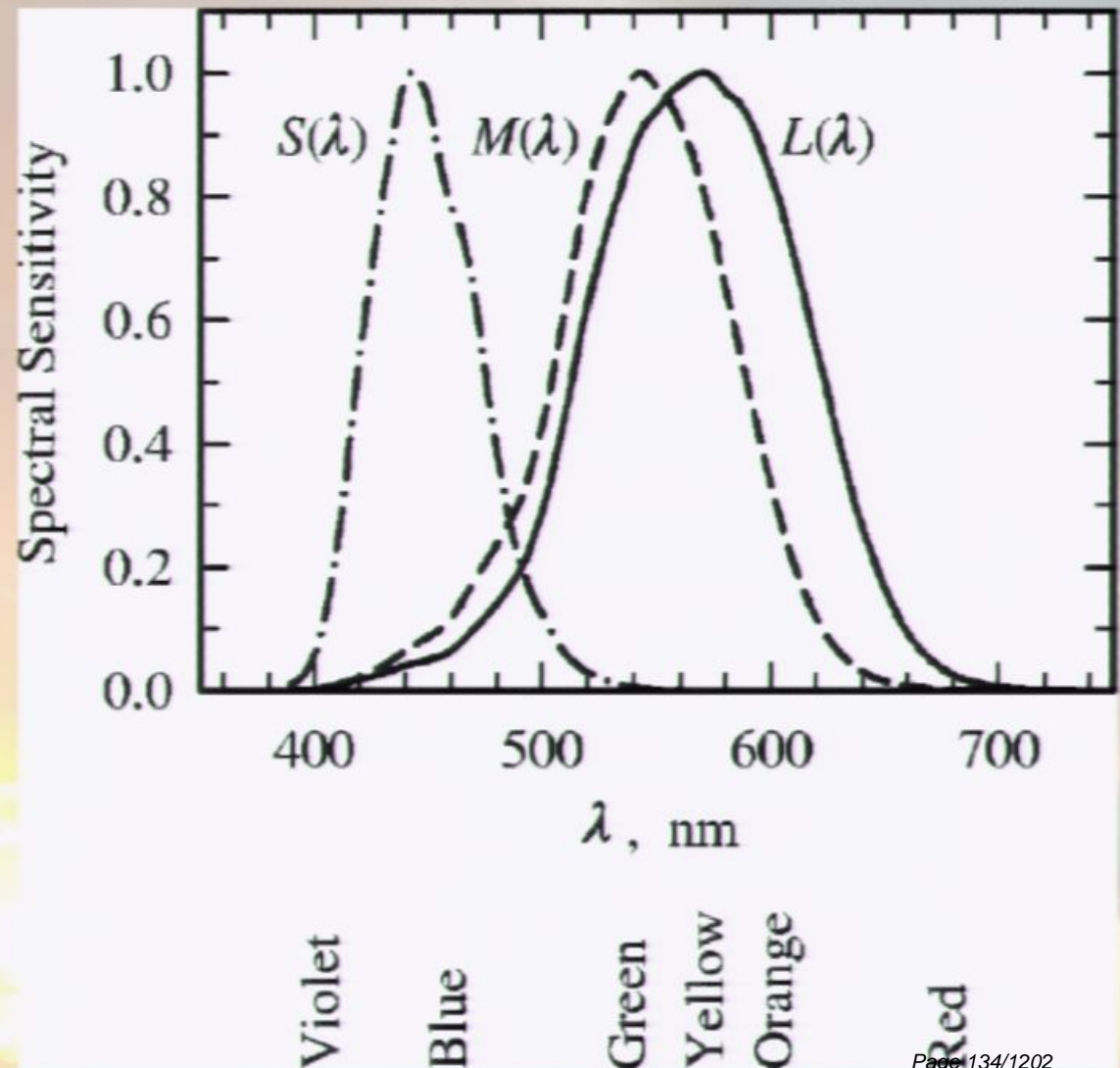




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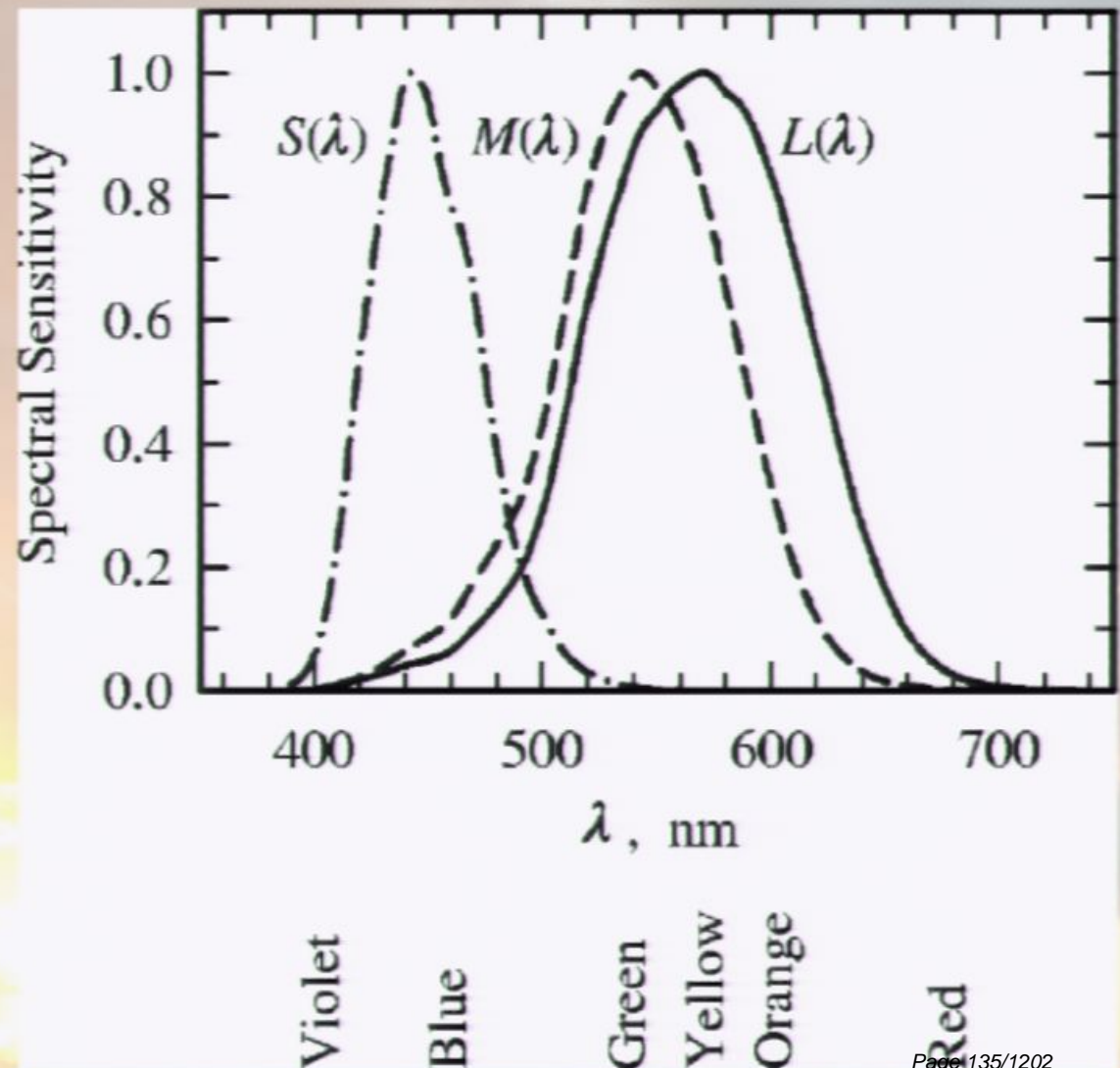
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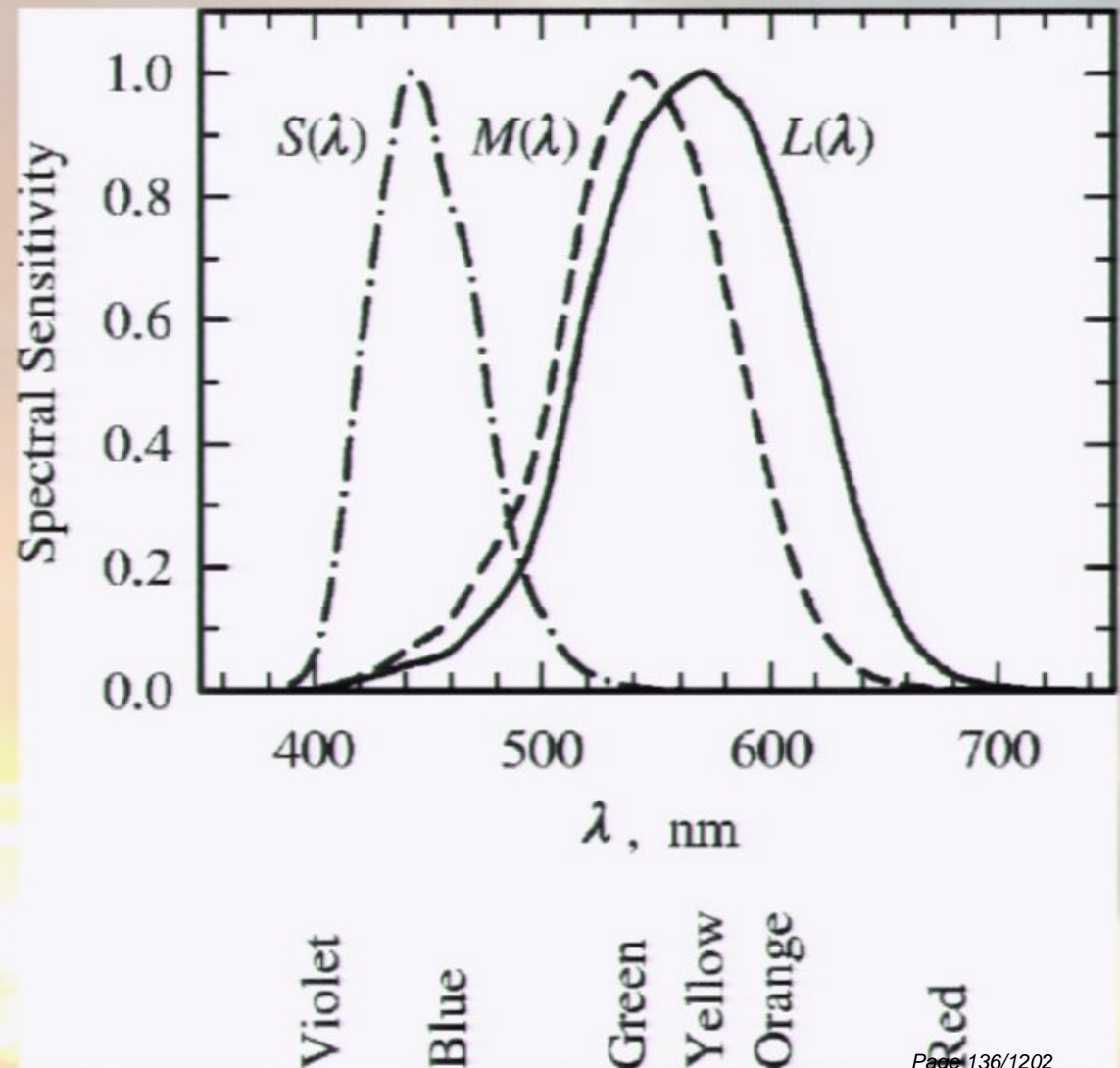
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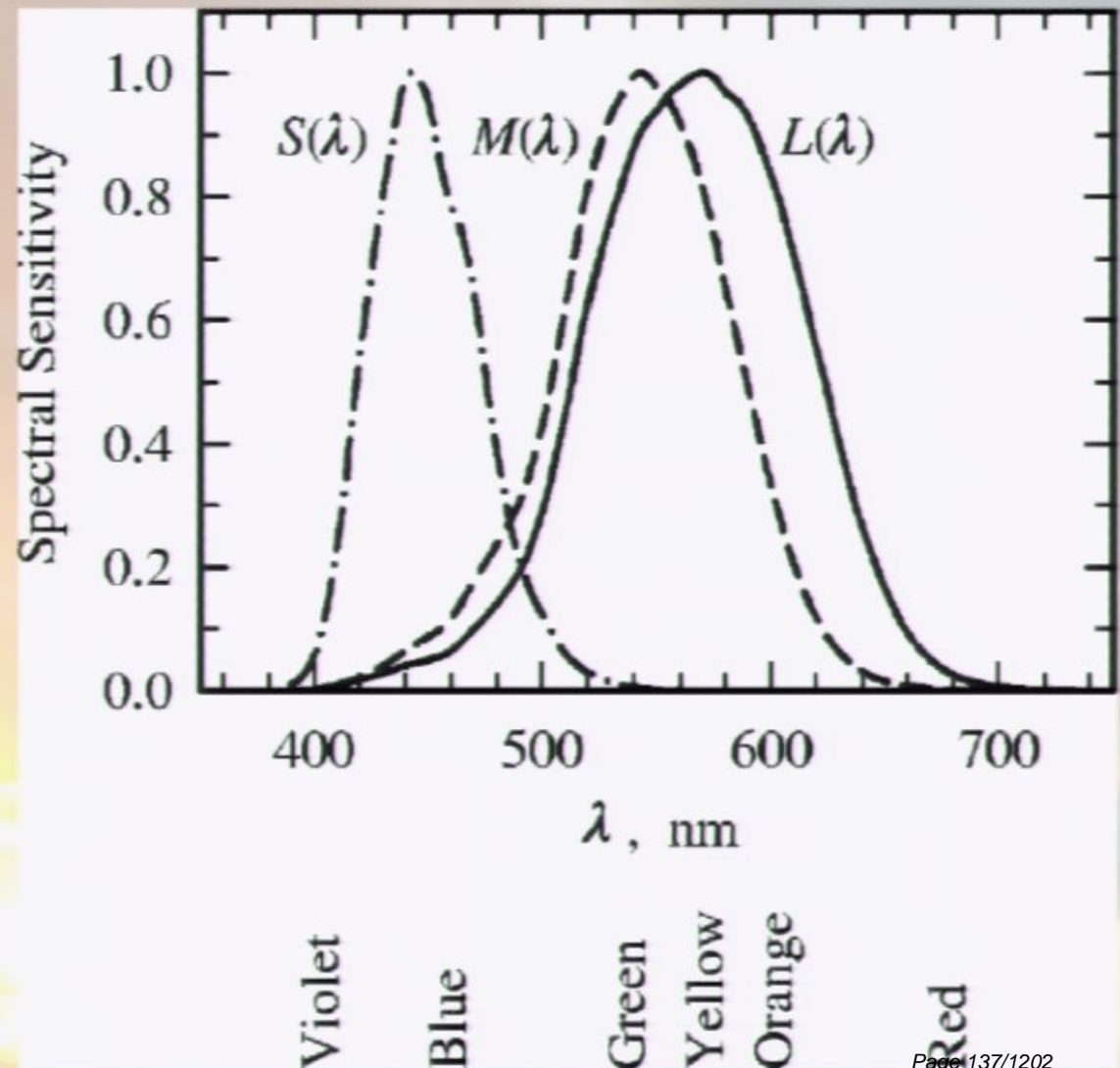




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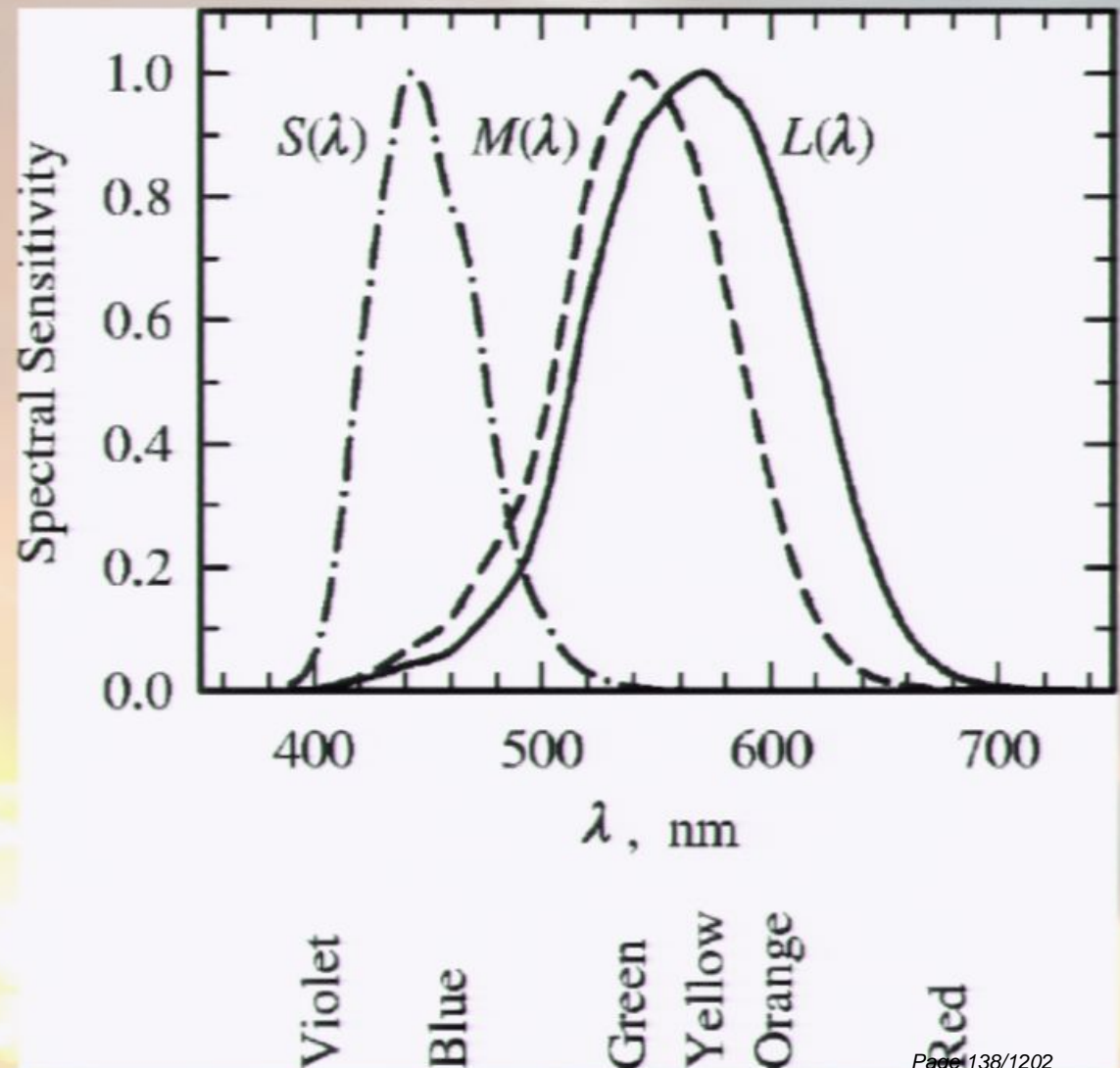
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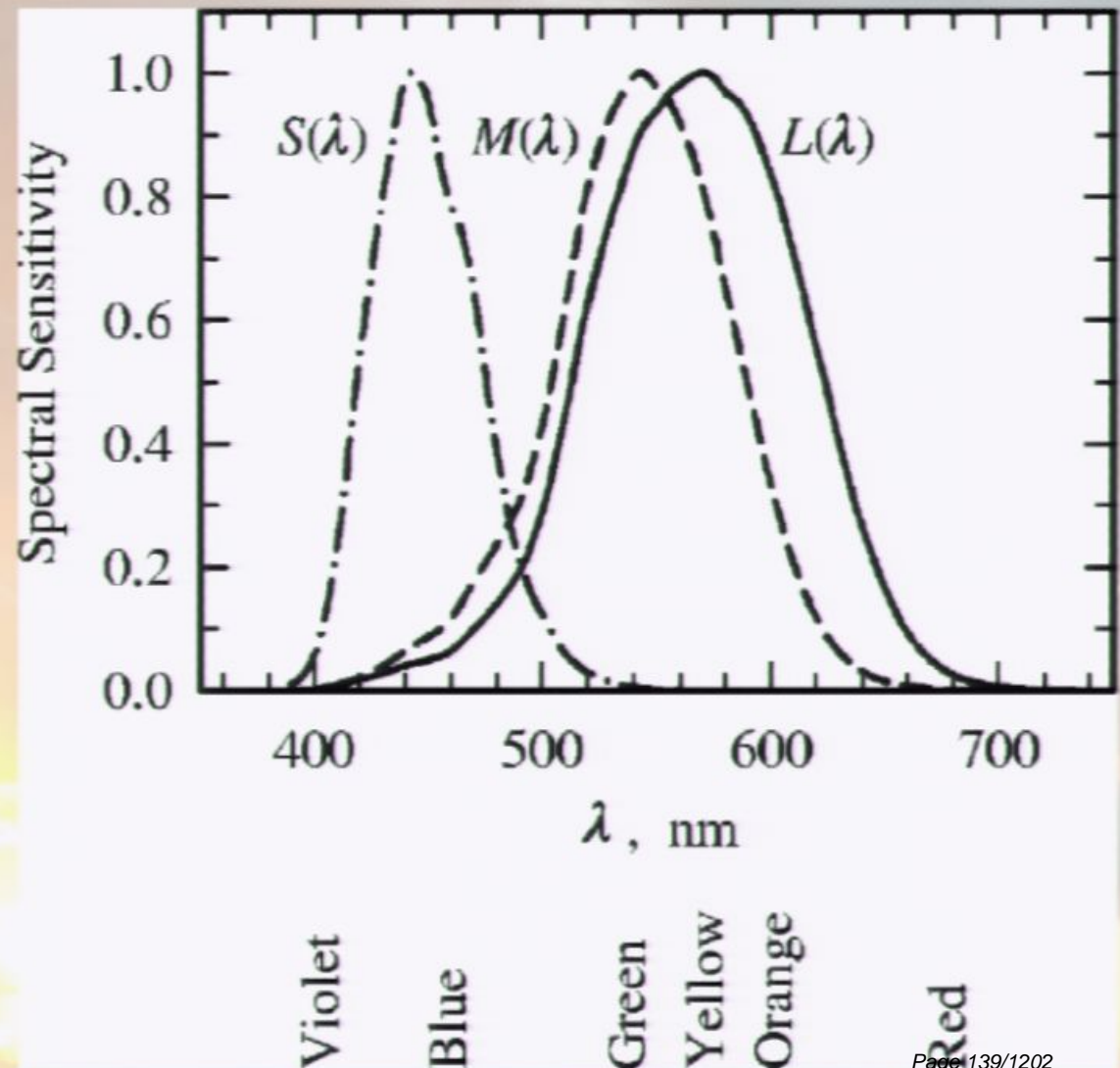




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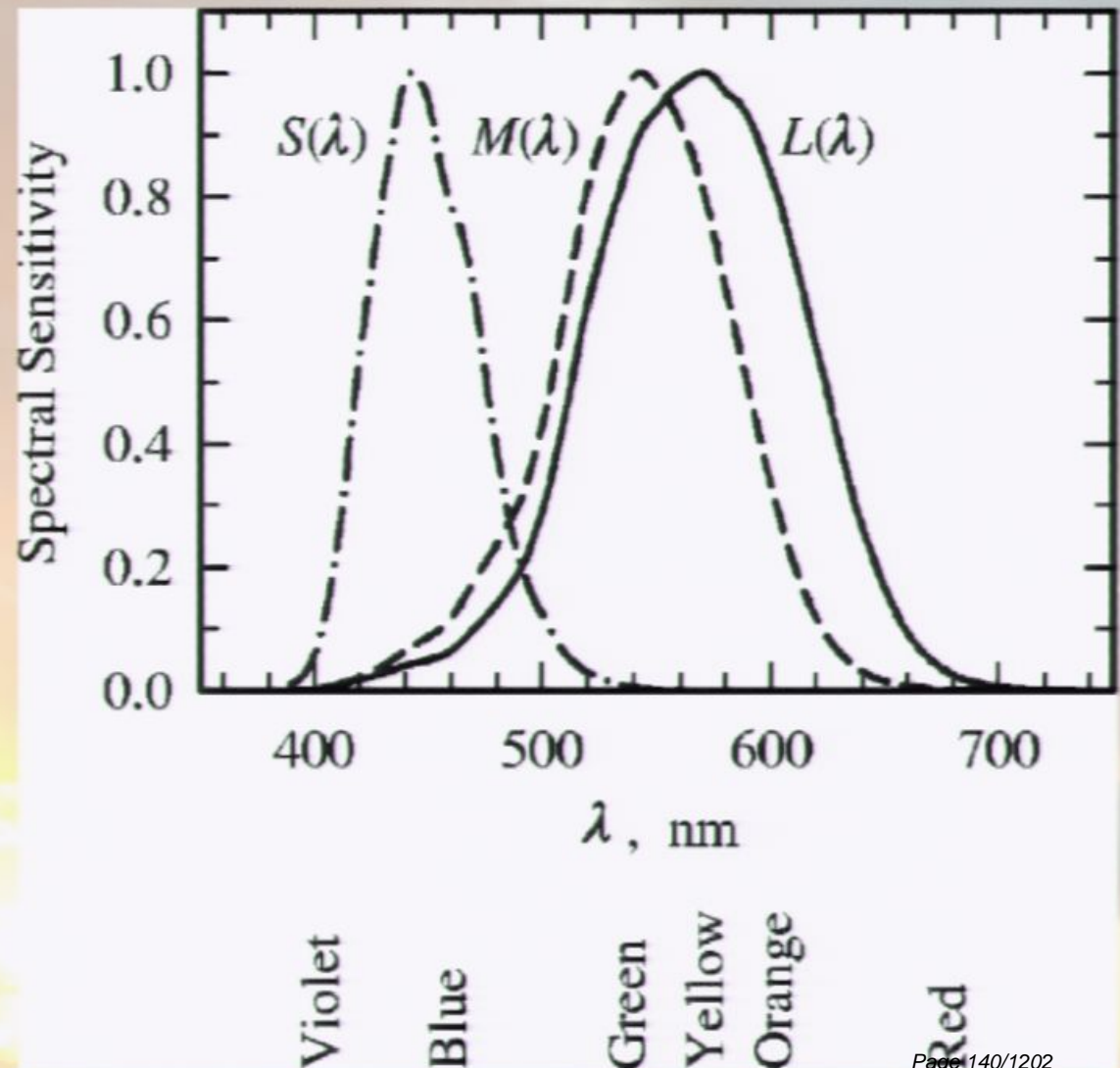
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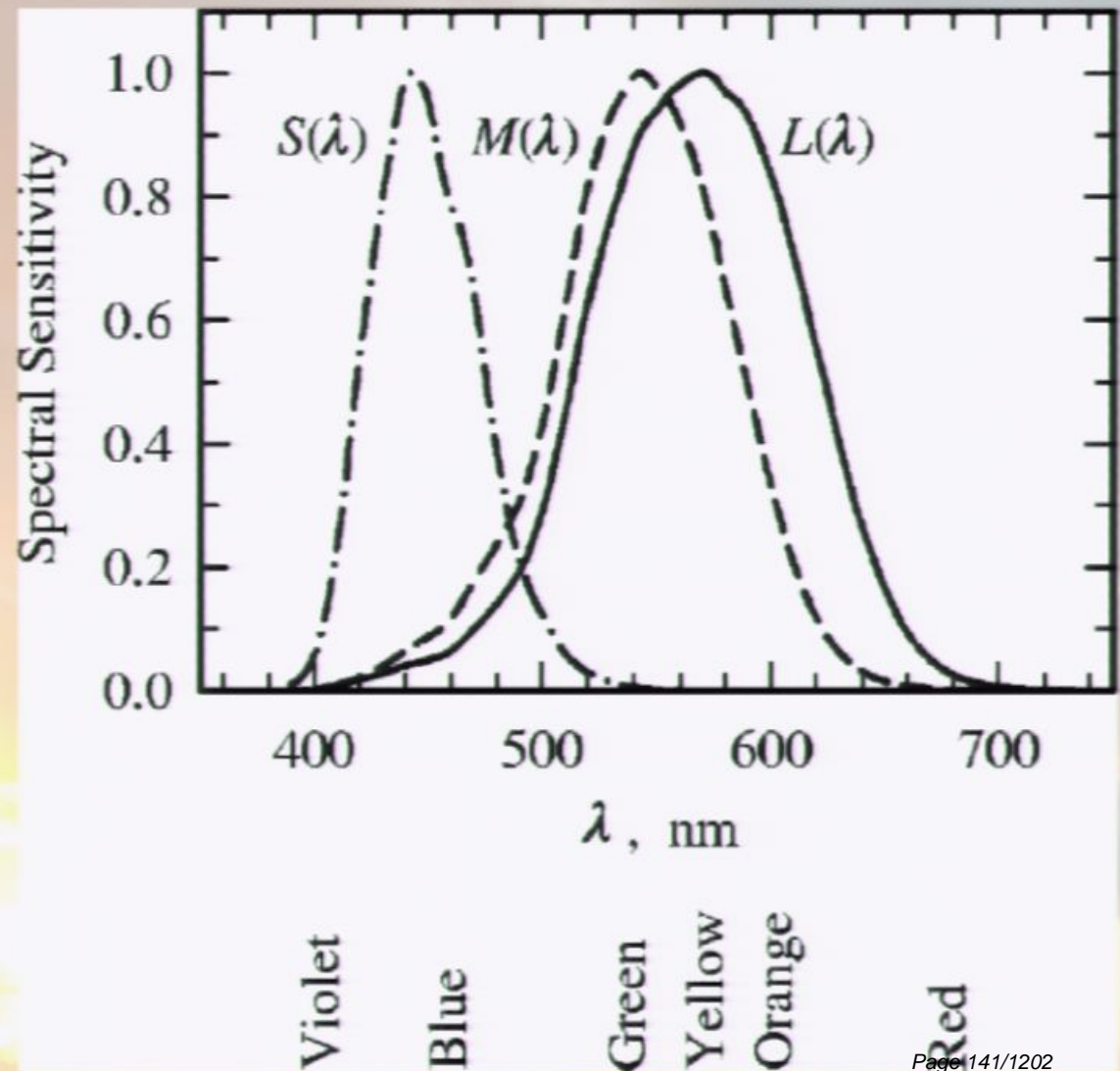
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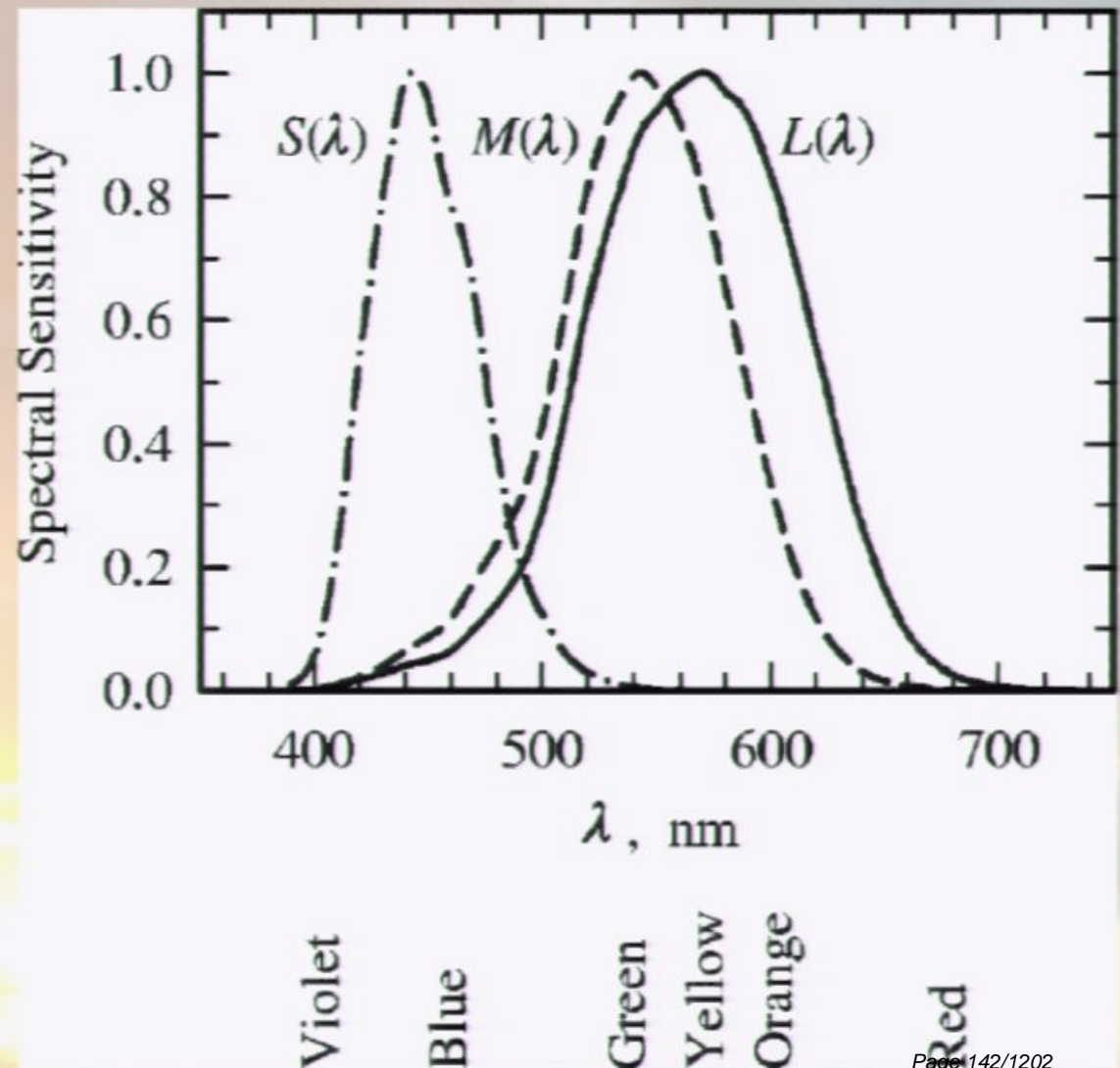




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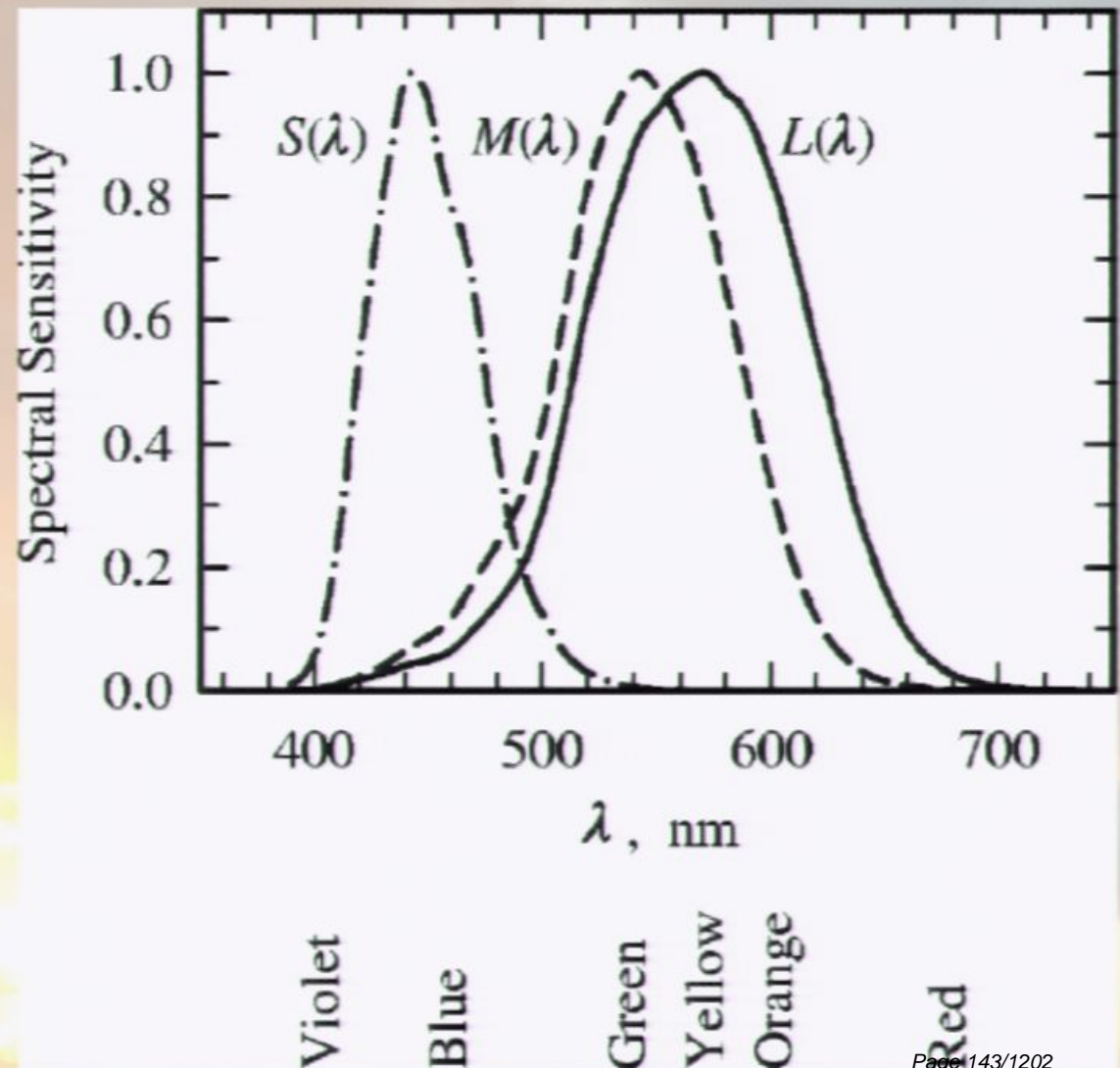
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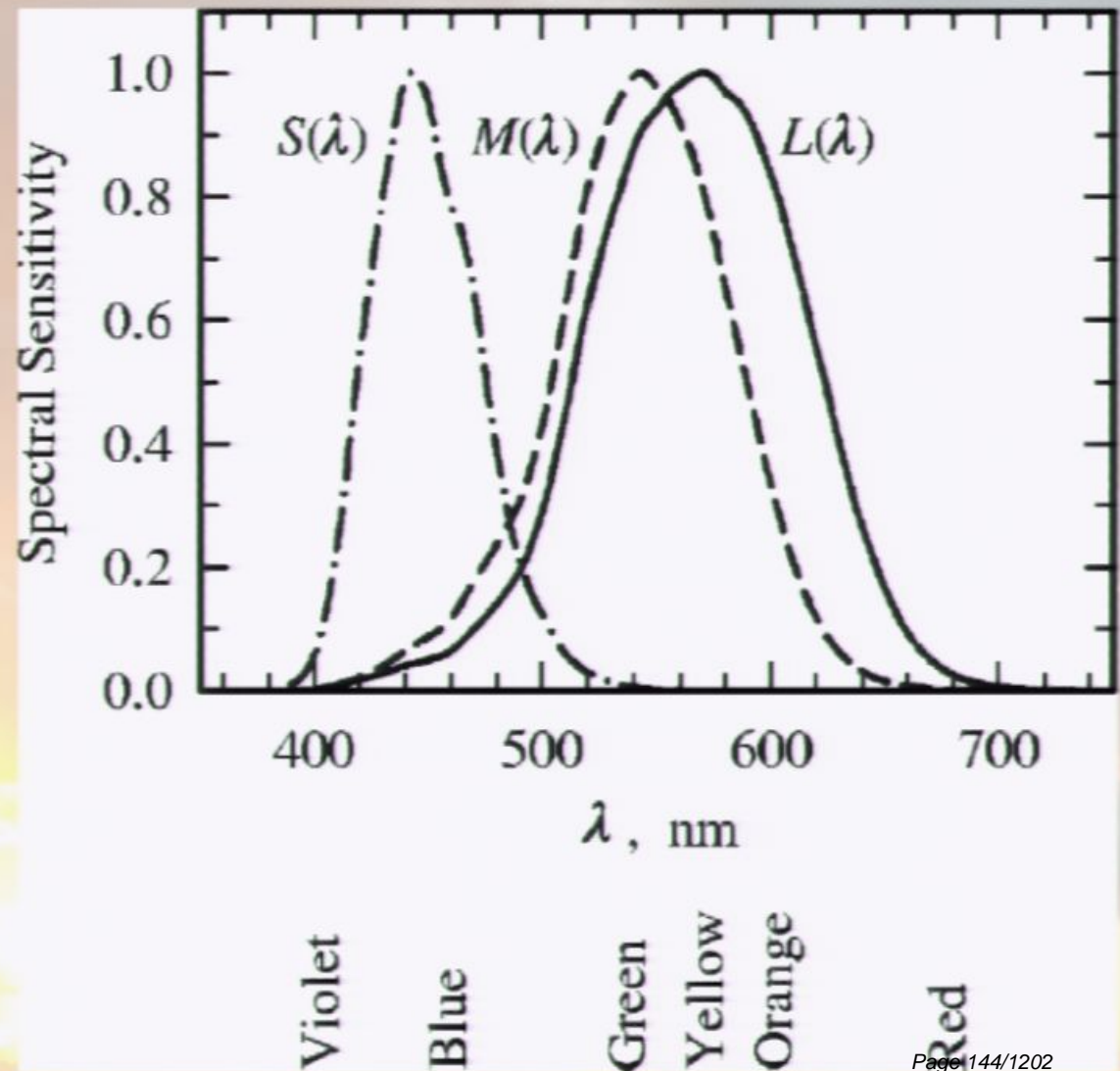
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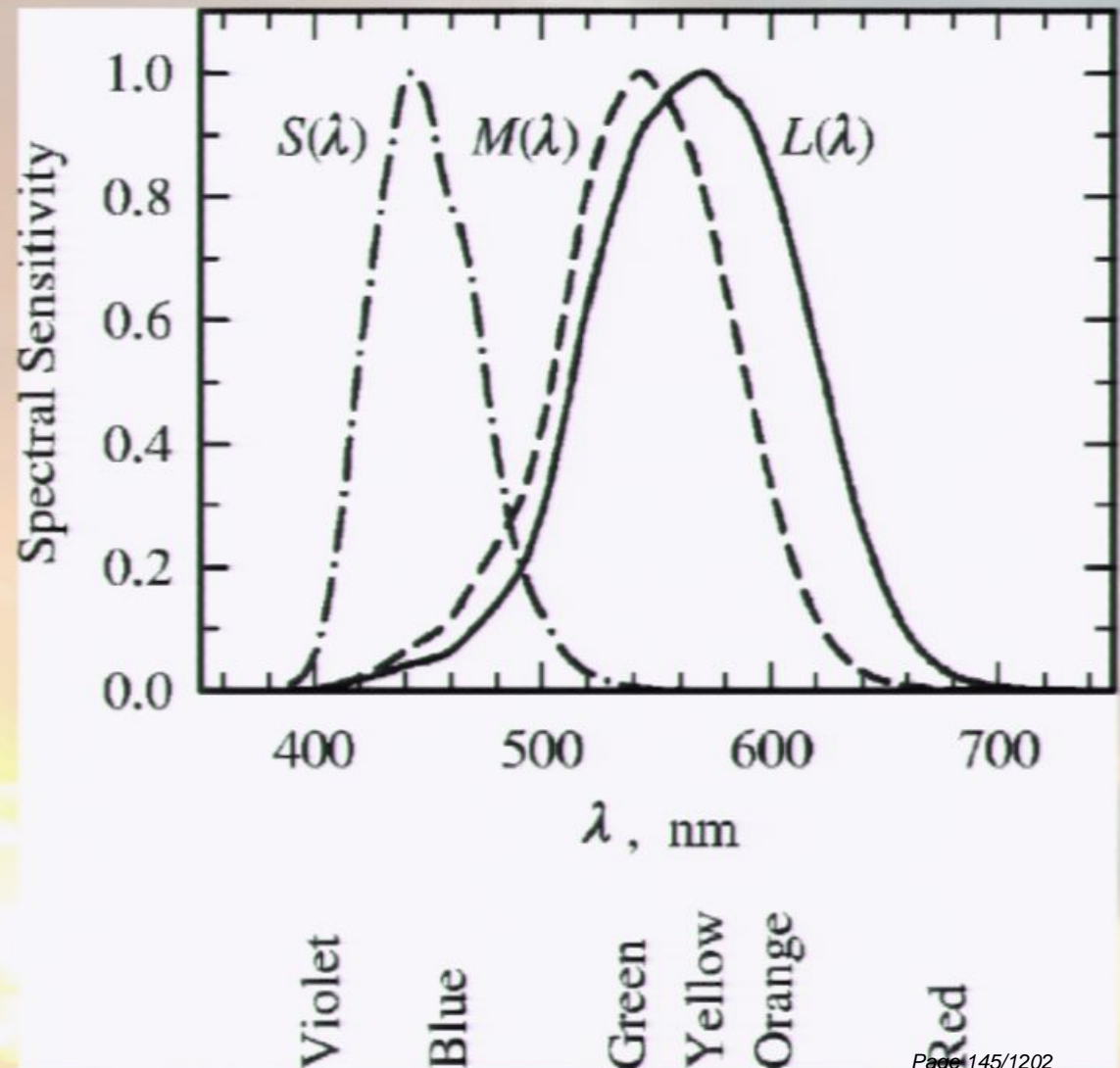




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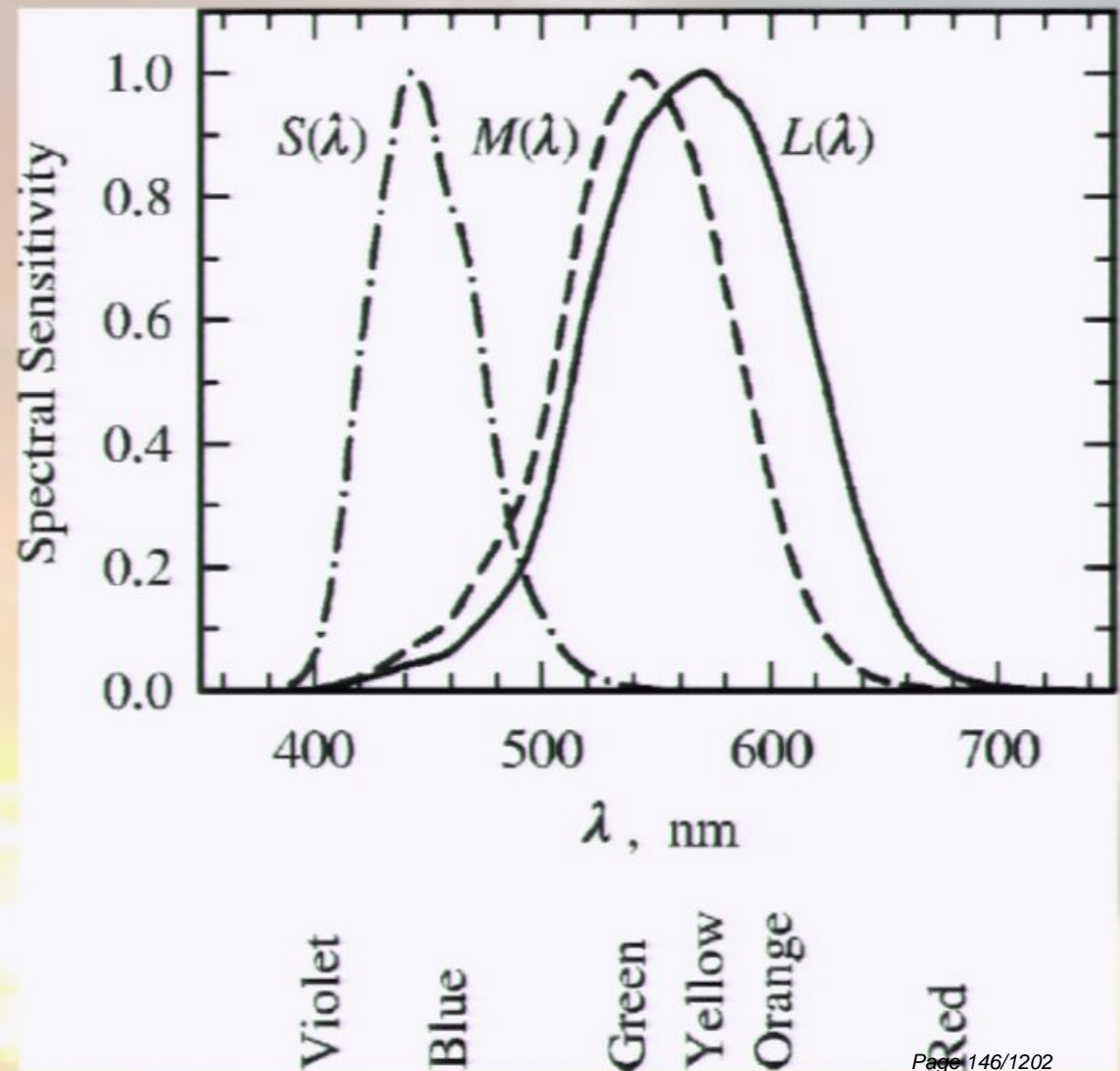




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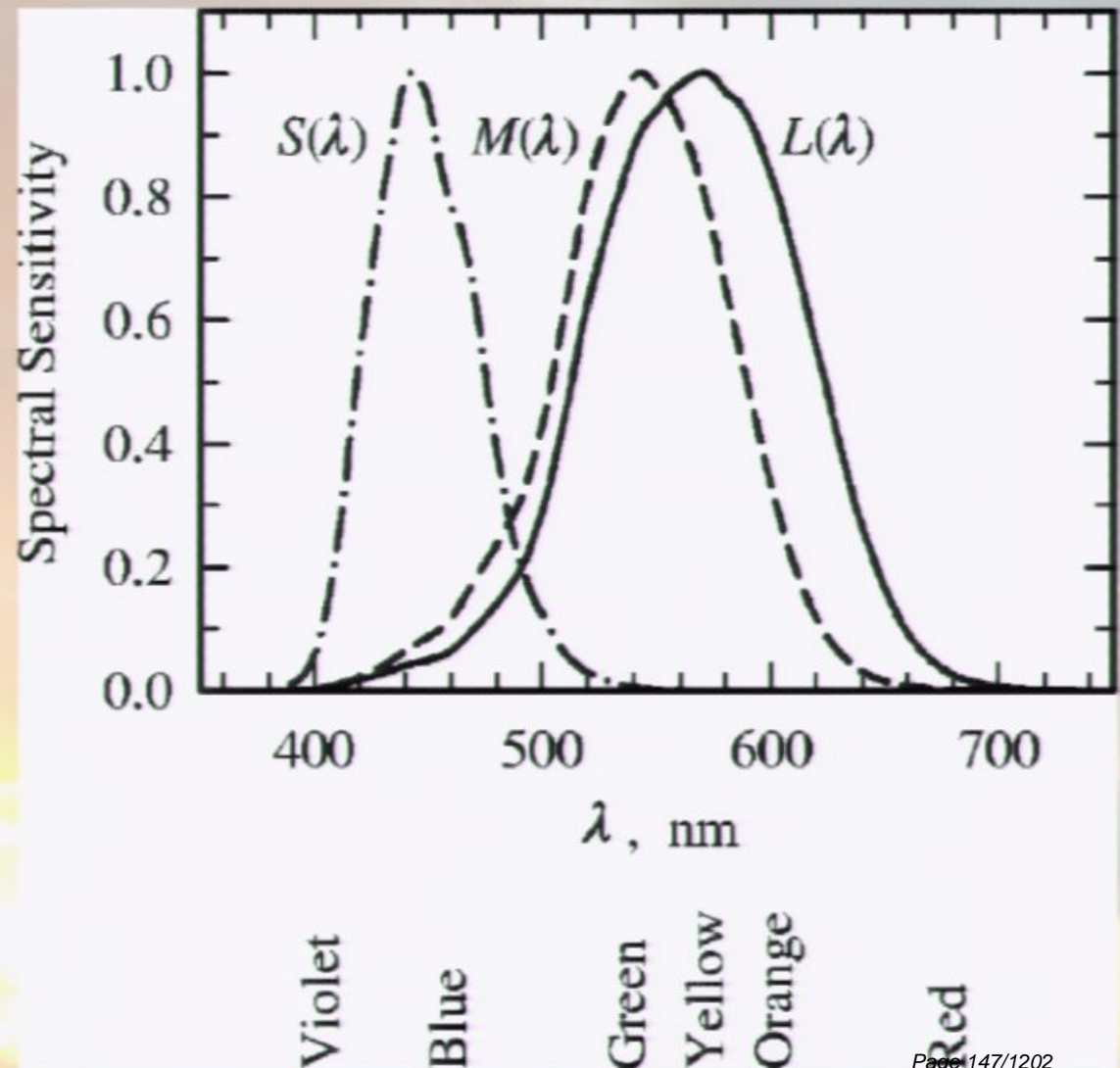
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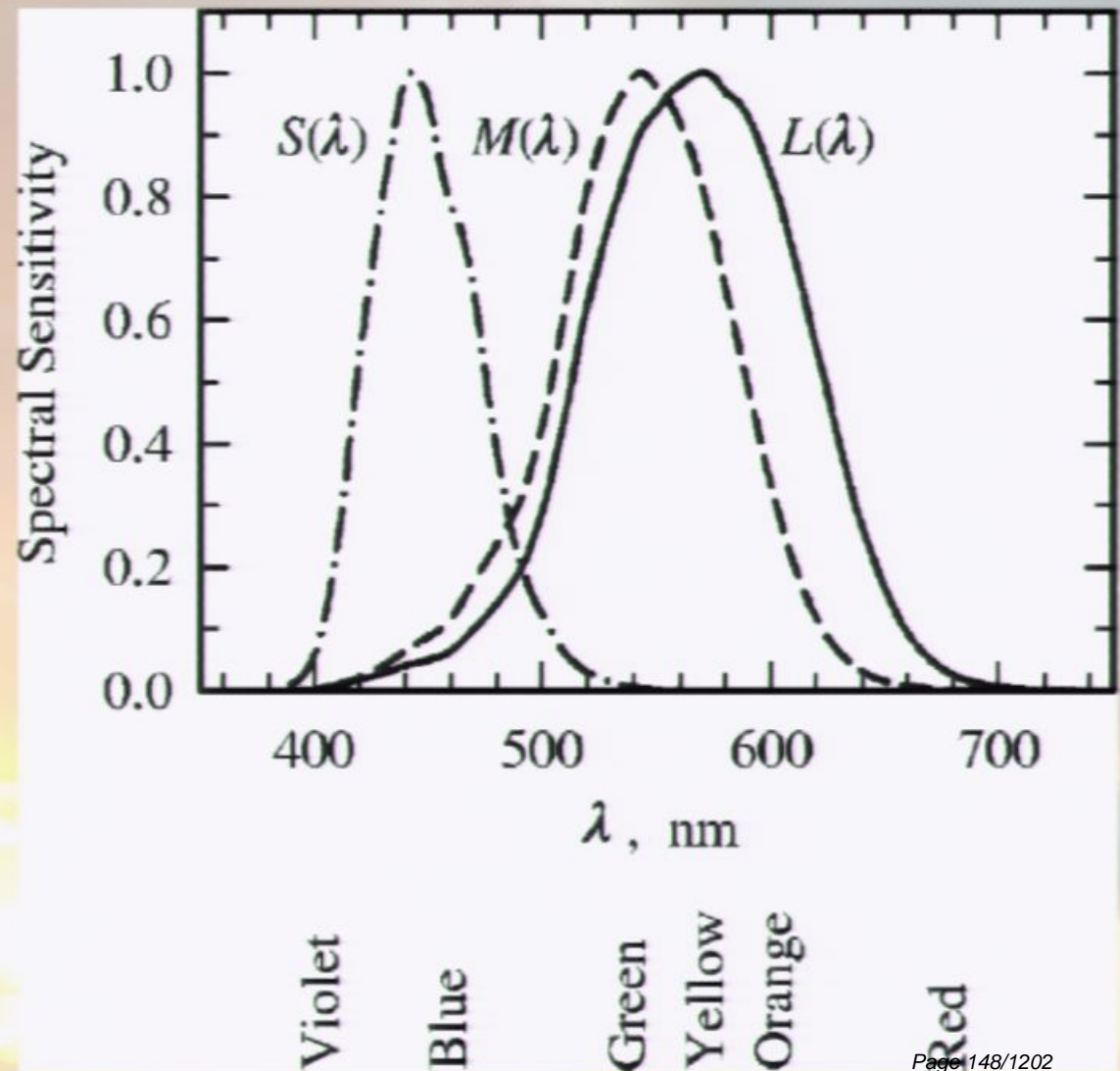
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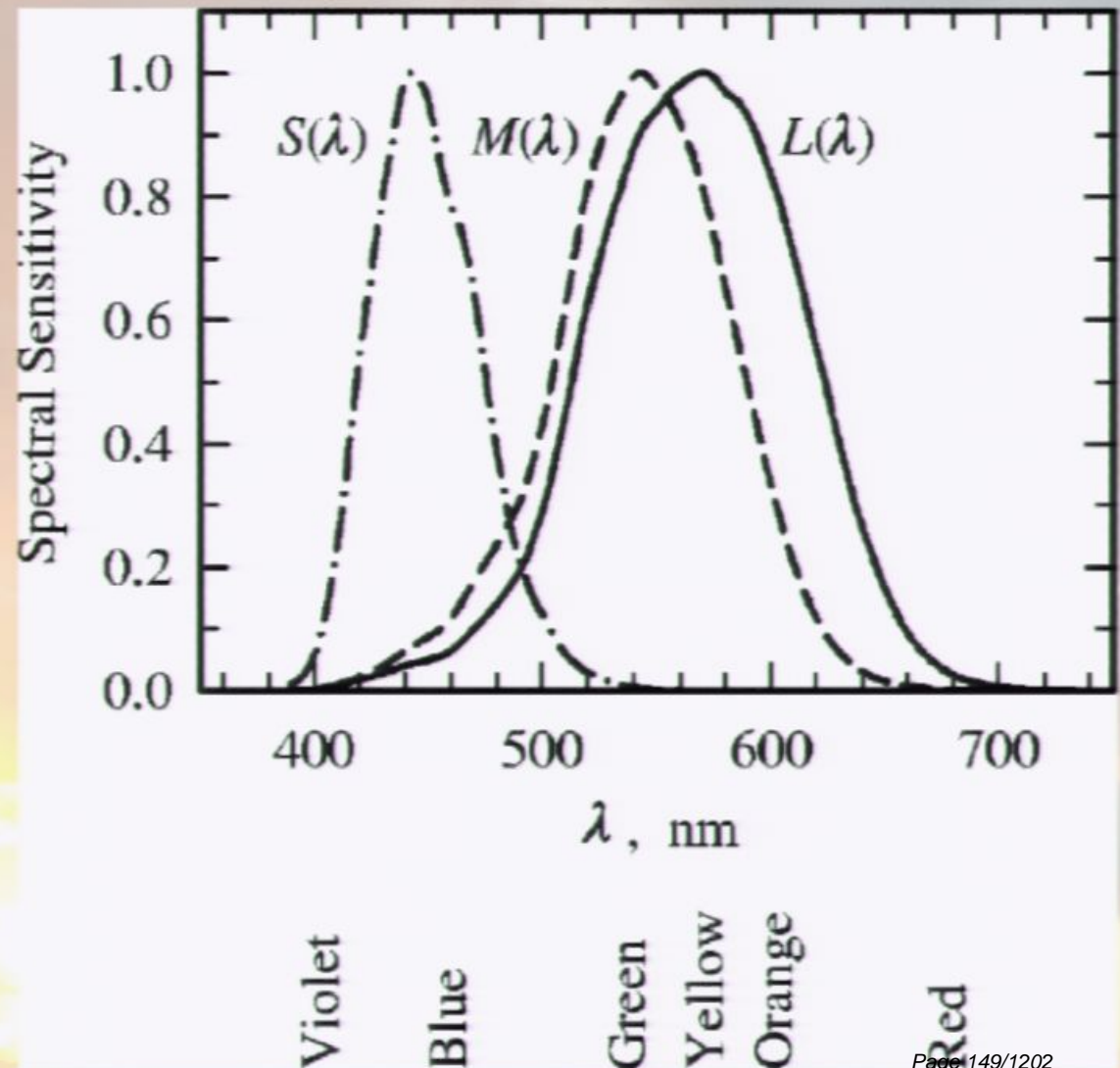




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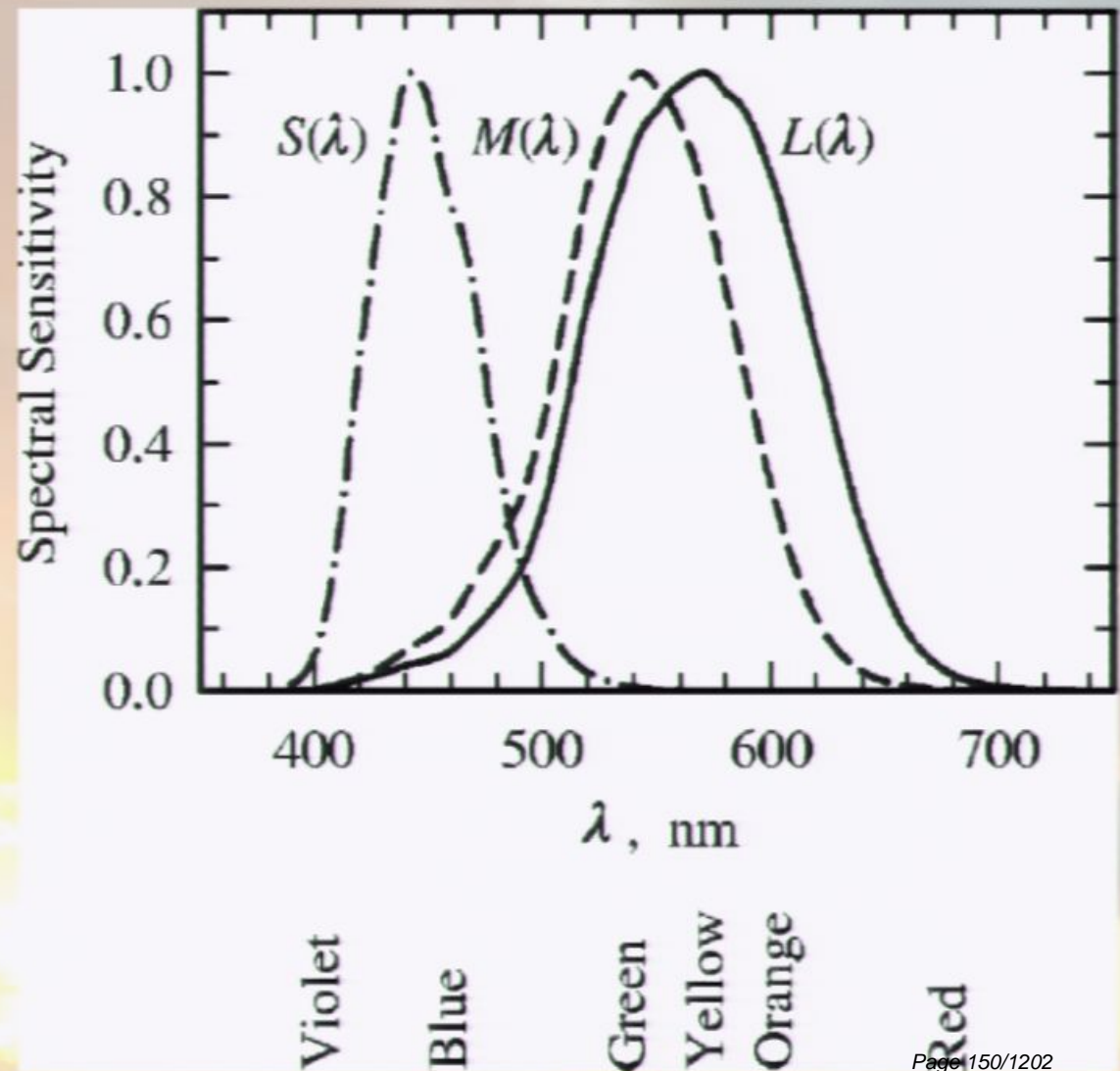
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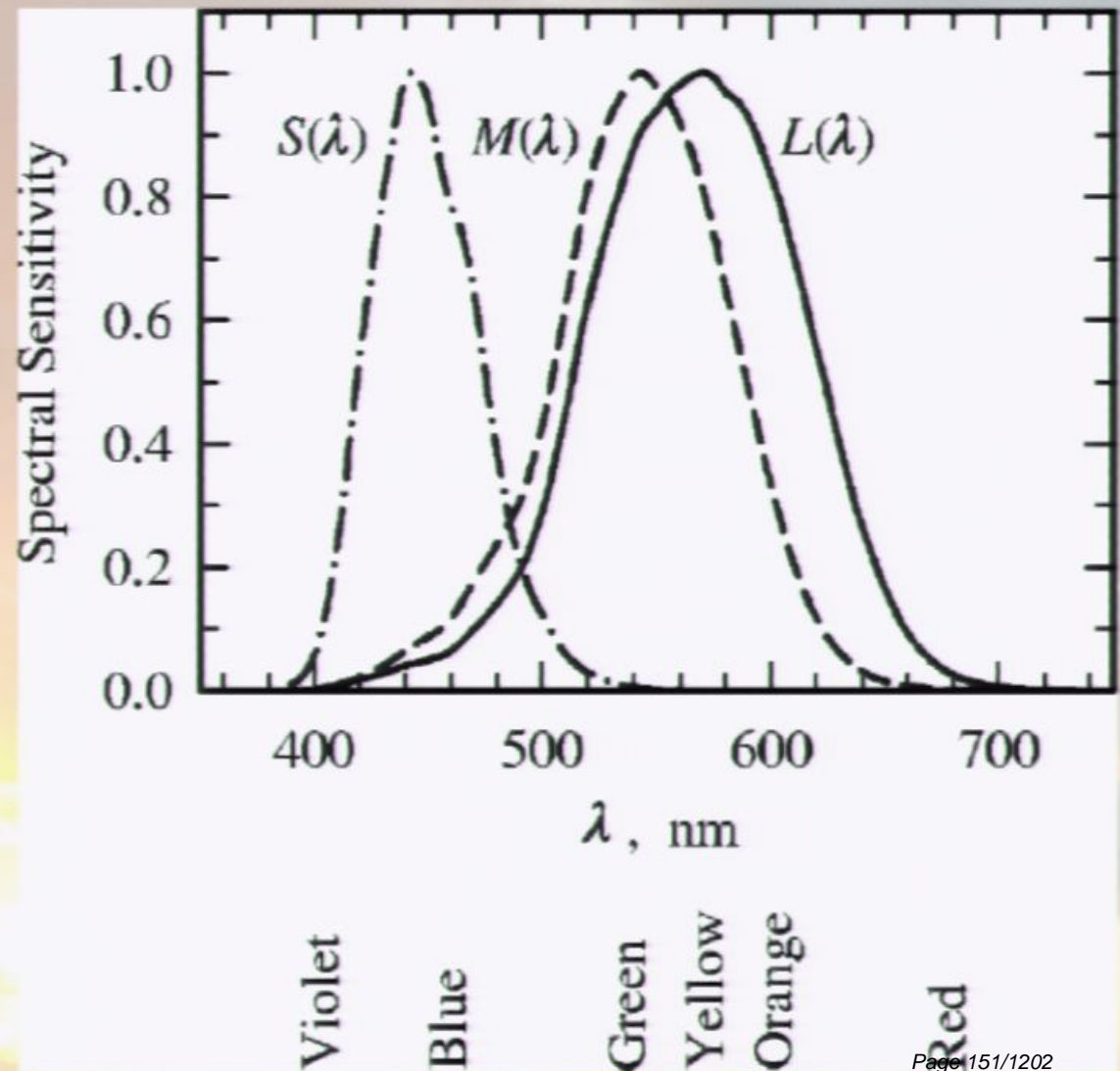
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# Looking at the sun

- Longer wavelengths are present in the area close to the sun



- Sky appears brighter because all wavelengths of light are present

- The sun itself appears white or yellowish during the day



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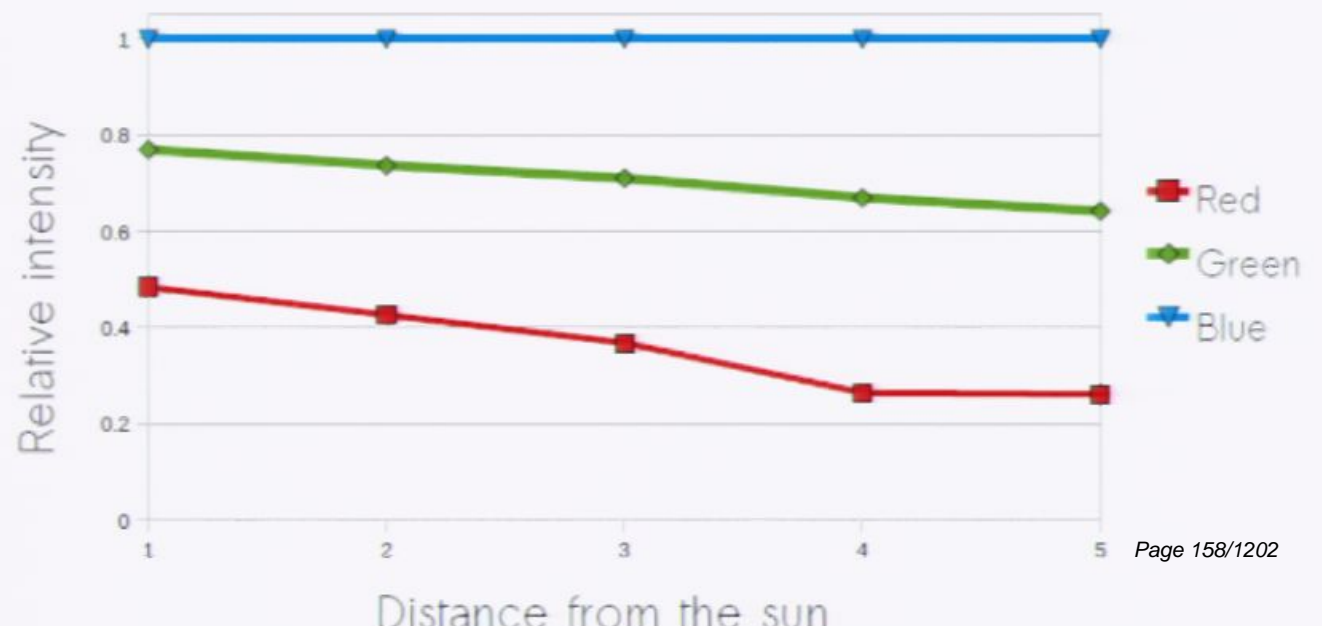
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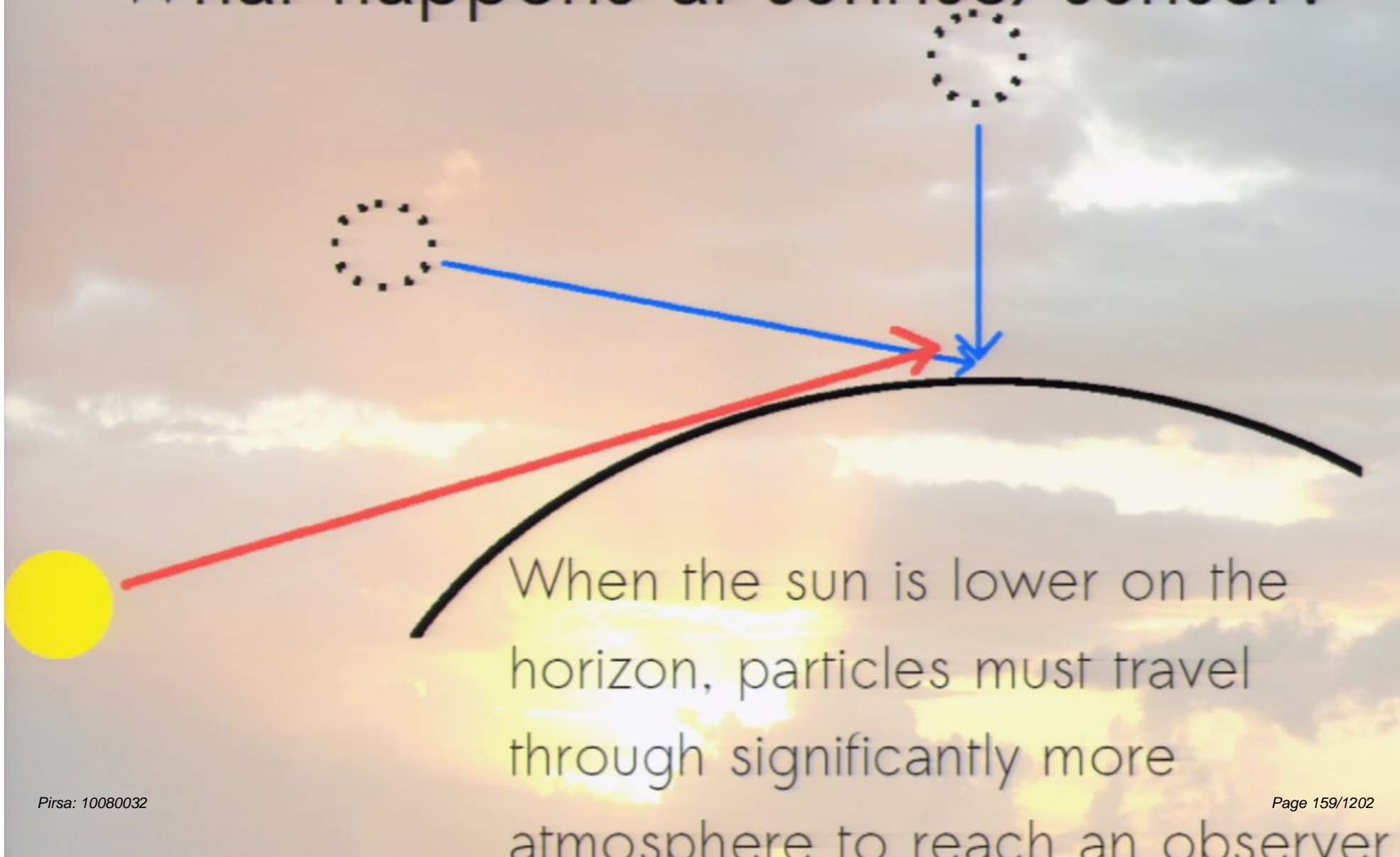


## Colour of light in the sky





# What happens at sunrise/sunset?



When the sun is lower on the horizon, particles must travel through significantly more atmosphere to reach an observer

# What happens at sunrise/sunset?



- Long wavelength light traveling far enough is effectively scattered, since light will counter enough atmospheric particles to scatter



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- Light scatters off different sizes of molecules differently (eg. Mie scattering and clouds)
- Particulates in the air can affect the colour of the sunrise or sunset:
  - Salt from the ocean
  - Dust in the air from passing storms
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# Particulates

- Dust can create a redder sky
- The main pollutants over eastern North America are sulphates (Husar and Wilson, Env. Sci. and Tech., 1993)
- Sulphates are hygroscopic, and aerosols are formed to approximately the same diameter as the wavelength of light
- Unless all aerosols are of the same diameter, haze or smog will scatter light just as clouds do



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# Conclusions

- The day sky appears blue because of Rayleigh scattering
- When the sun is low on the horizon, longer wavelengths are scattered
- Particulates in the sky can either tint the sky or create a faded, pastel appearance



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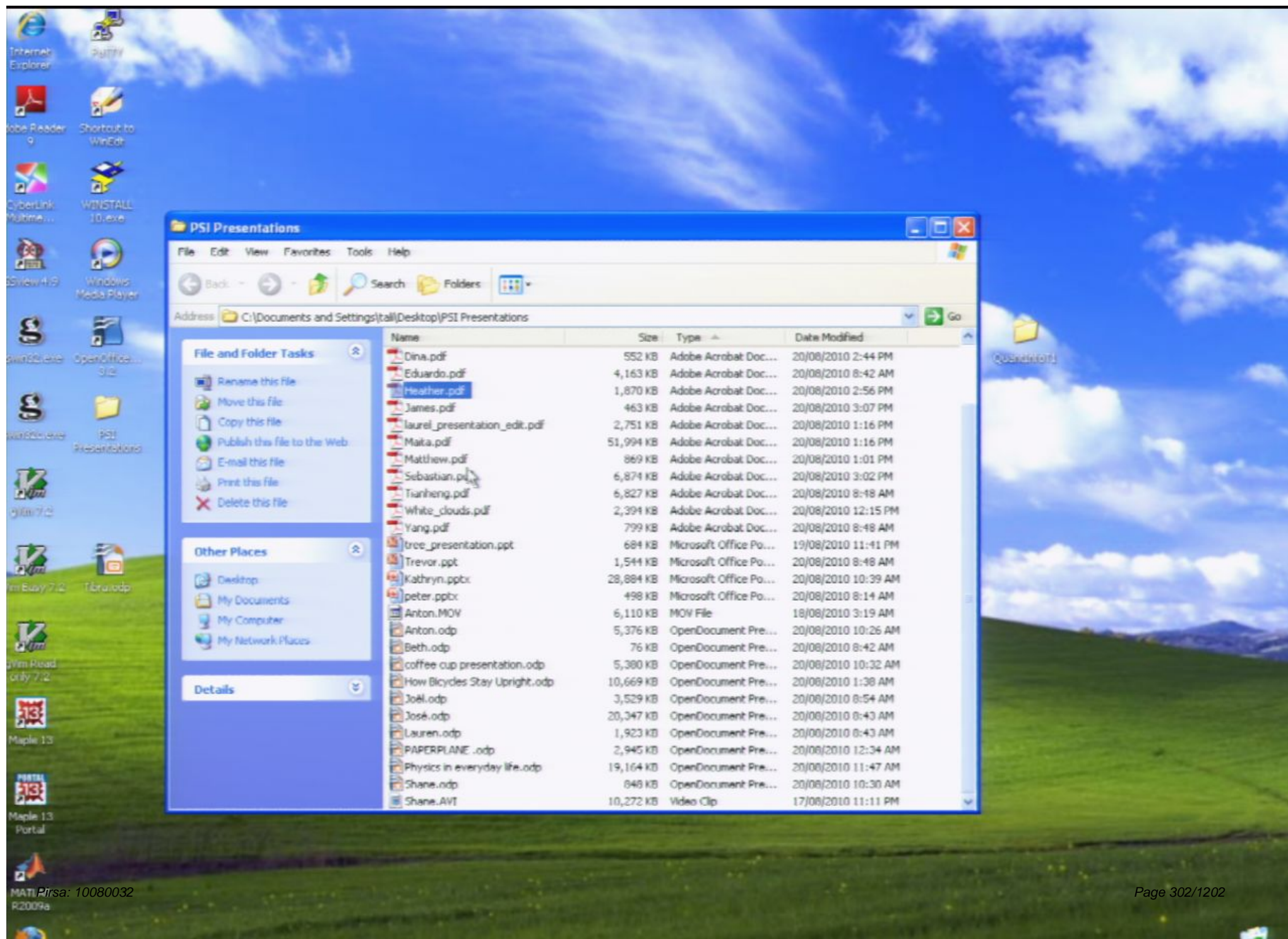
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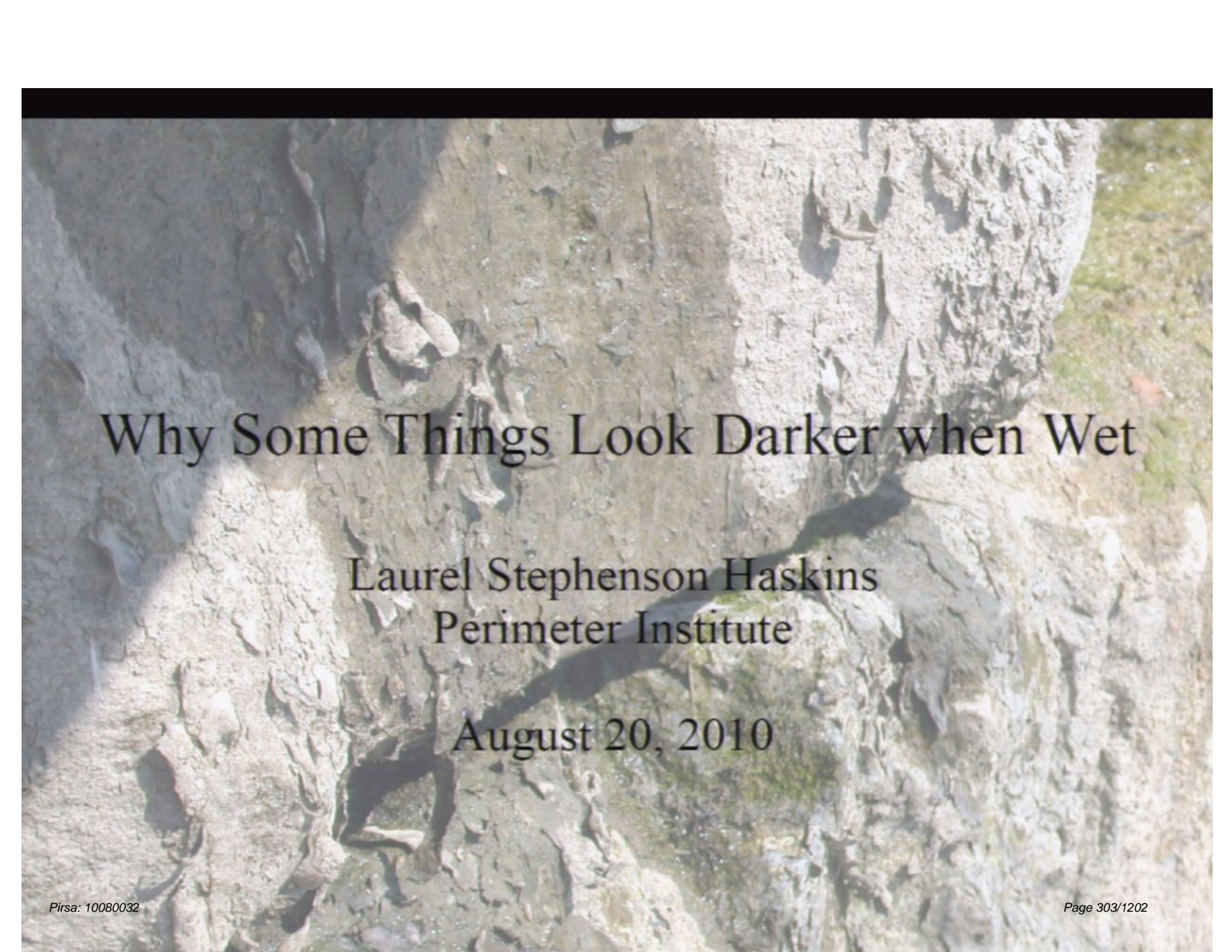


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# Why Some Things Look Darker when Wet

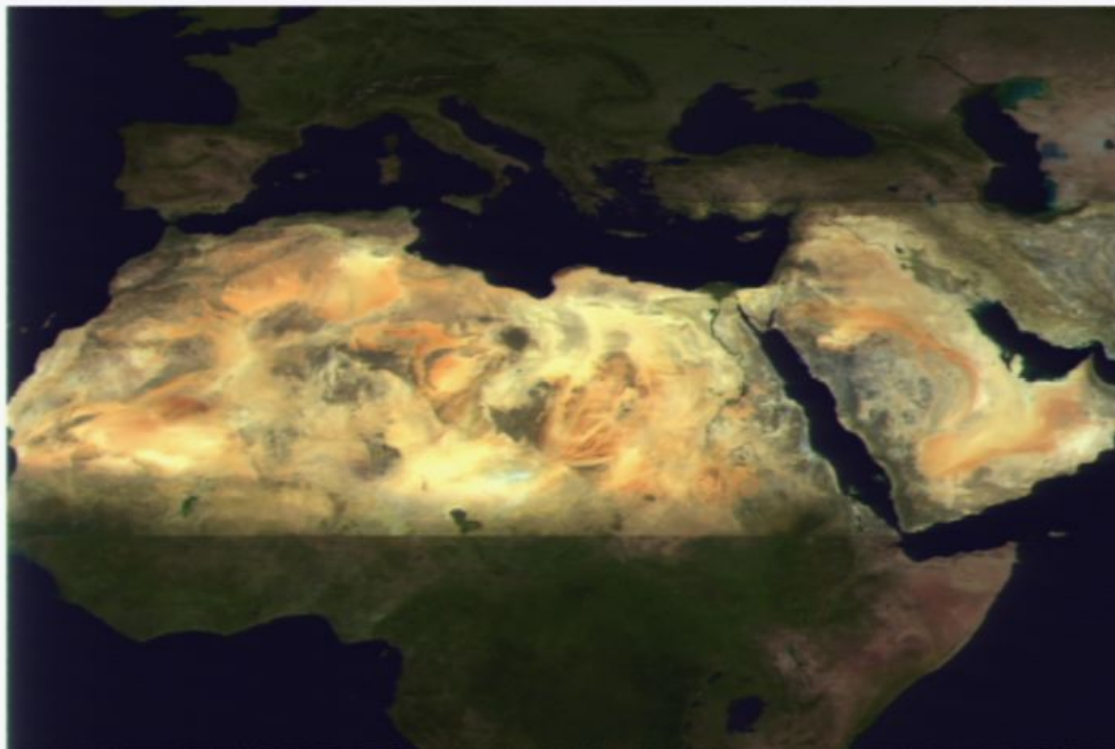
Laurel Stephenson Haskins  
Perimeter Institute

August 20, 2010



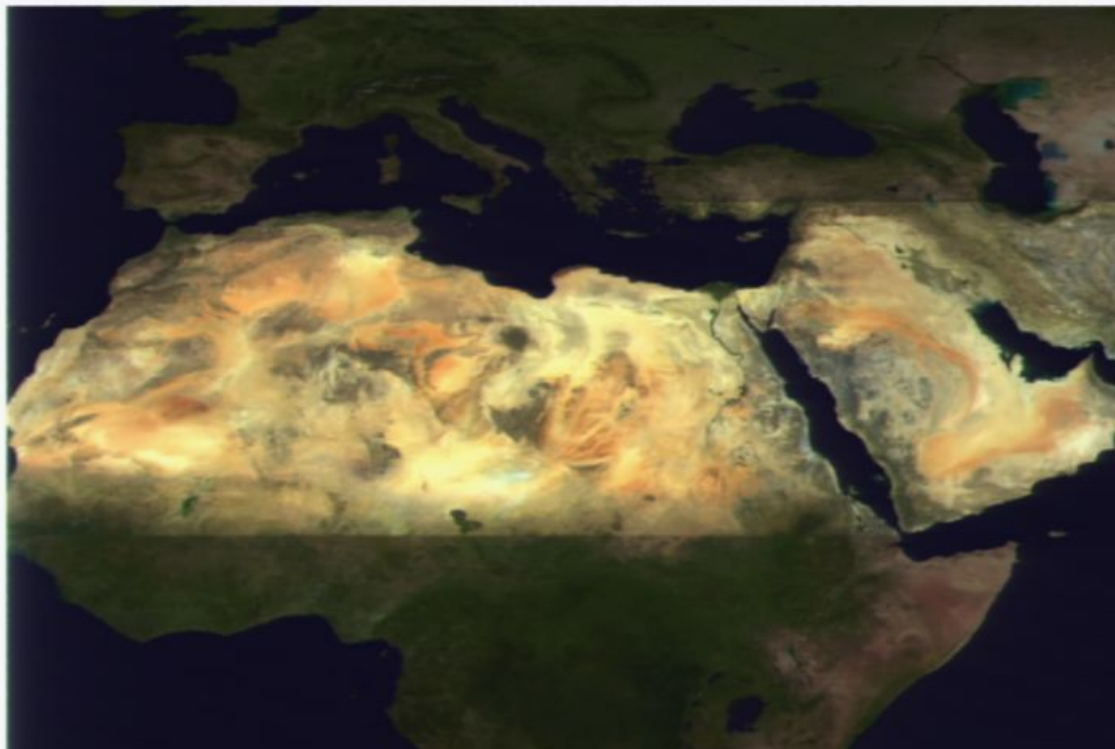
# Motivation

- Environmentally important, because the issue of surface albedo on a larger scale is essential to our understanding of Earth's climate.



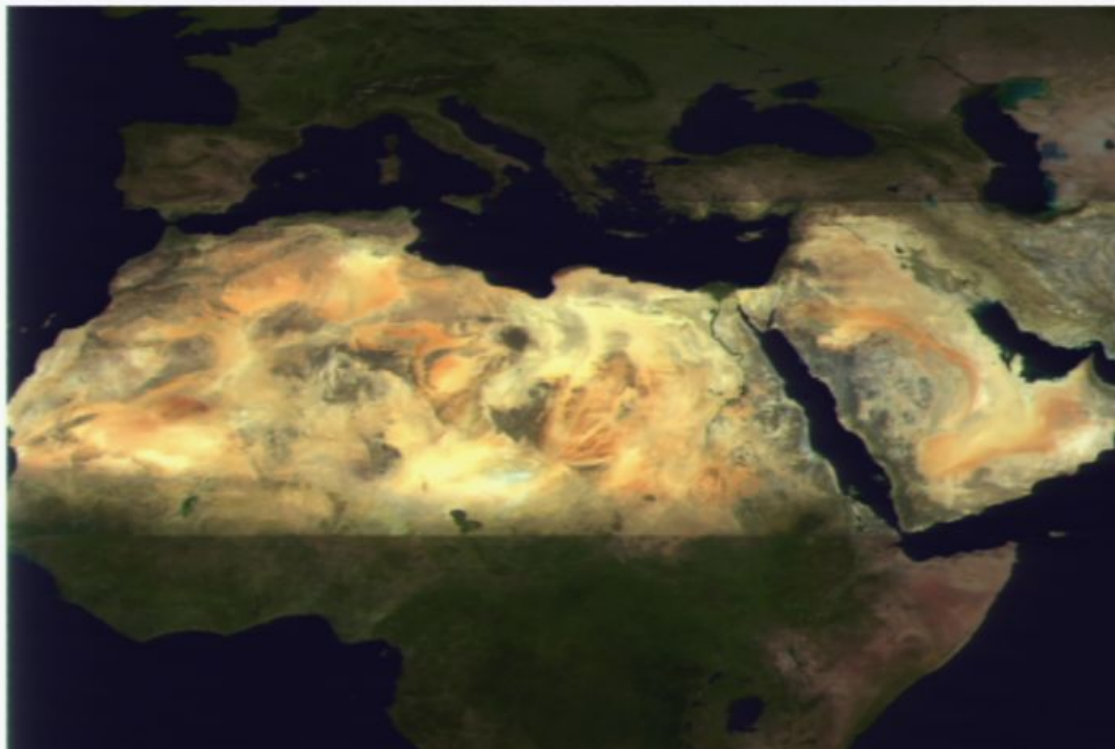
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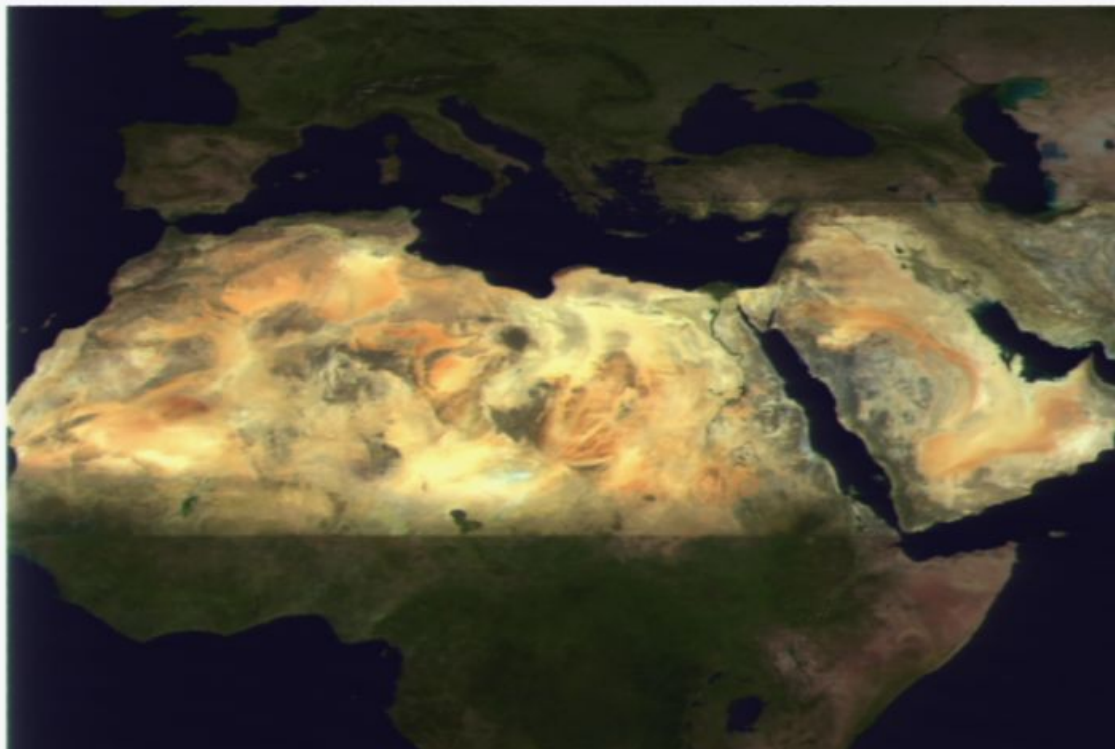
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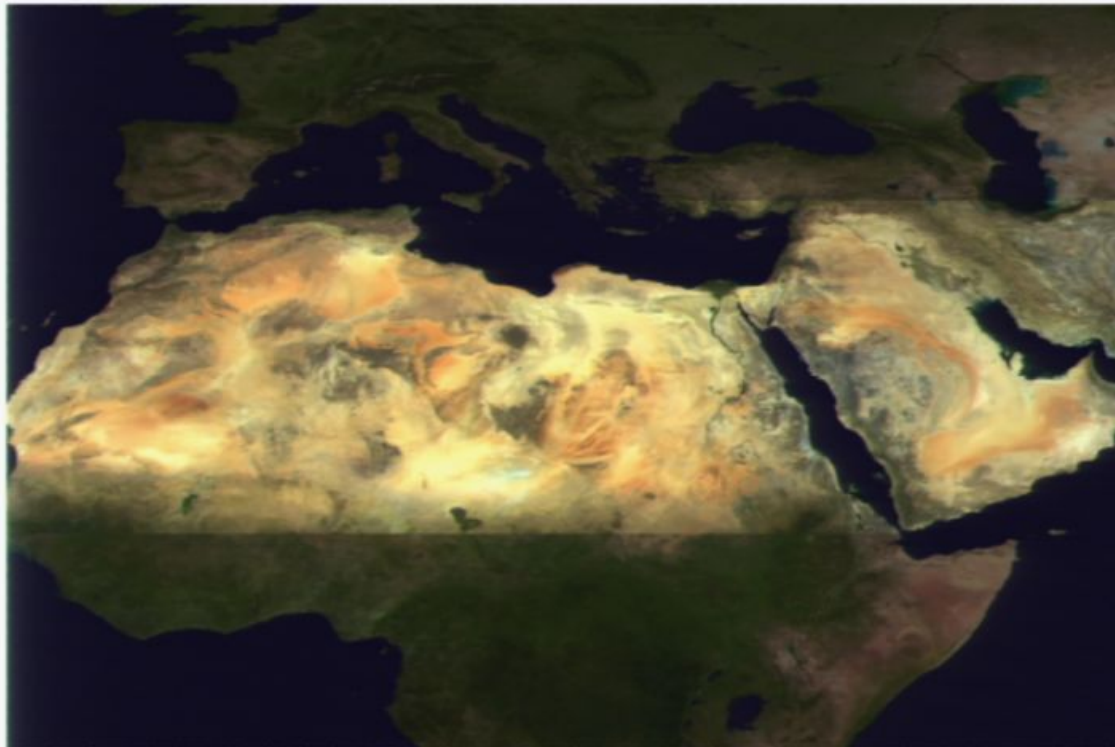
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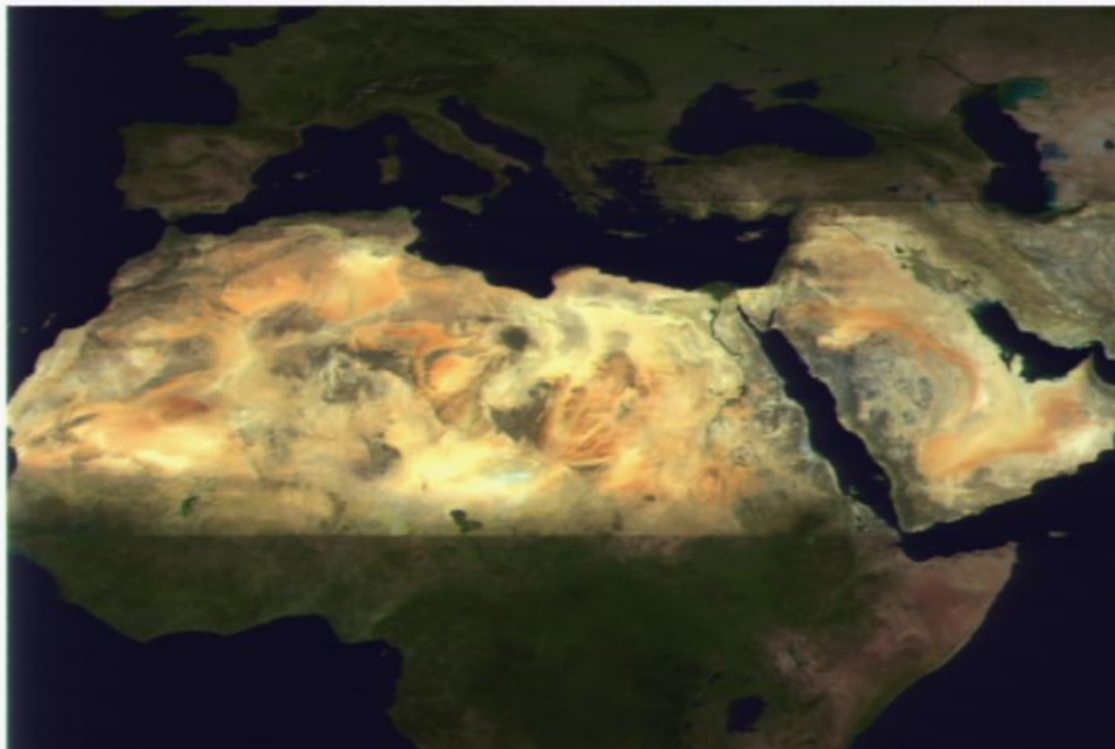
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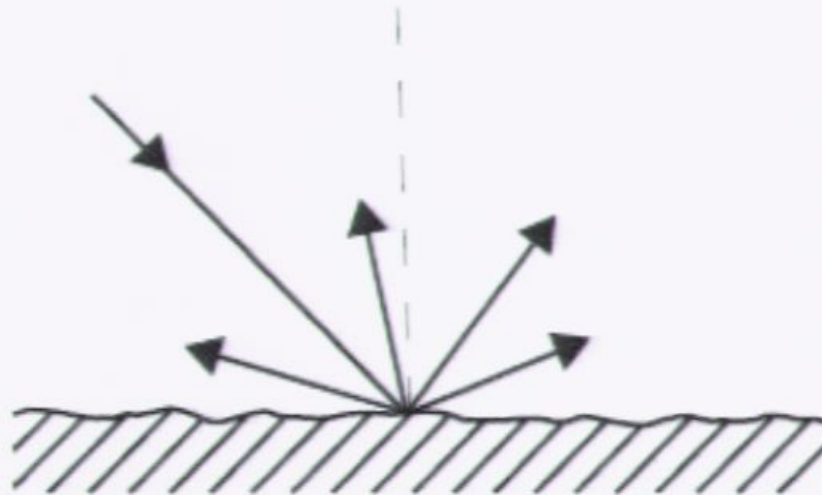
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# Ångstrom's Explanation

- Rough surfaces reflect diffusely.
- Lambertian surfaces model this with equal reflection in all directions:

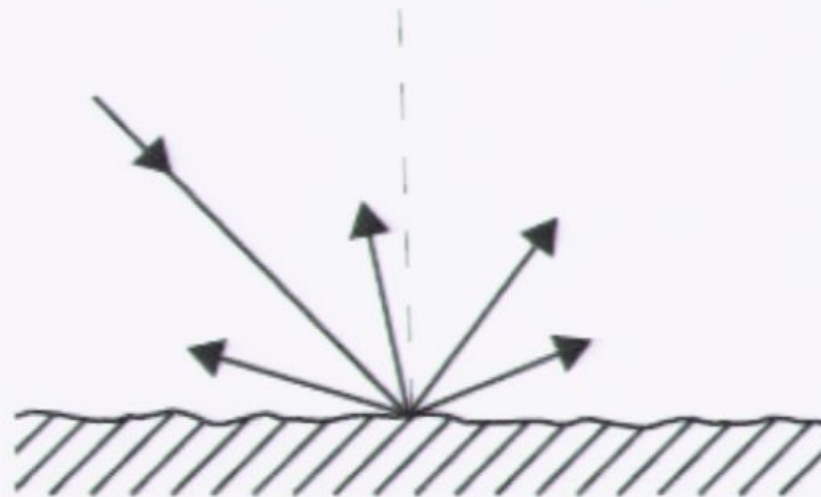


Diffuse reflection

<http://knol.google.com/k/lighting-and-its-measurement#>

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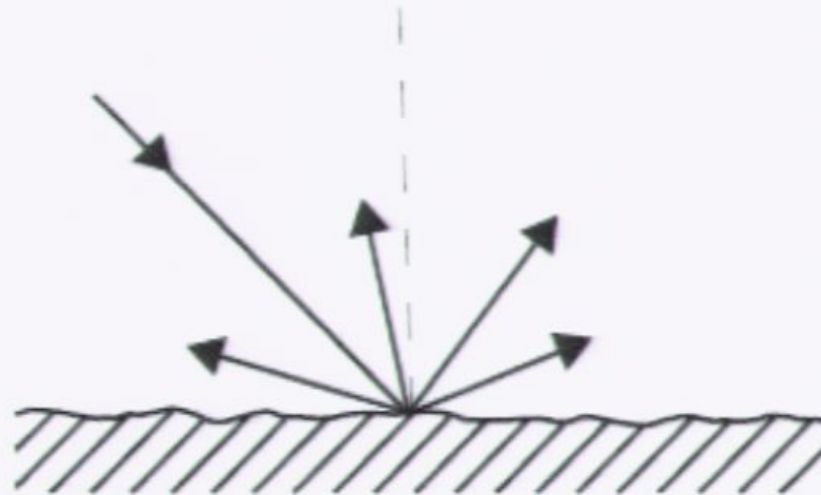


Diffuse reflection

<http://knol.google.com/k/lighting-and-its-measurement#>

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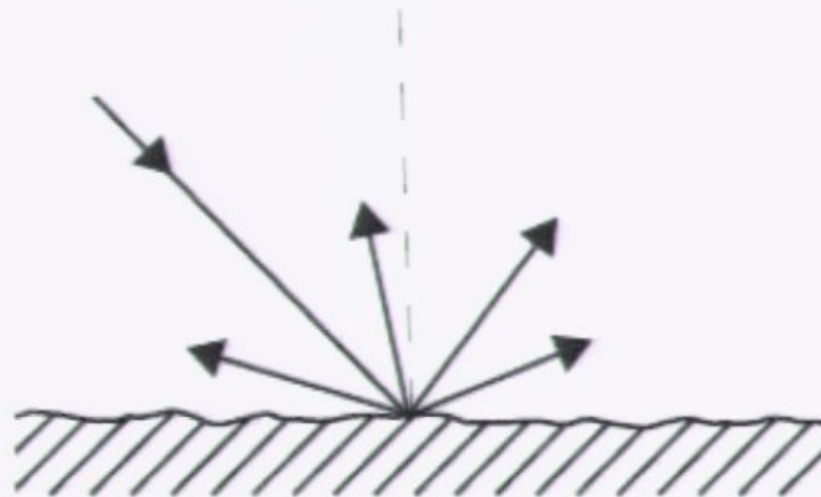
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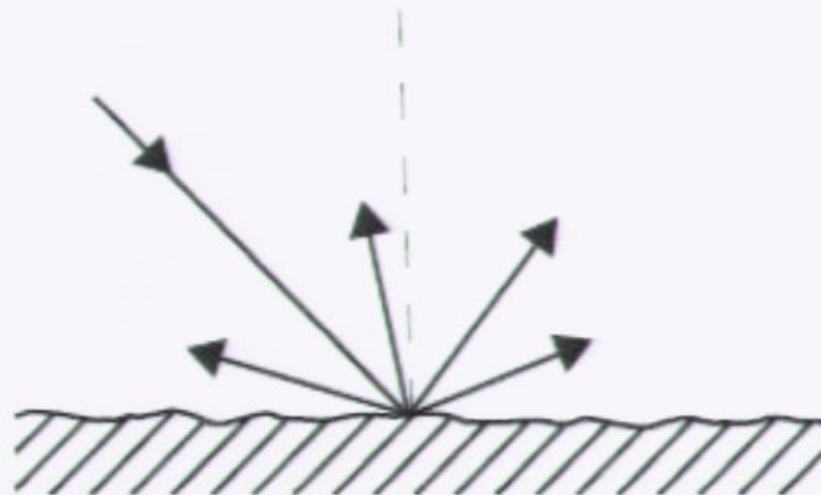


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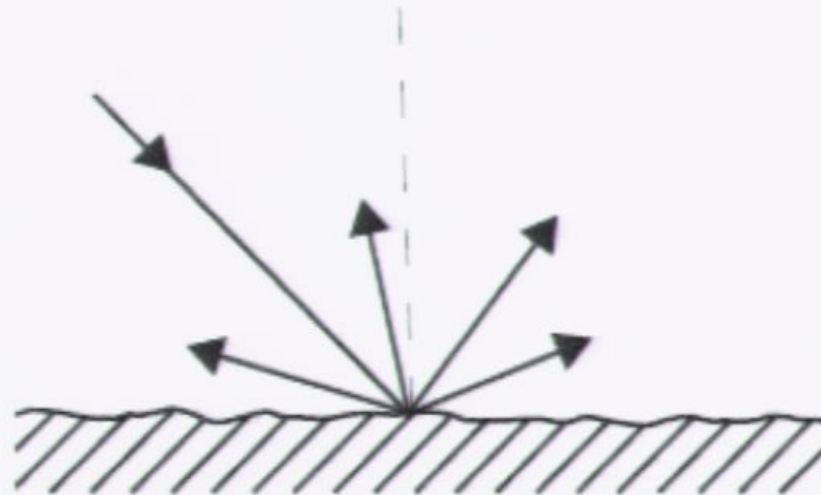


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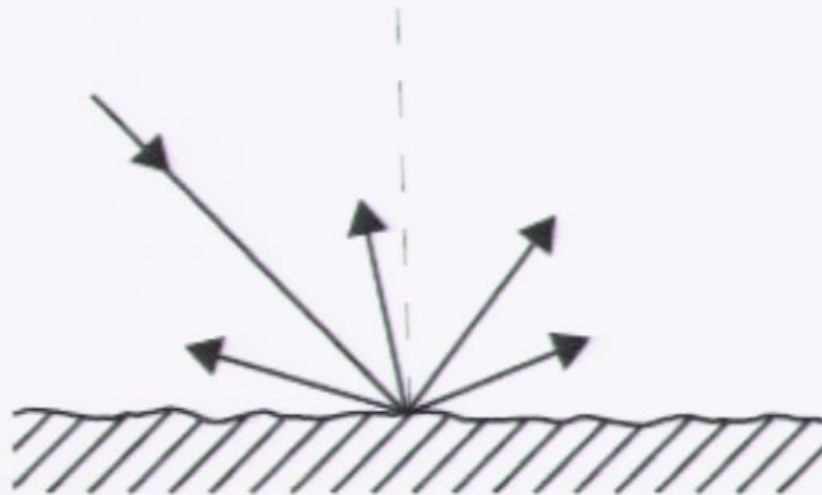
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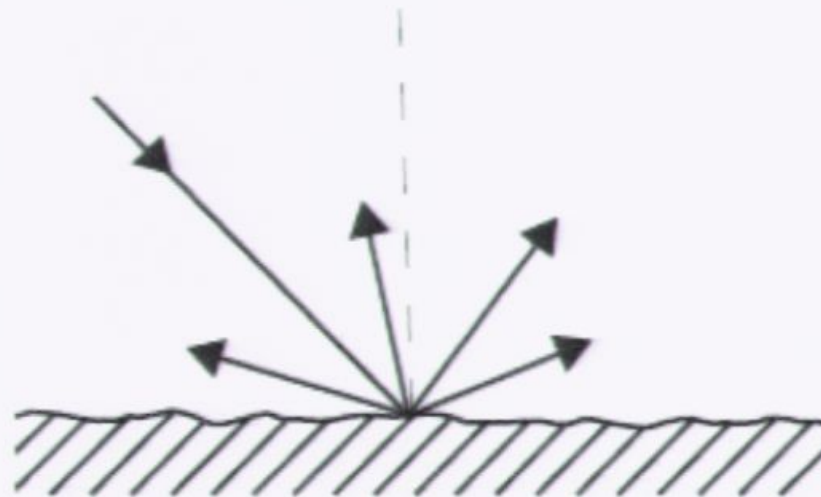


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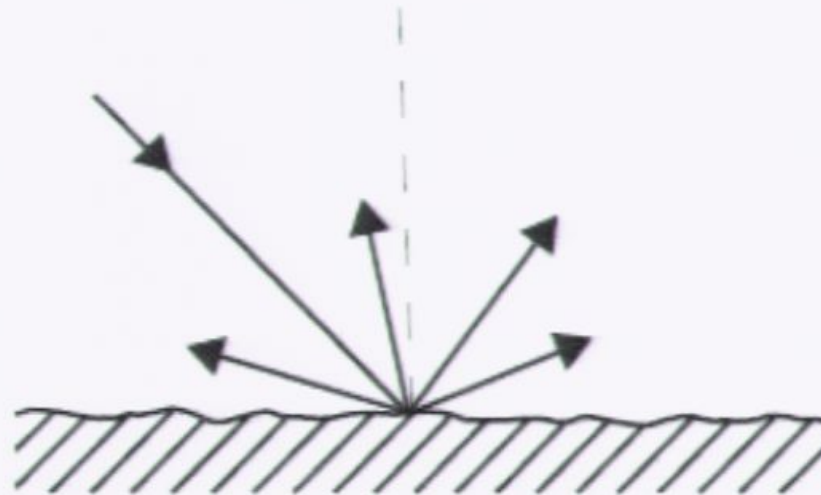


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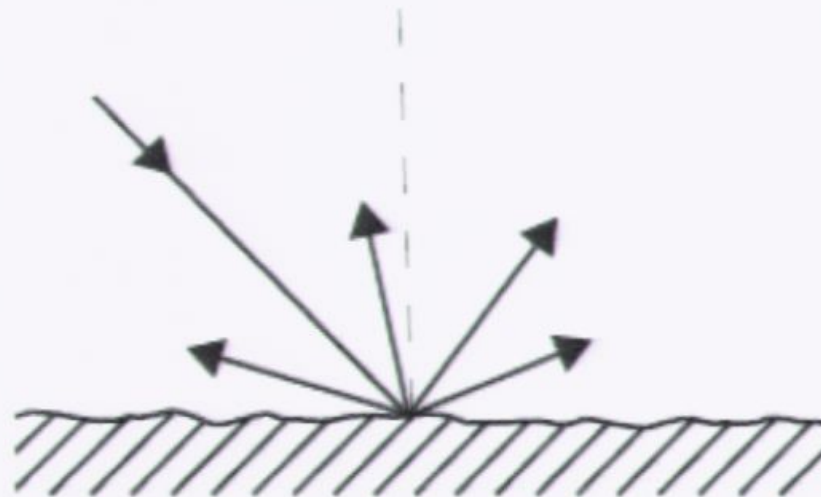


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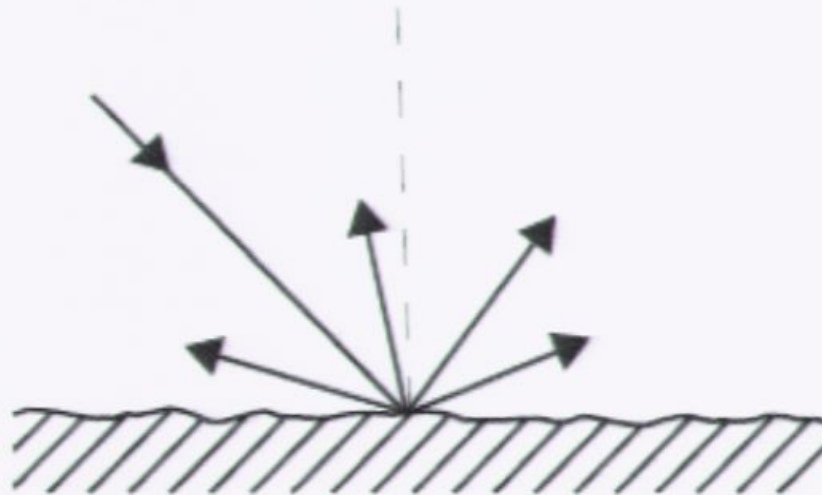
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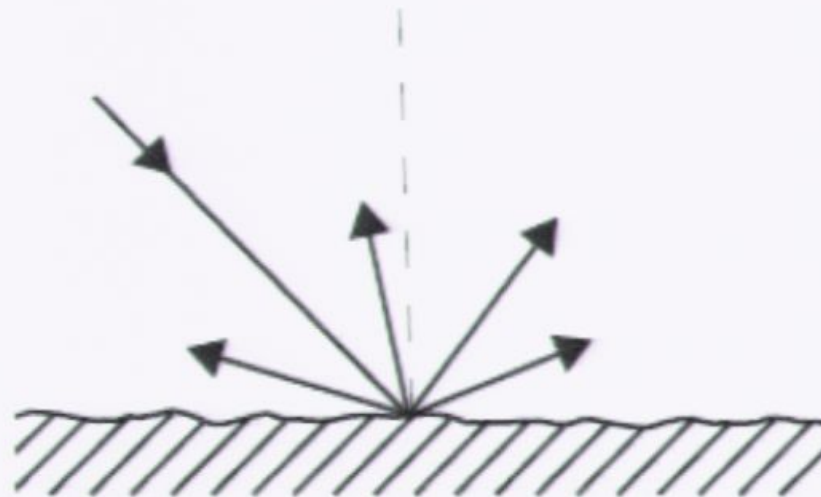


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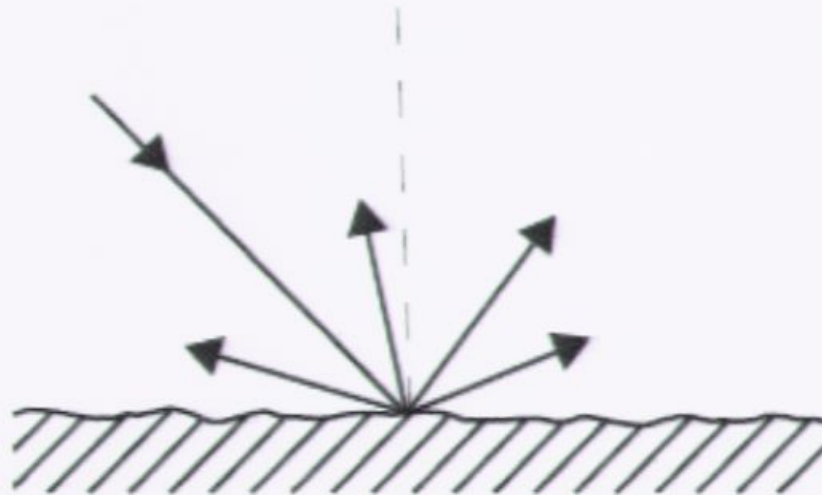


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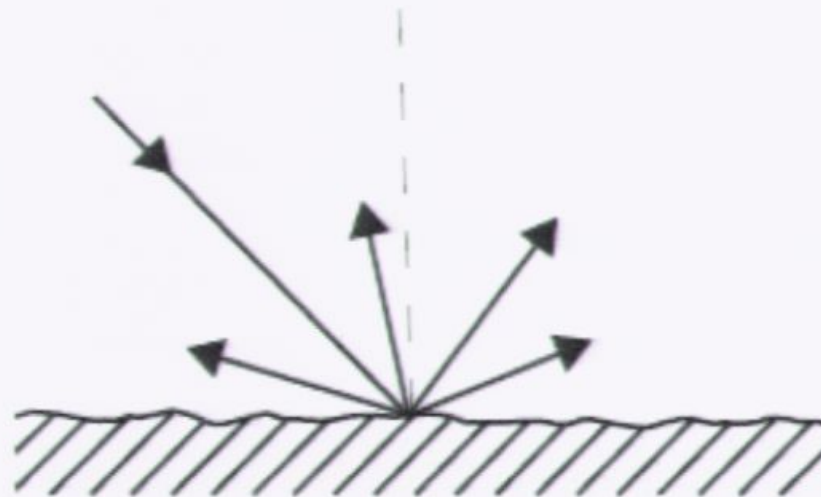


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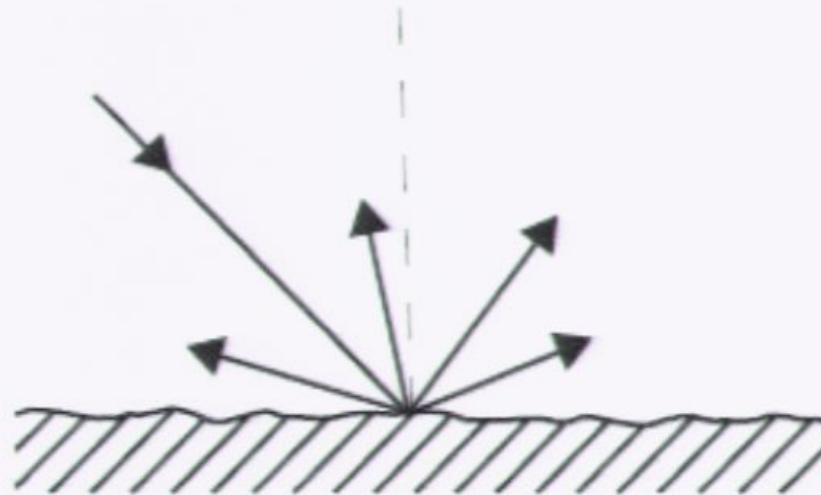
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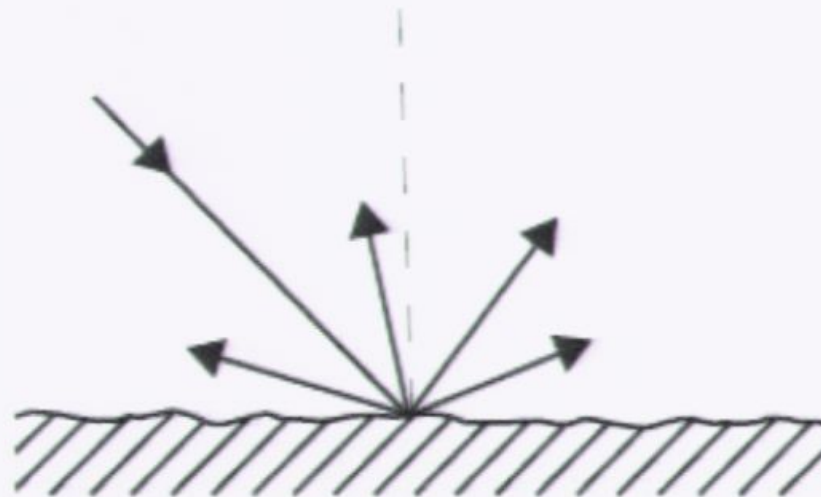


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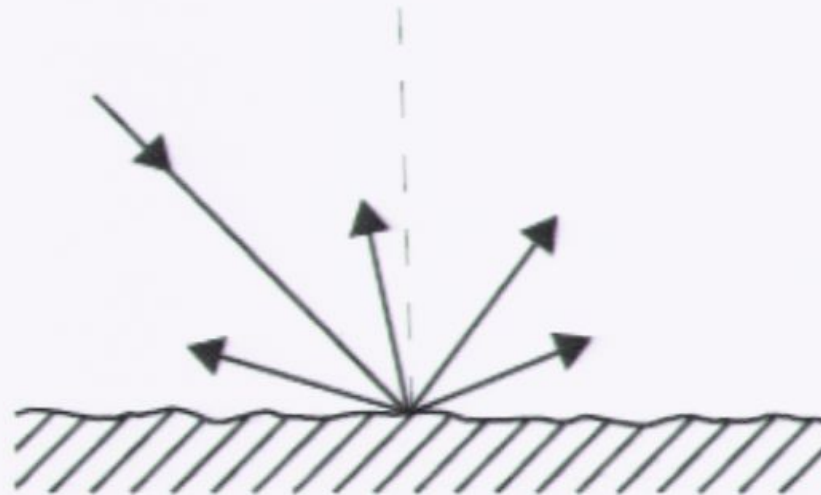


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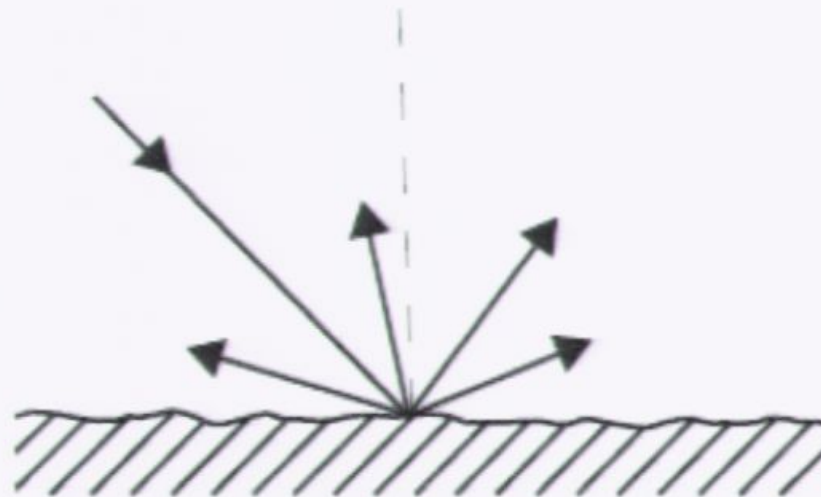


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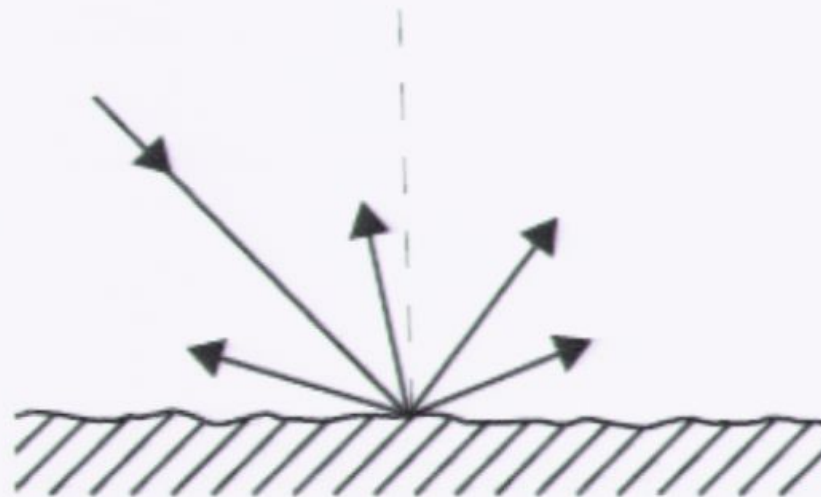
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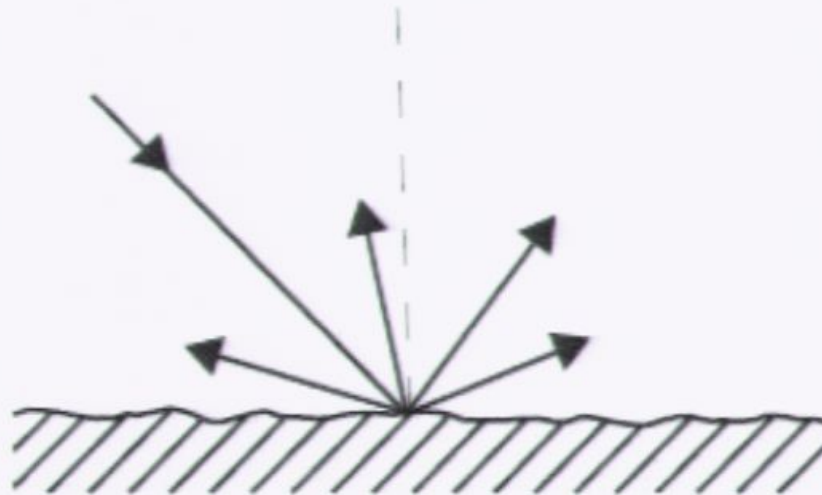


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# Ångstrom's Explanation, continued

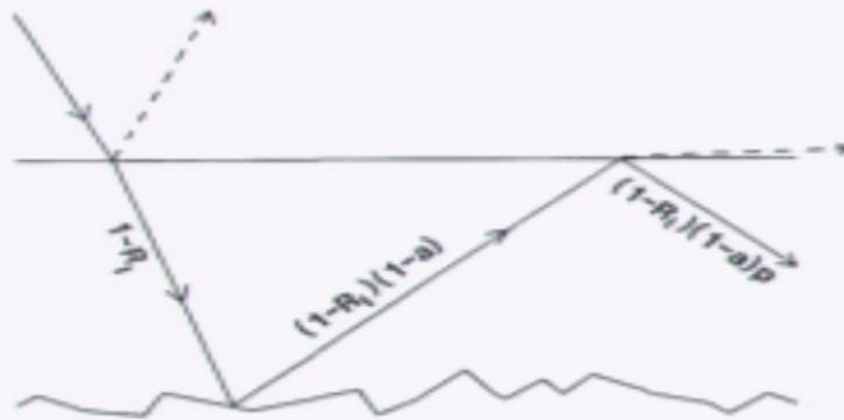
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Rough surface covered with liquid  
Lekner and Dorf, 1988

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Rough surface covered with liquid  
Lekner and Dorf, 1988



# Ångstrom's Explanation, continued

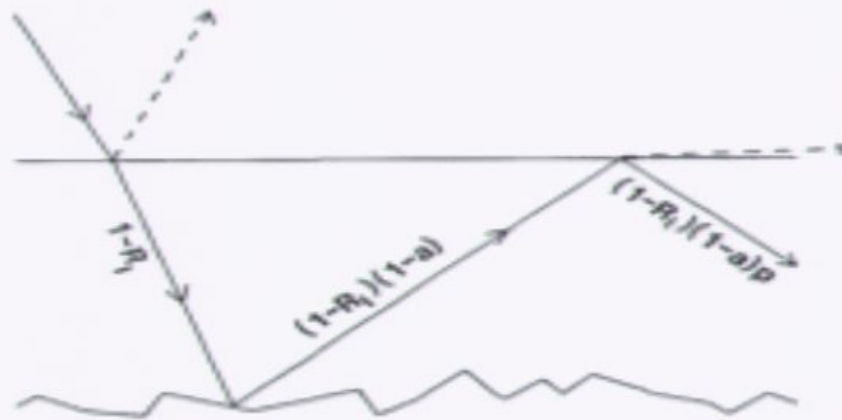
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Rough surface covered with liquid  
Lekner and Dorf, 1988

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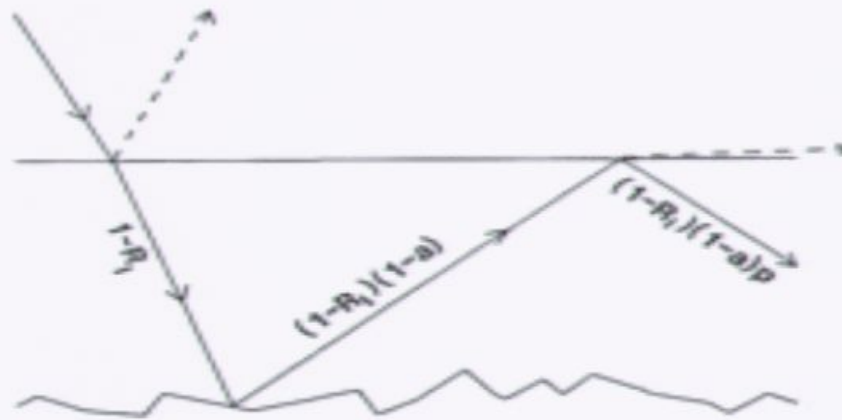
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Lekner and Dorf, 1988

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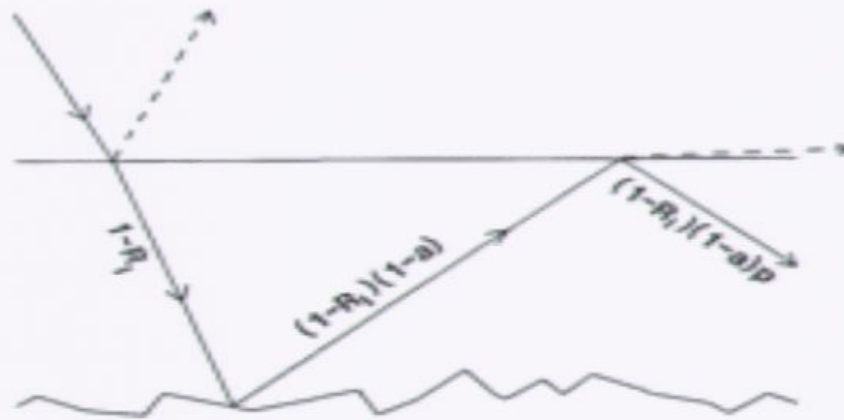


Rough surface covered with liquid  
Lekner and Dorf, 1988



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Lekner and Dorf, 1988

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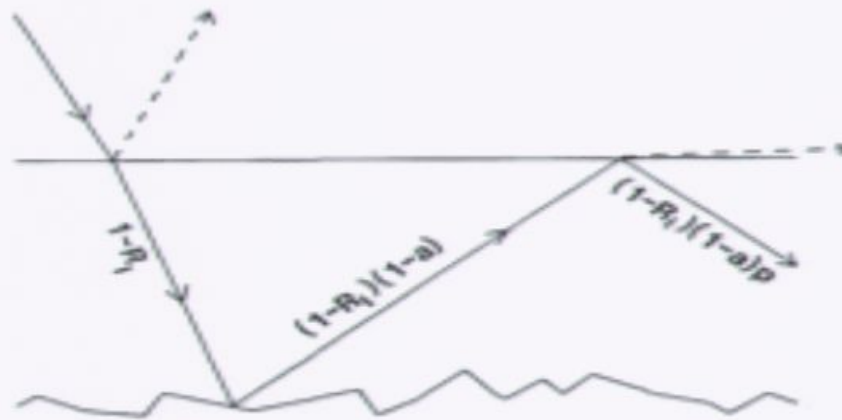
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Rough surface covered with liquid  
Lekner and Dorf, 1988

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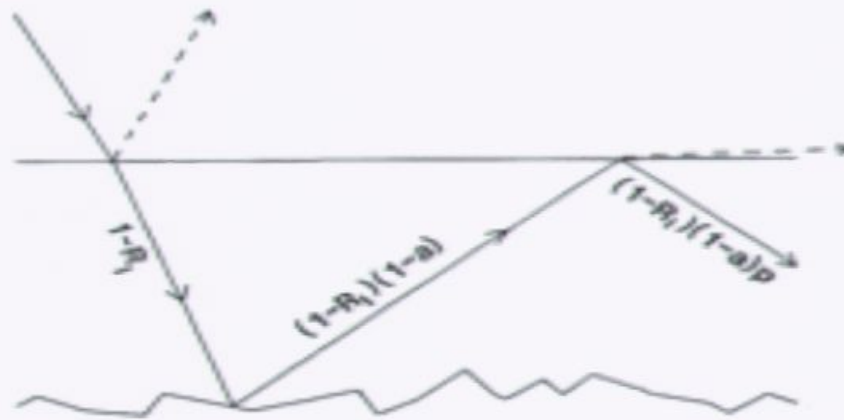
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Lekner and Dorf, 1988

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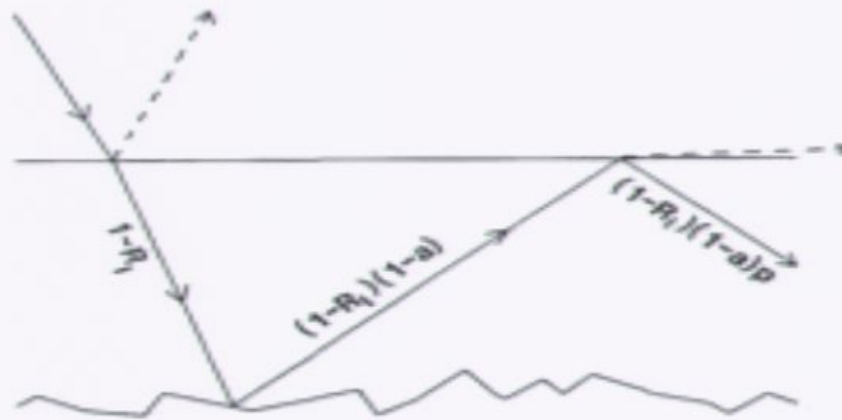


Rough surface covered with liquid  
Lekner and Dorf, 1988



# Ångstrom's Explanation, continued

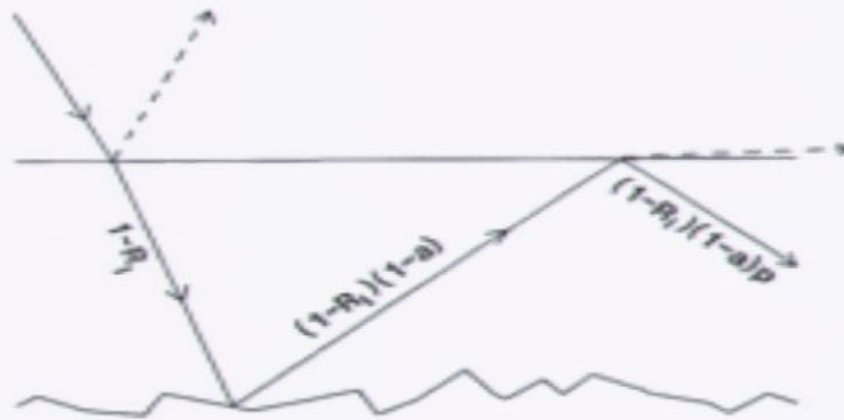
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Lekner and Dorf, 1988

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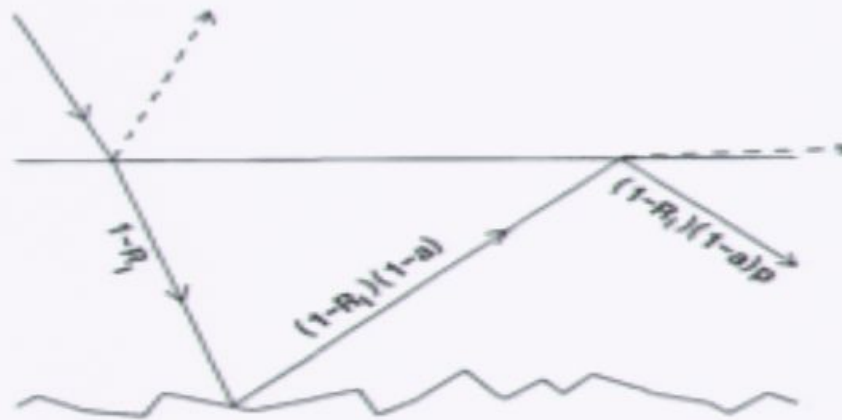


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Lekner and Dorf, 1988

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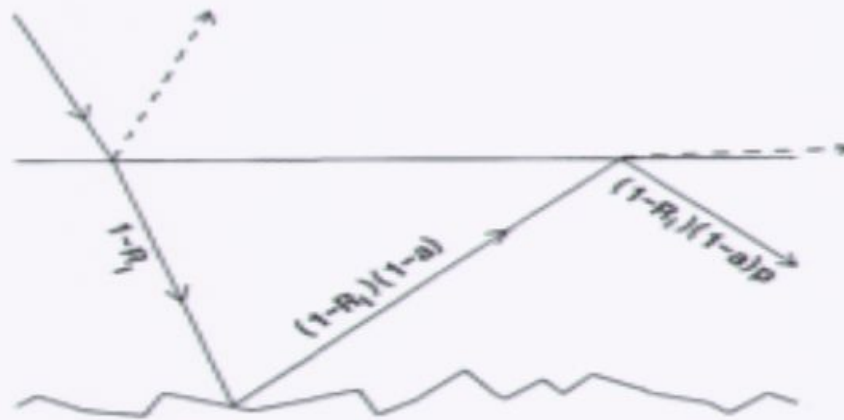
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Lekner and Dorf, 1988

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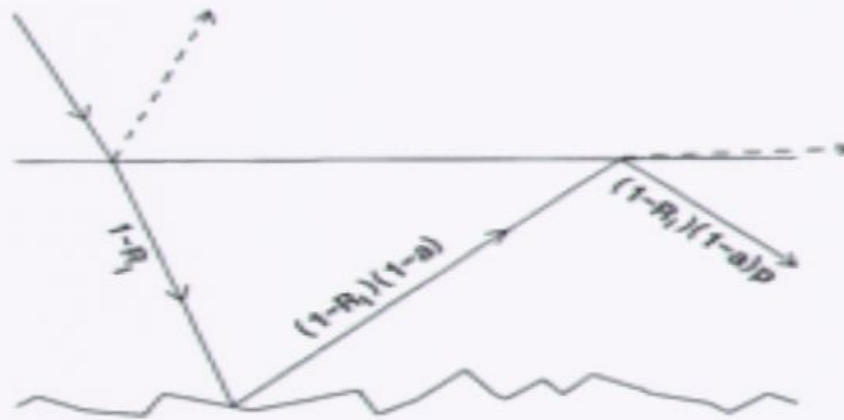
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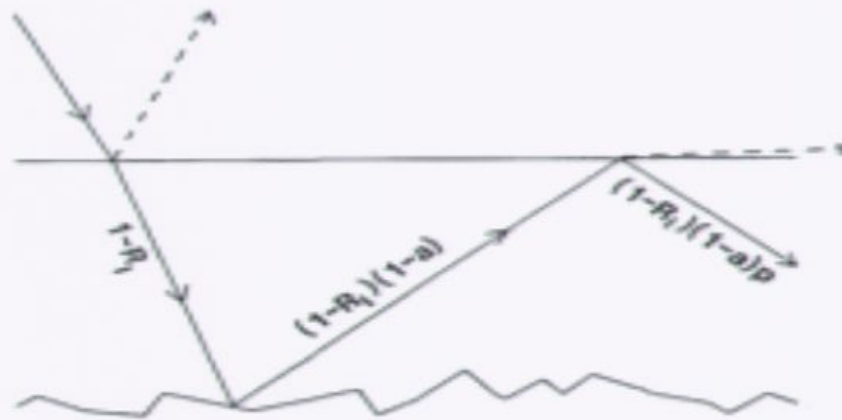


Rough surface covered with liquid  
Lekner and Dorf, 1988



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Rough surface covered with liquid  
Lekner and Dorf, 1988

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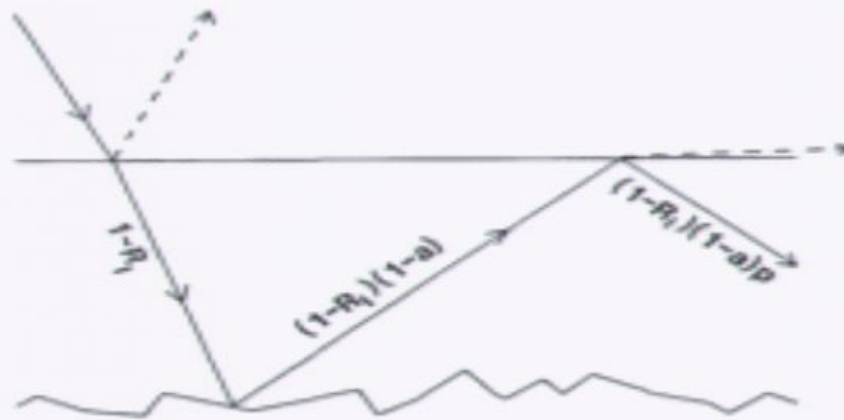
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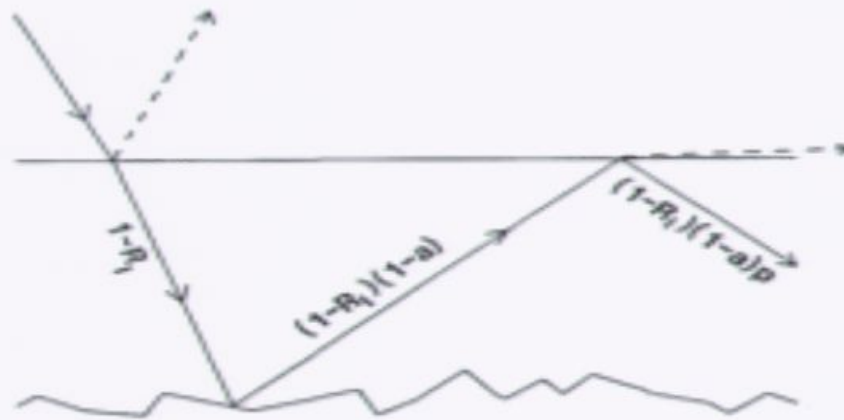


Rough surface covered with liquid  
Lekner and Dorf, 1988



# Ångstrom's Explanation, continued

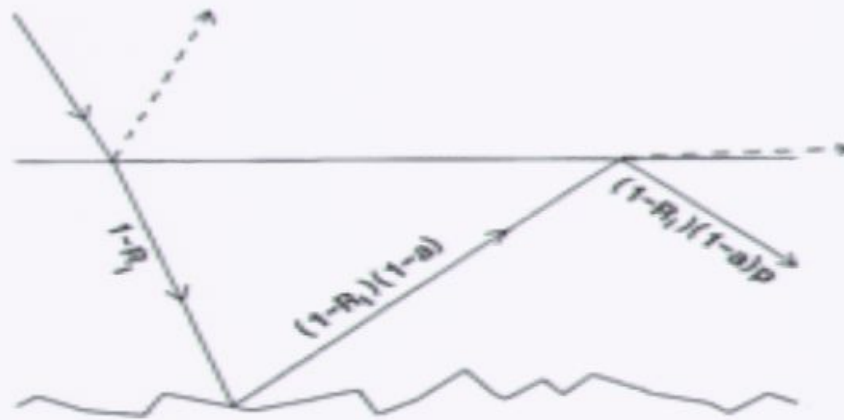
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Lekner and Dorf, 1988

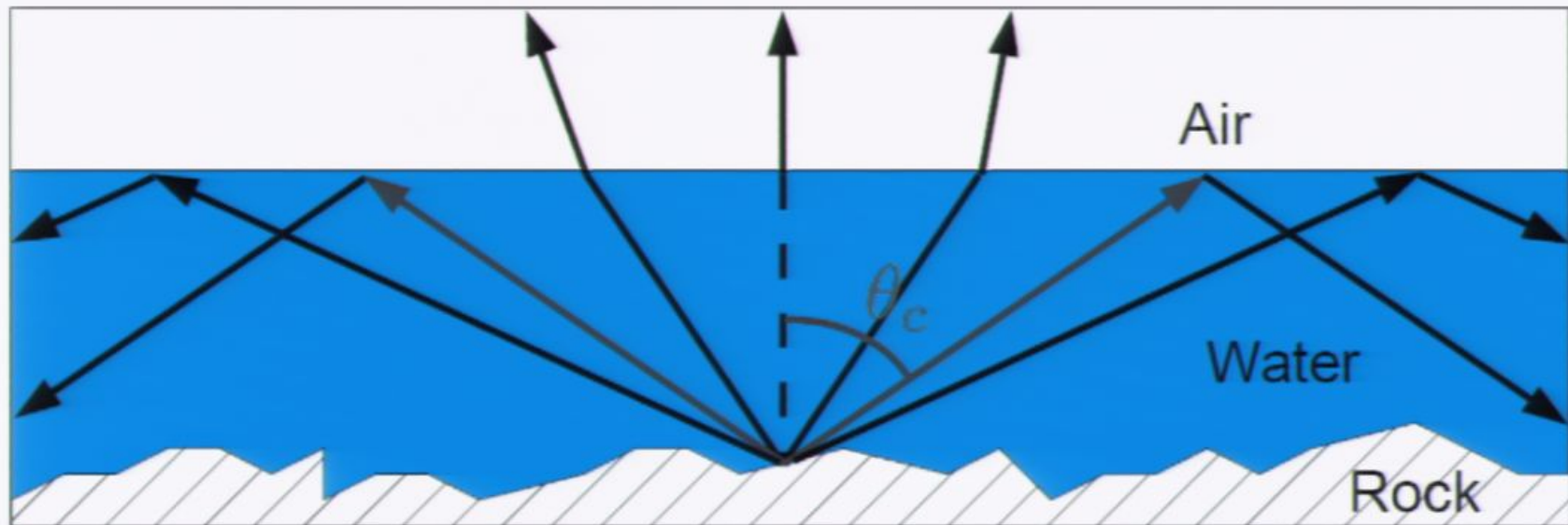
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Rough surface covered with liquid  
Lekner and Dorf, 1988

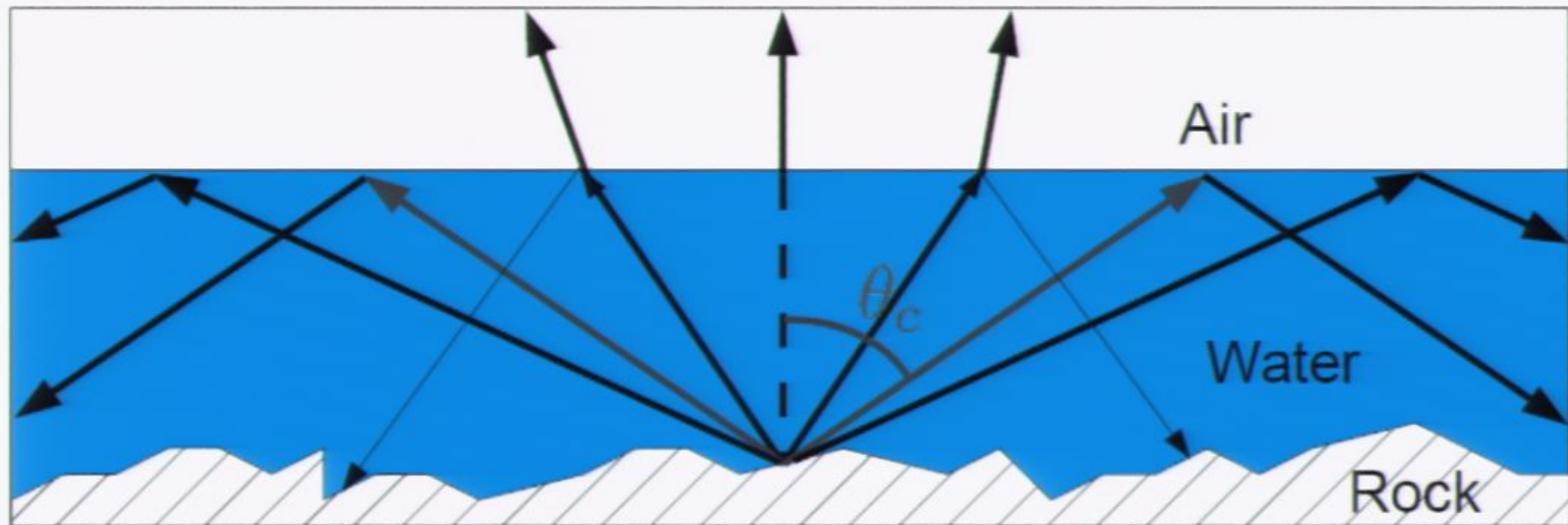
# Lekner and Dorf Modification



Rough surface covered with liquid

# Lekner and Dorf Modification

- There is also partial reflection at the water-air interface of beams that are not totally internally reflected

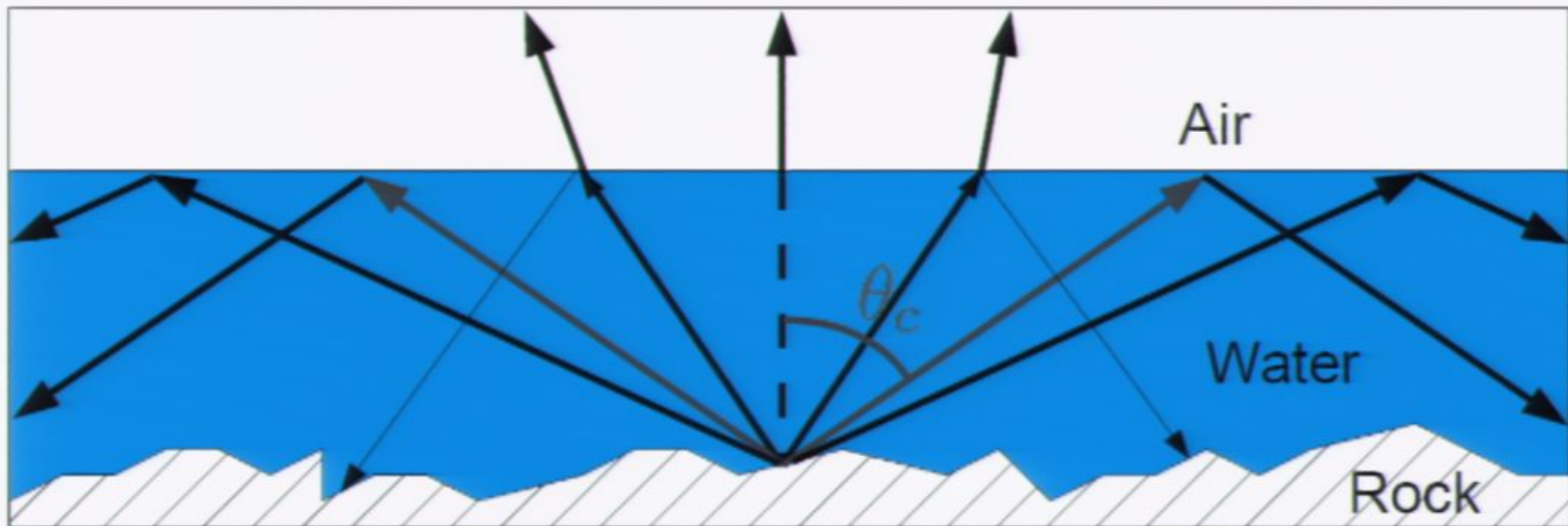


Rough surface covered with liquid



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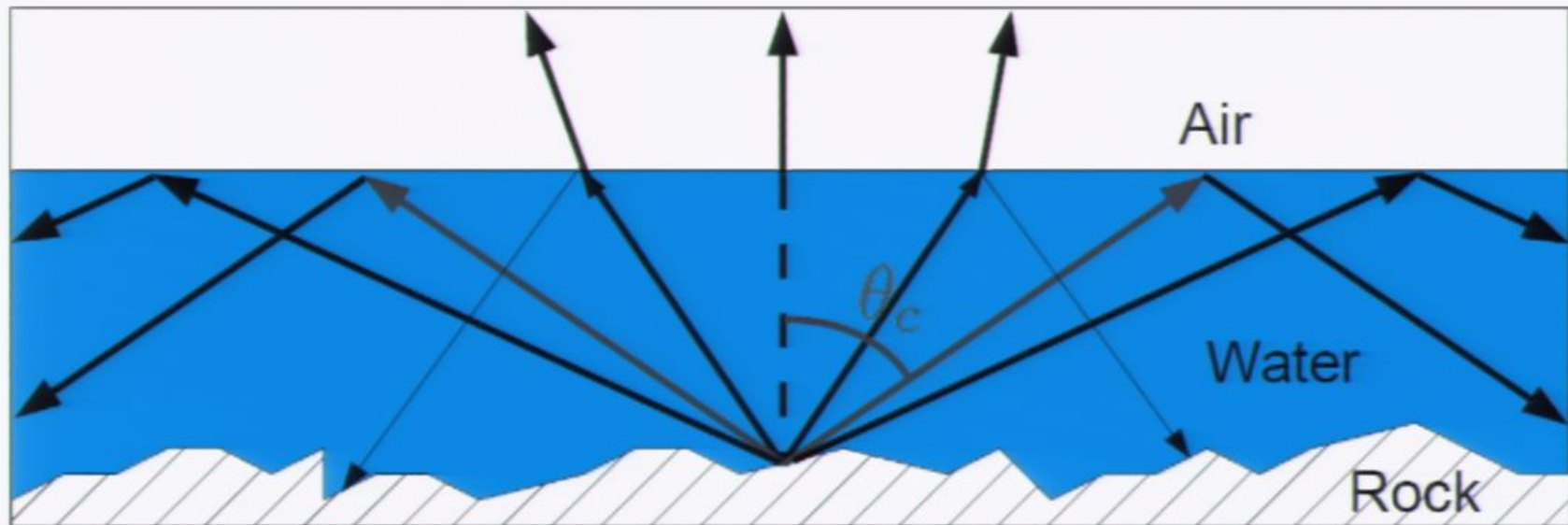
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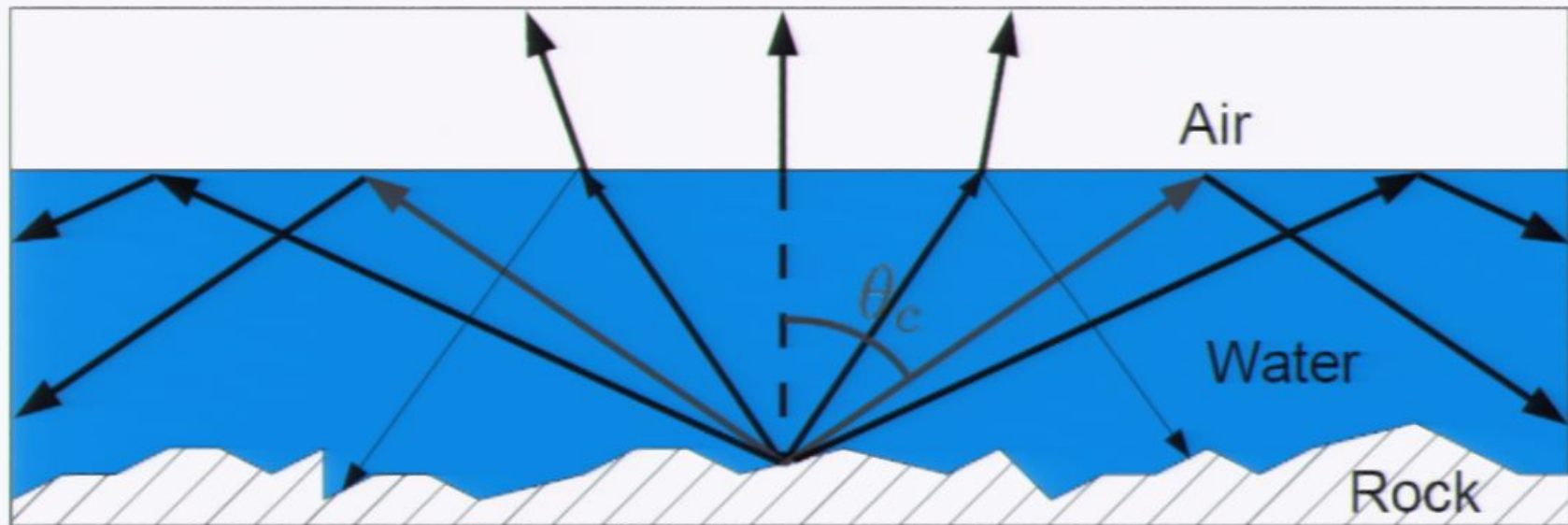
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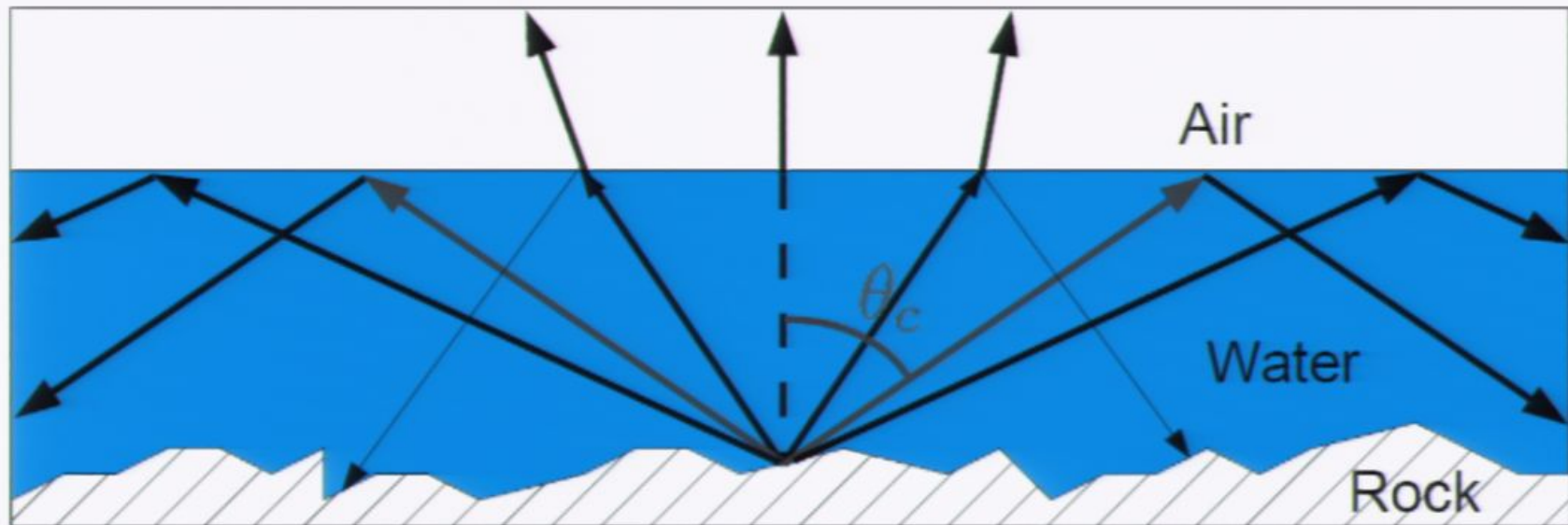
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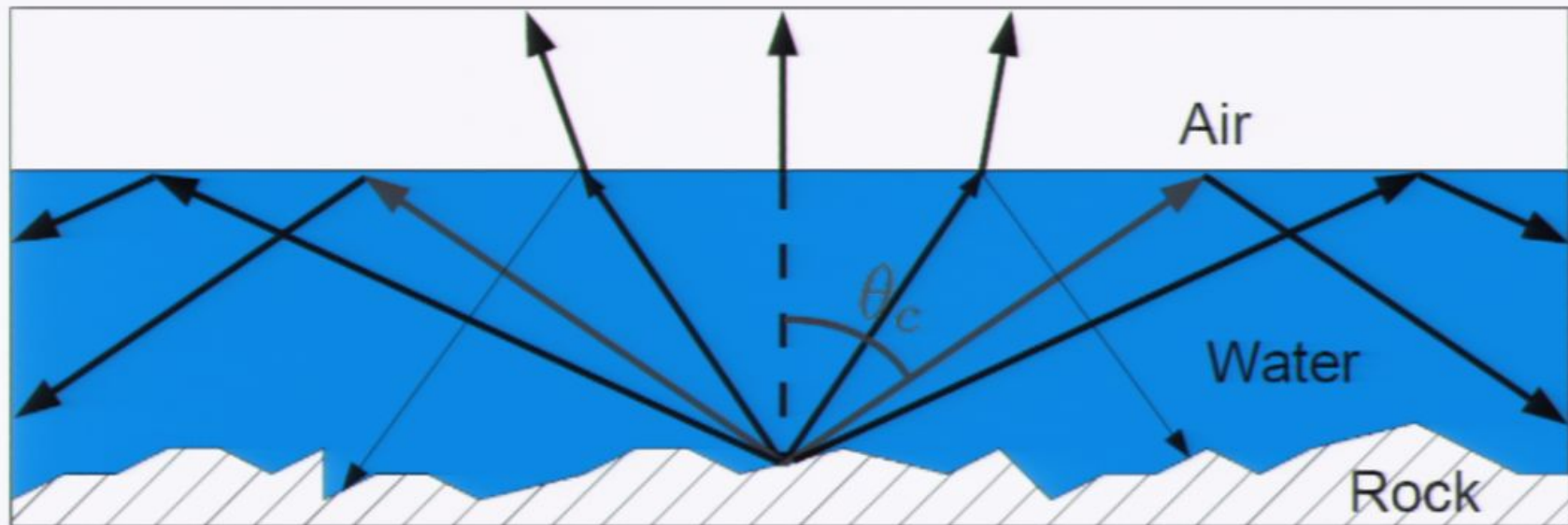


Rough surface covered with liquid



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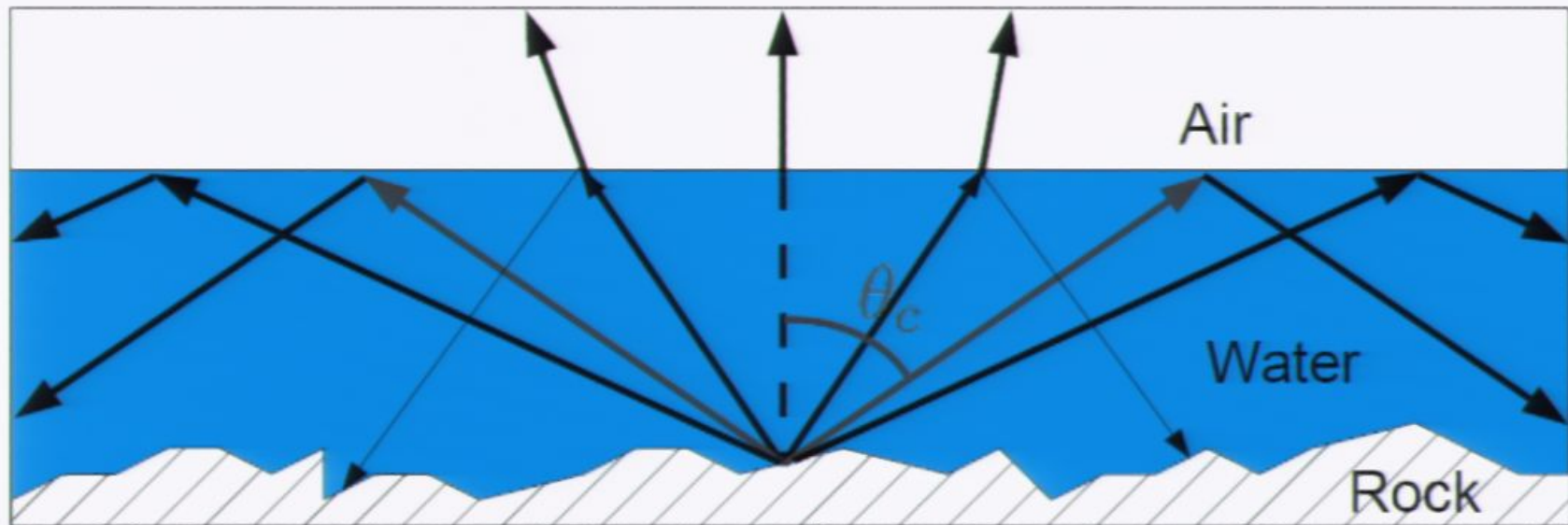
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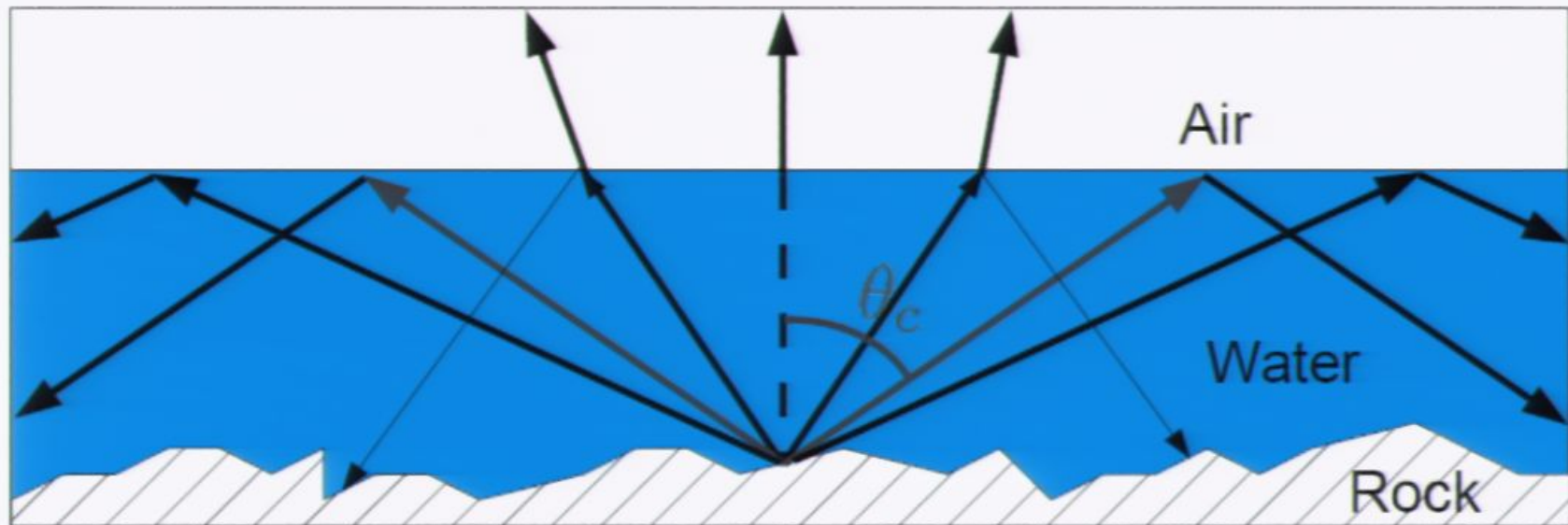
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Rough surface covered with liquid

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Rough surface covered with liquid

## Lekner and Dorf, continued

- Ångström underestimated how much light gets trapped in by the water.
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  - Even less light will ever escape to the air.



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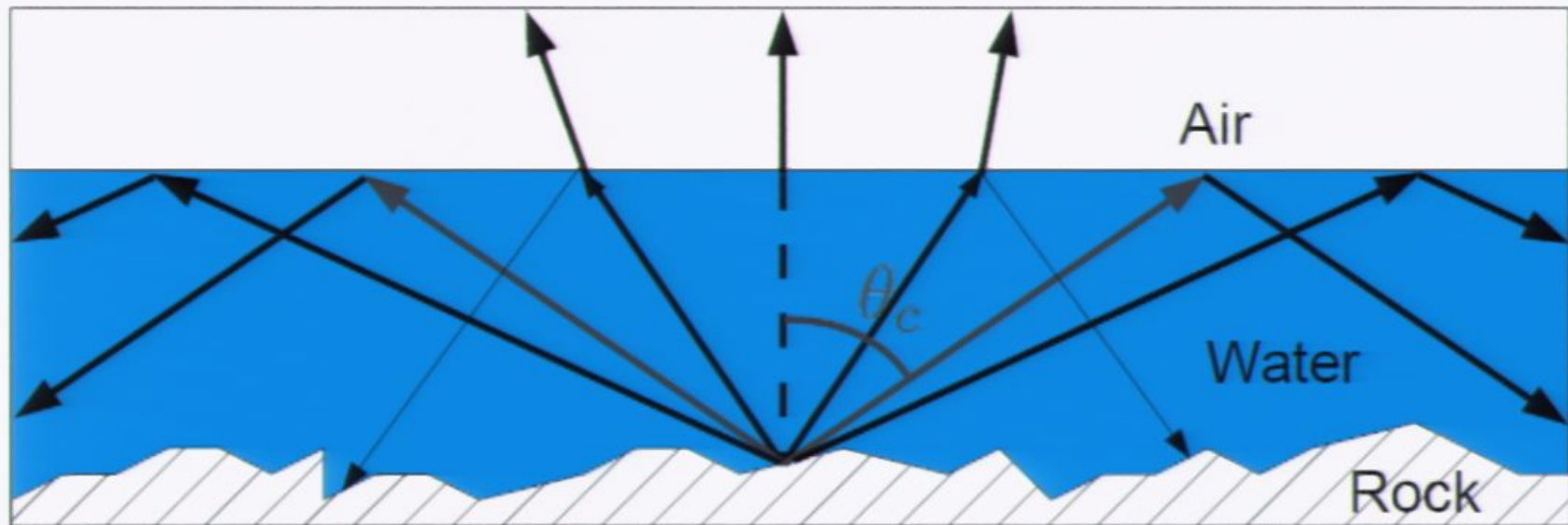
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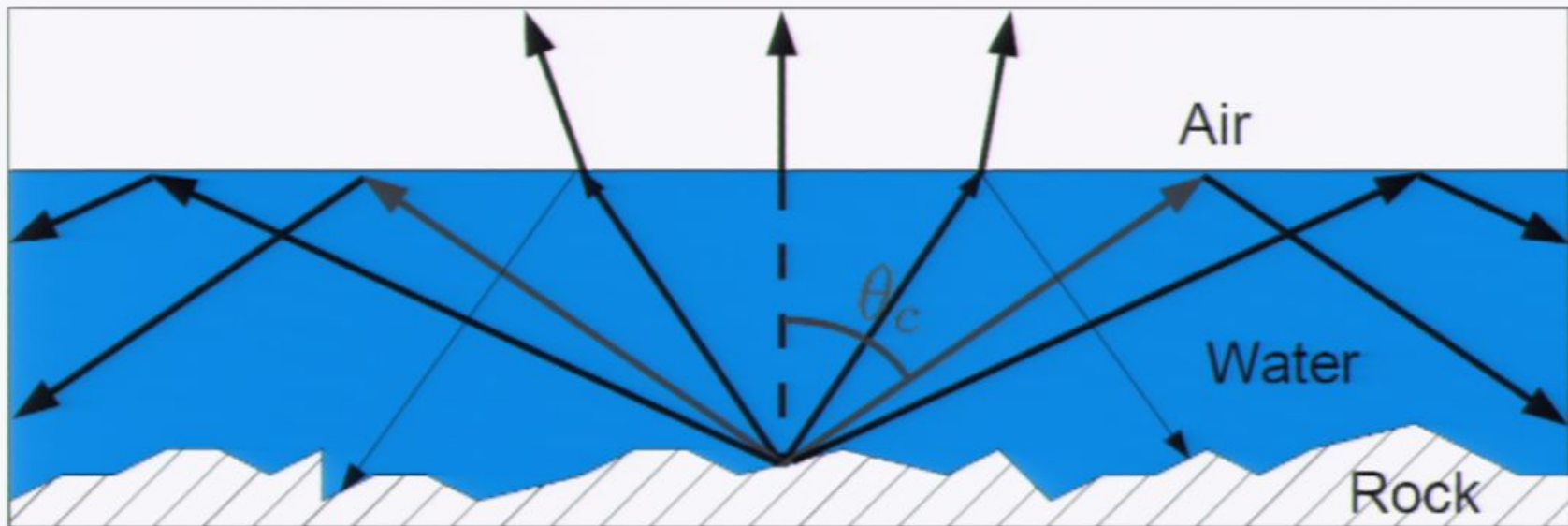


Rough surface covered with liquid



# Lekner and Dorf Modification

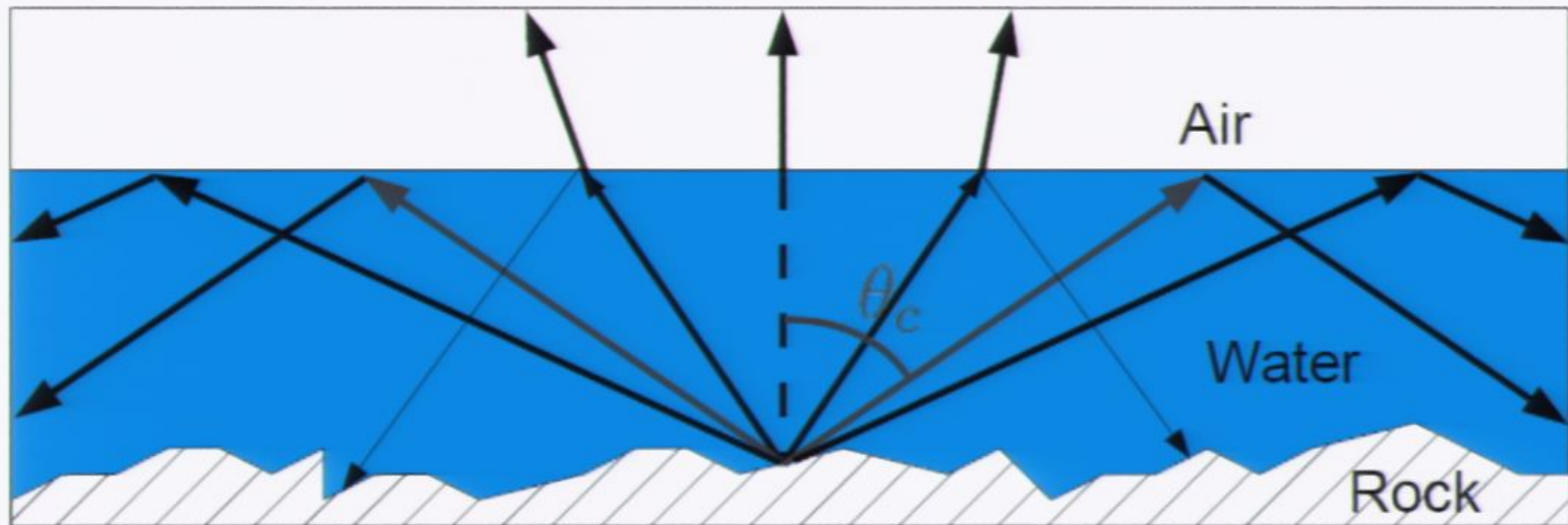
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Rough surface covered with liquid

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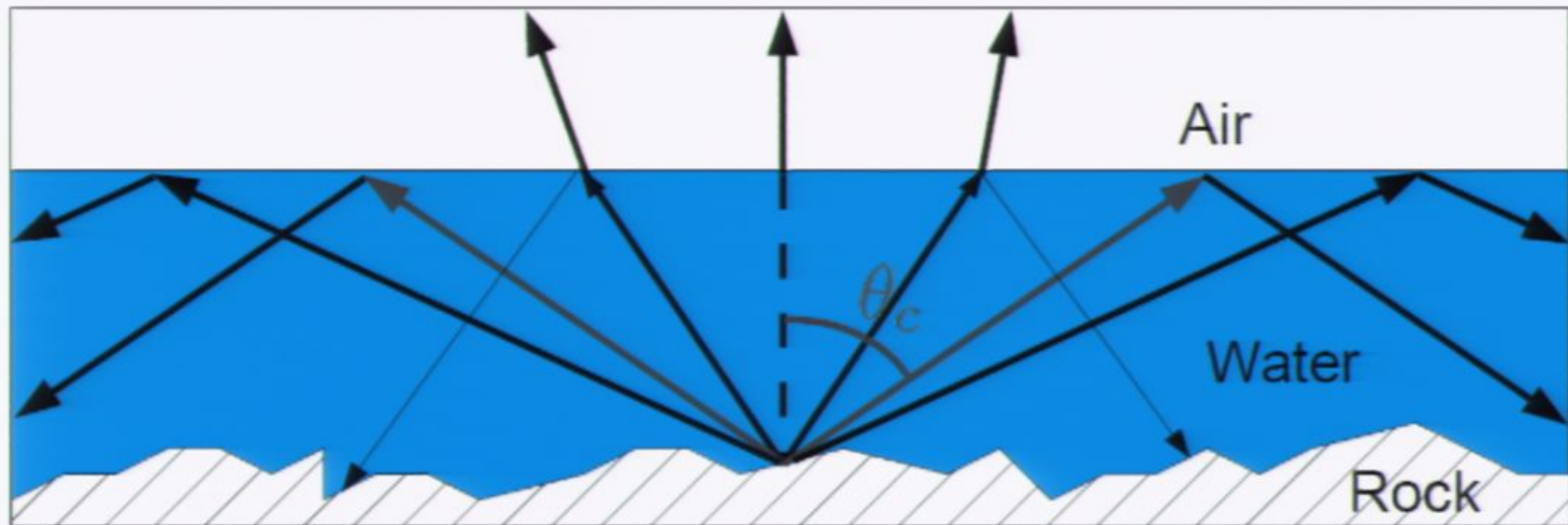
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Rough surface covered with liquid

# Lekner and Dorf Modification

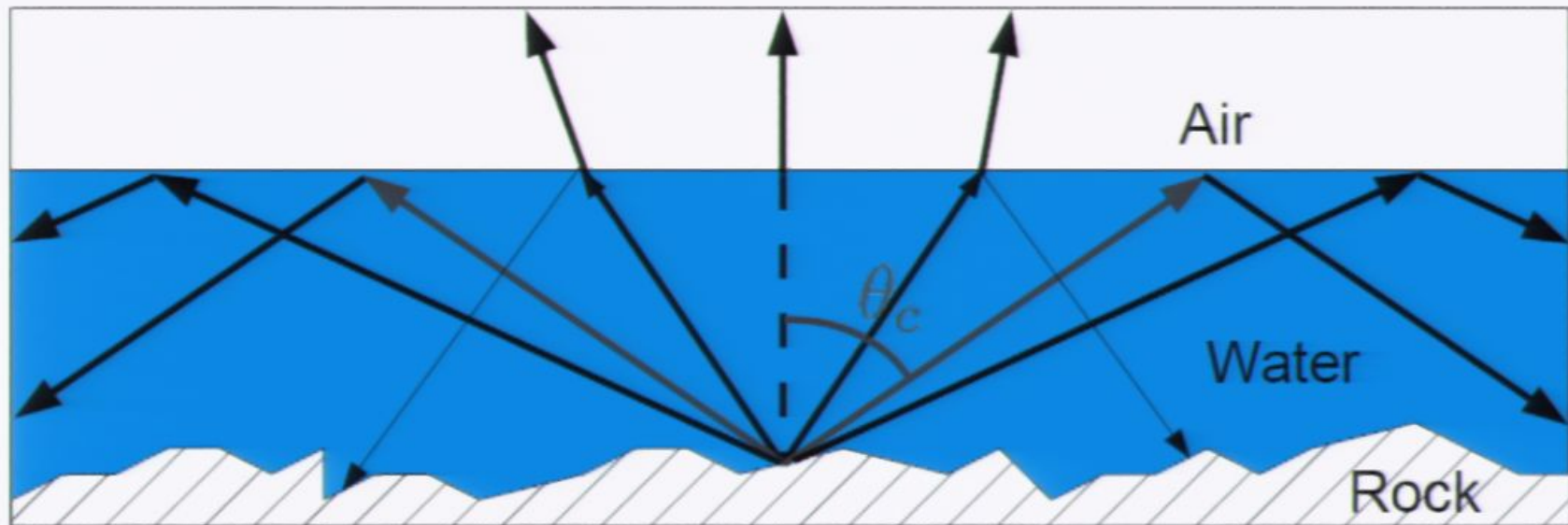
- There is also partial reflection at the water-air interface of beams that are not totally internally reflected



Rough surface covered with liquid

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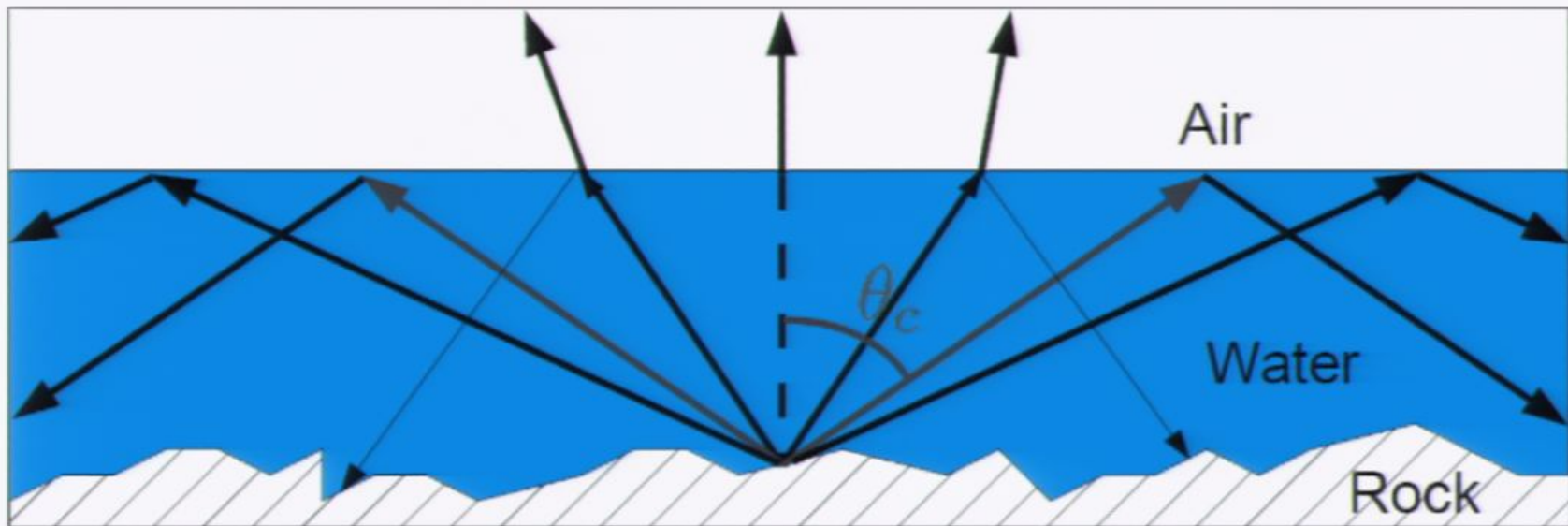


Rough surface covered with liquid



# Lekner and Dorf Modification

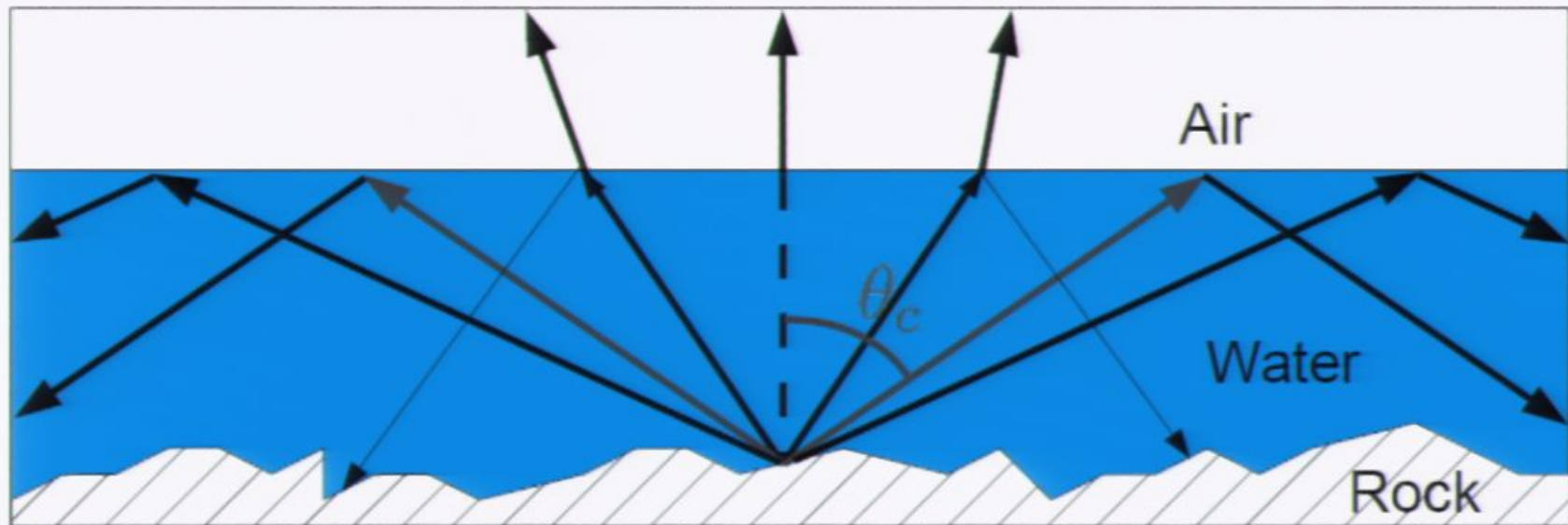
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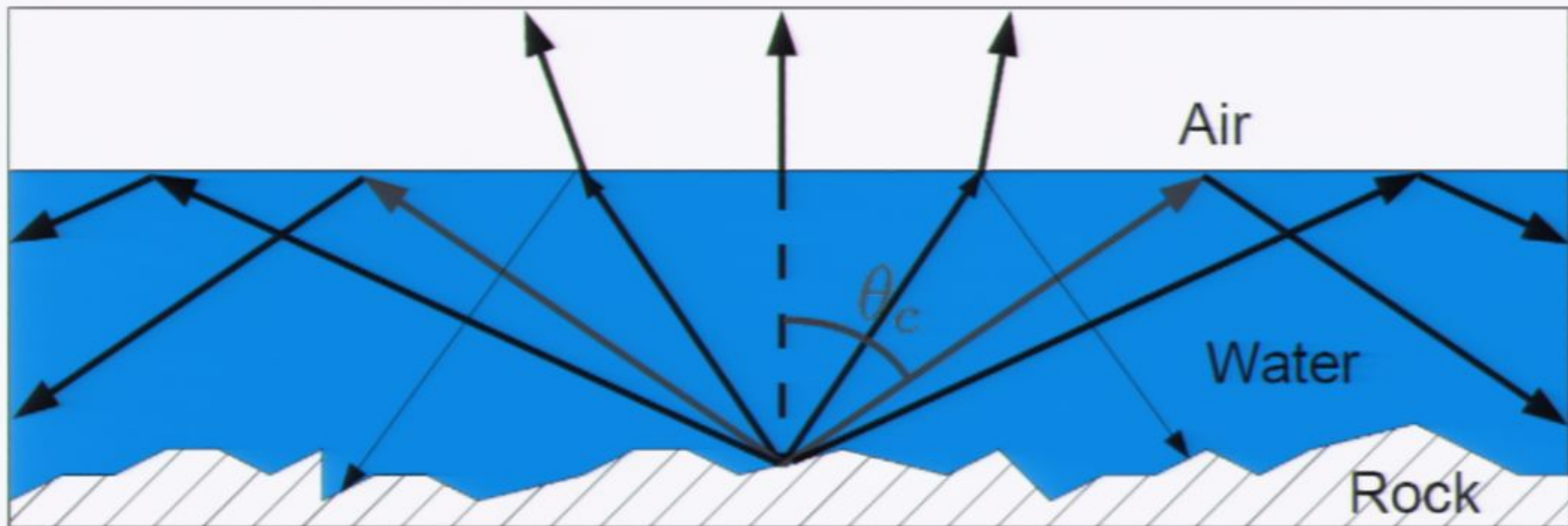
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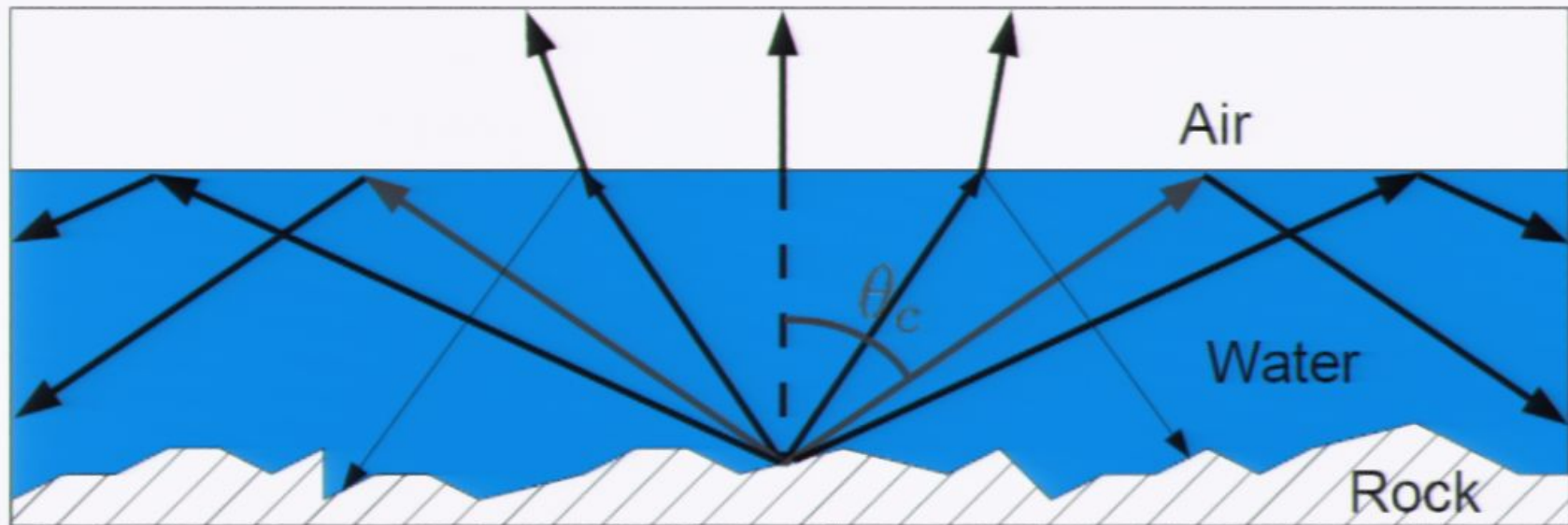
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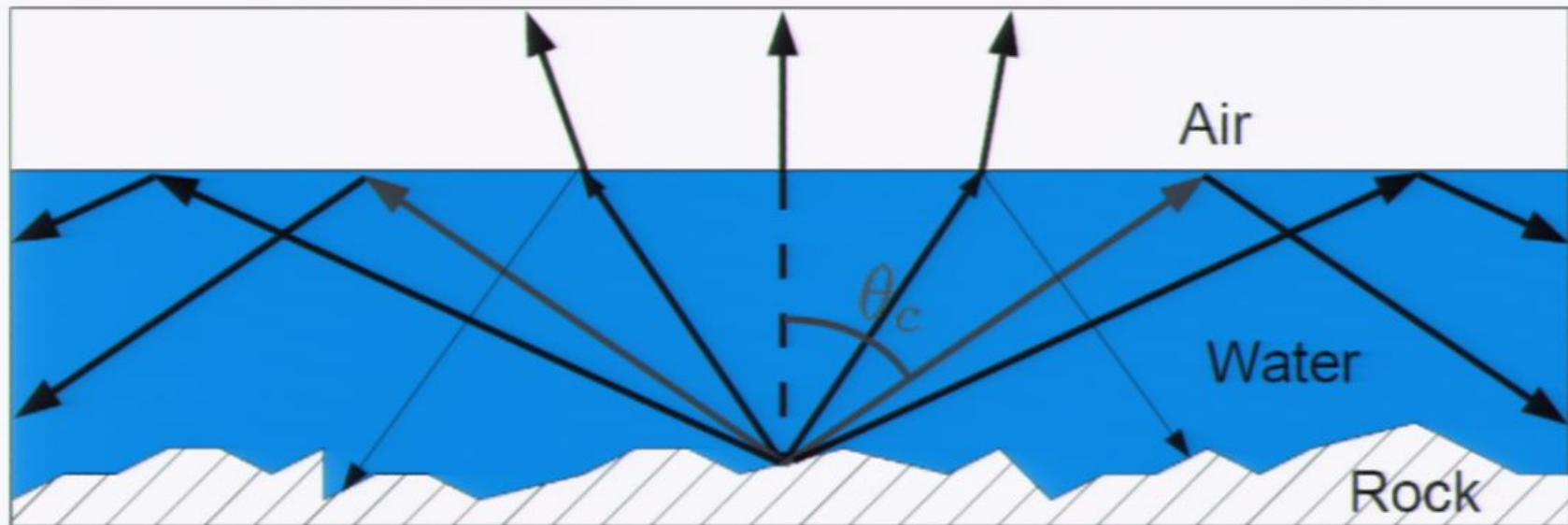


Rough surface covered with liquid



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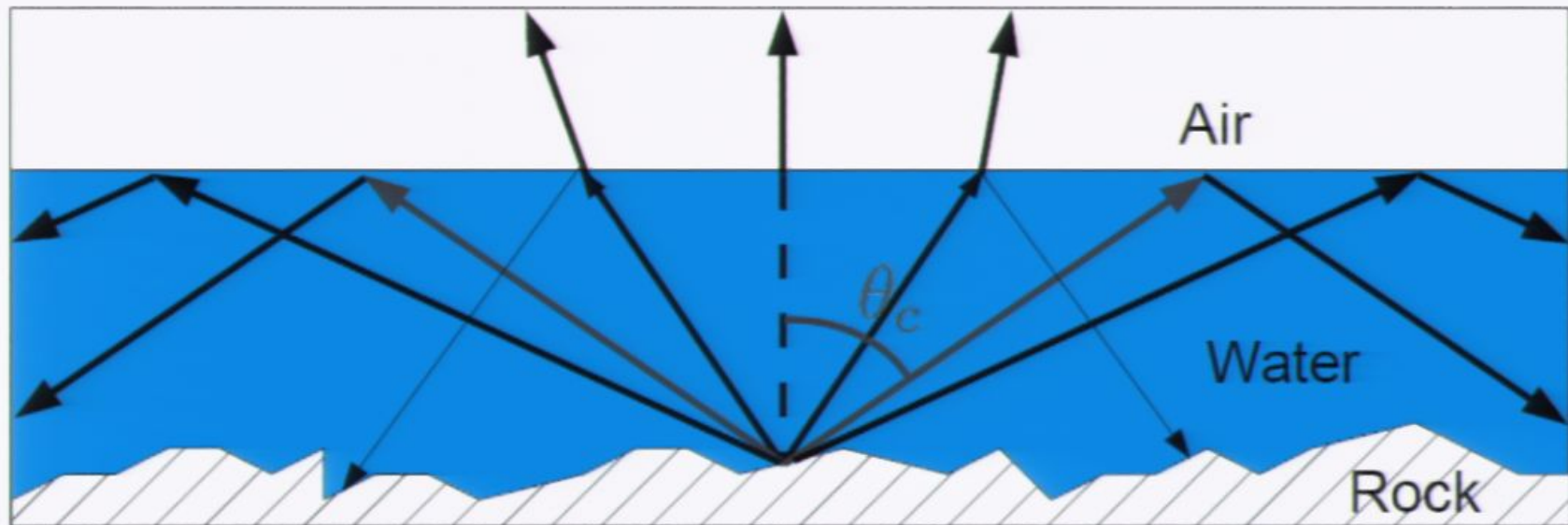
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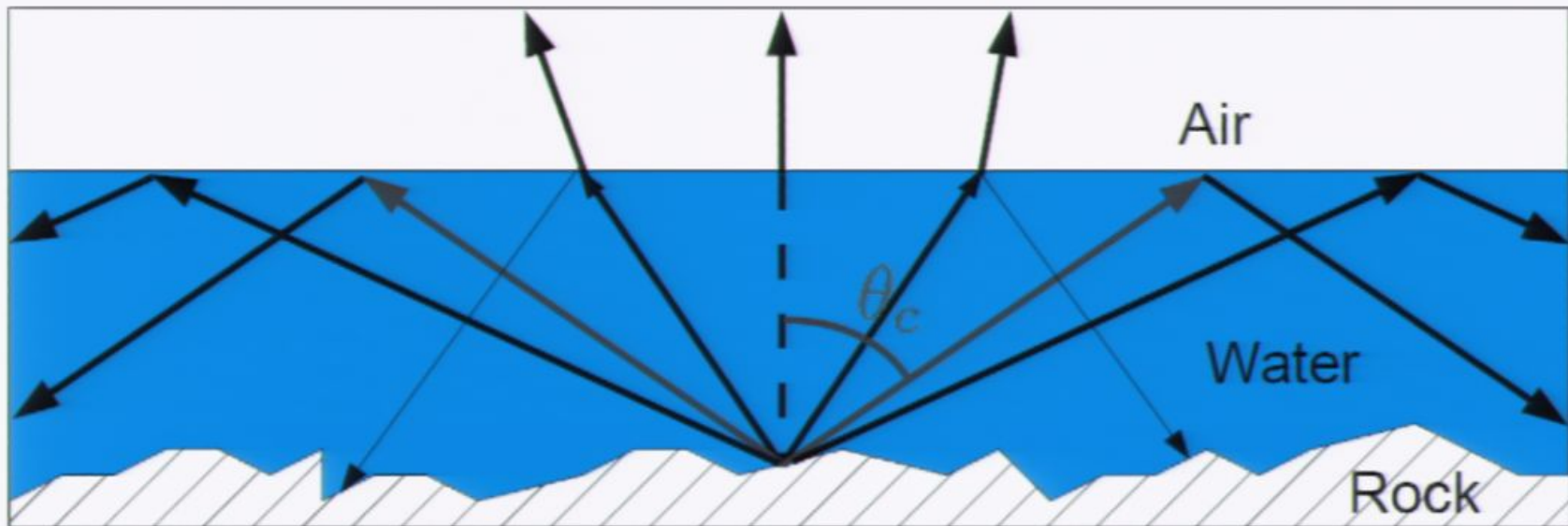
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Rough surface covered with liquid

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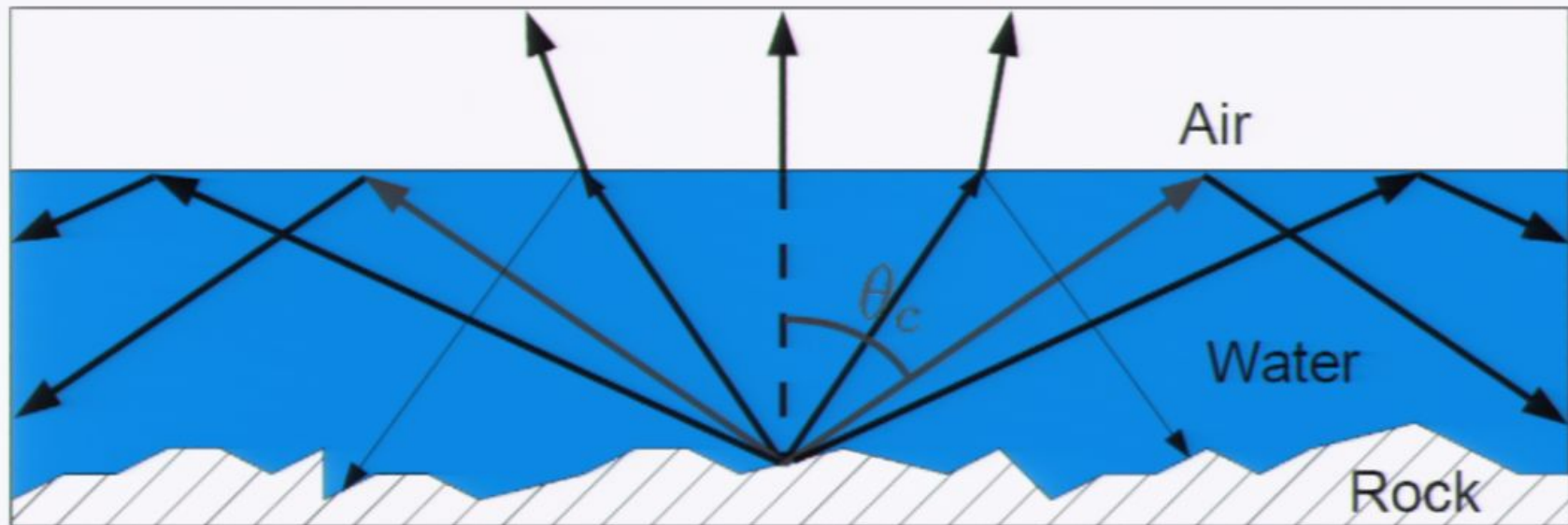
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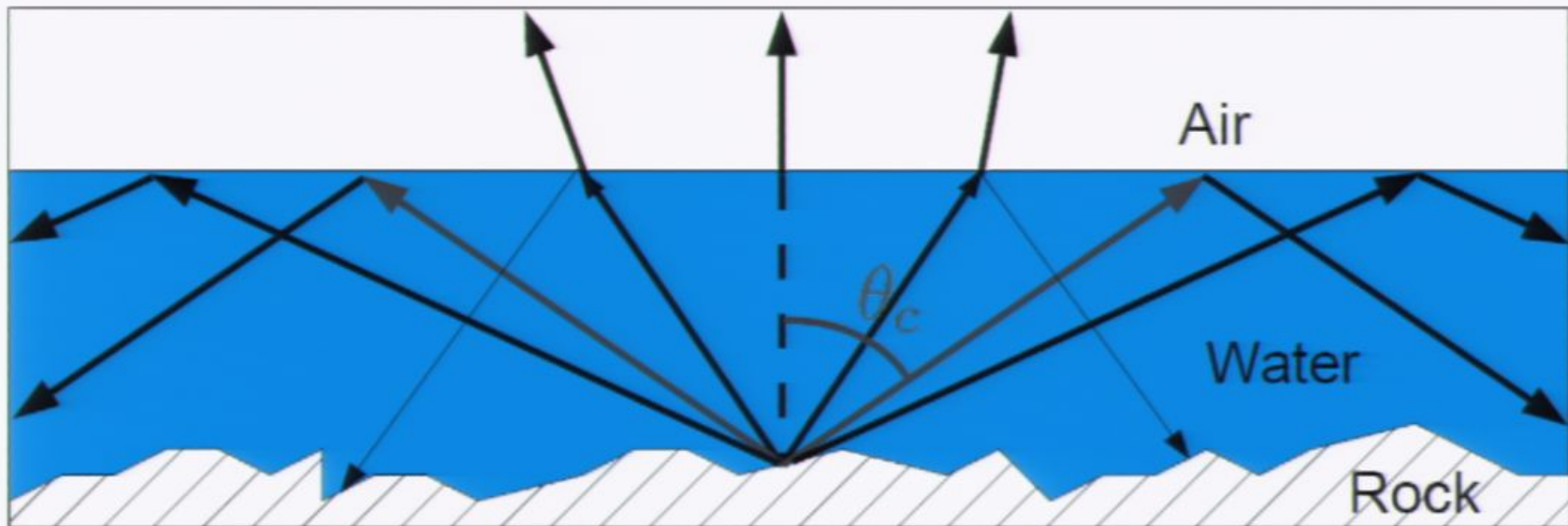


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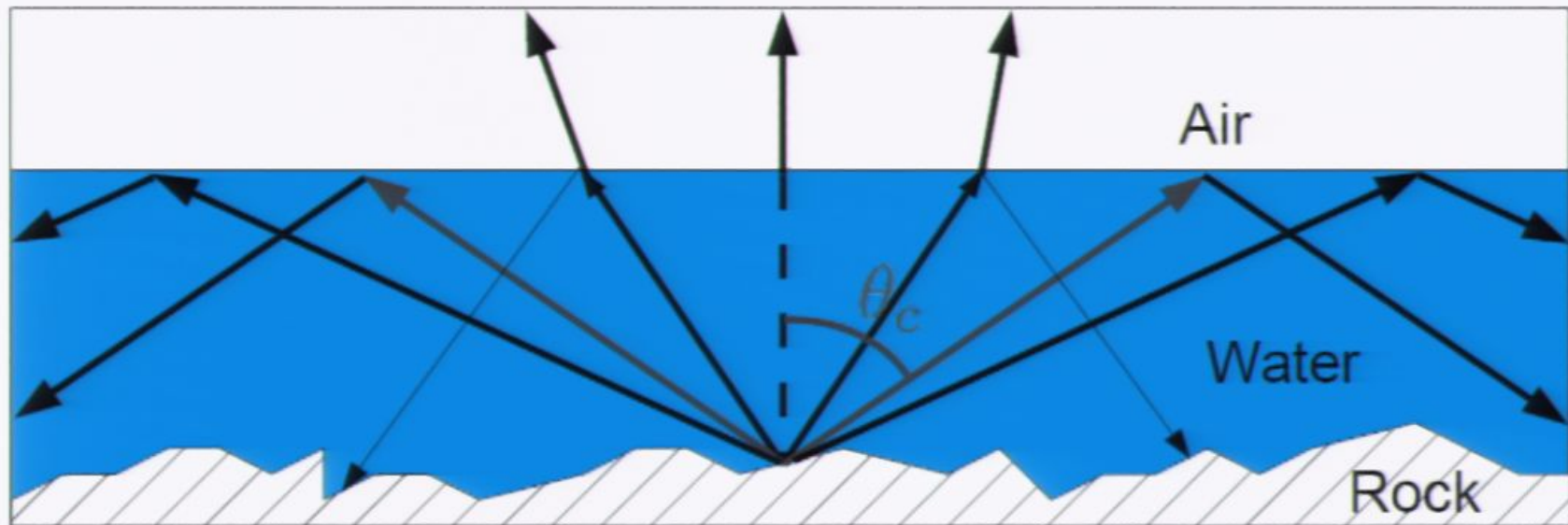
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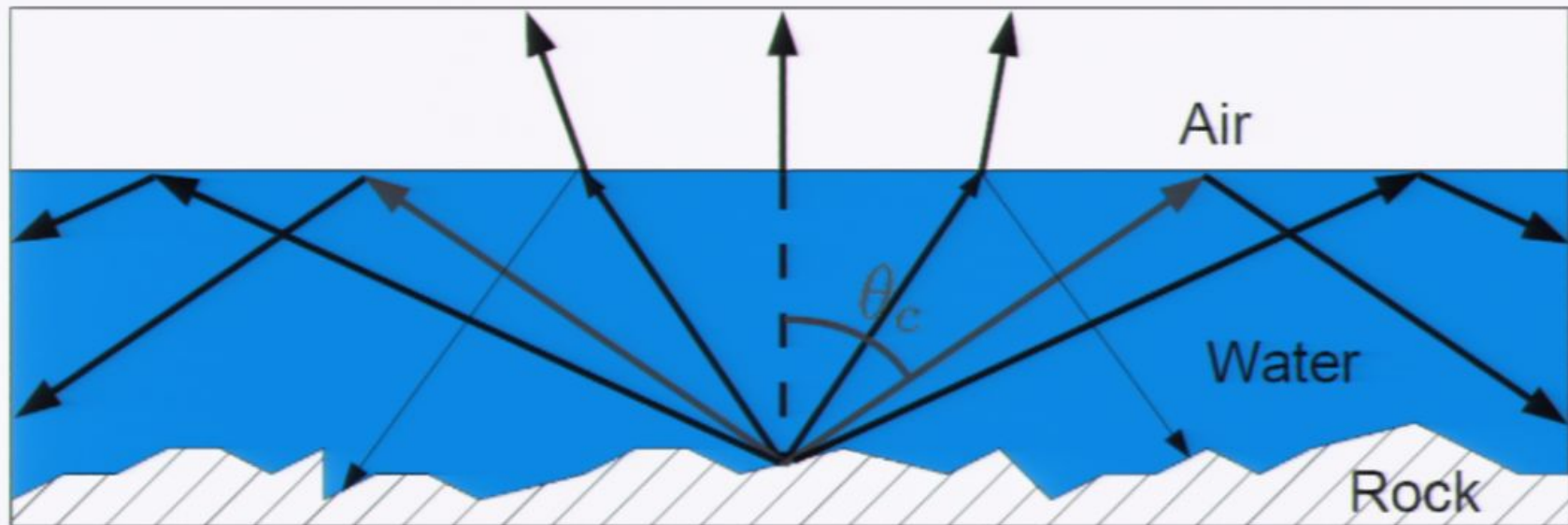
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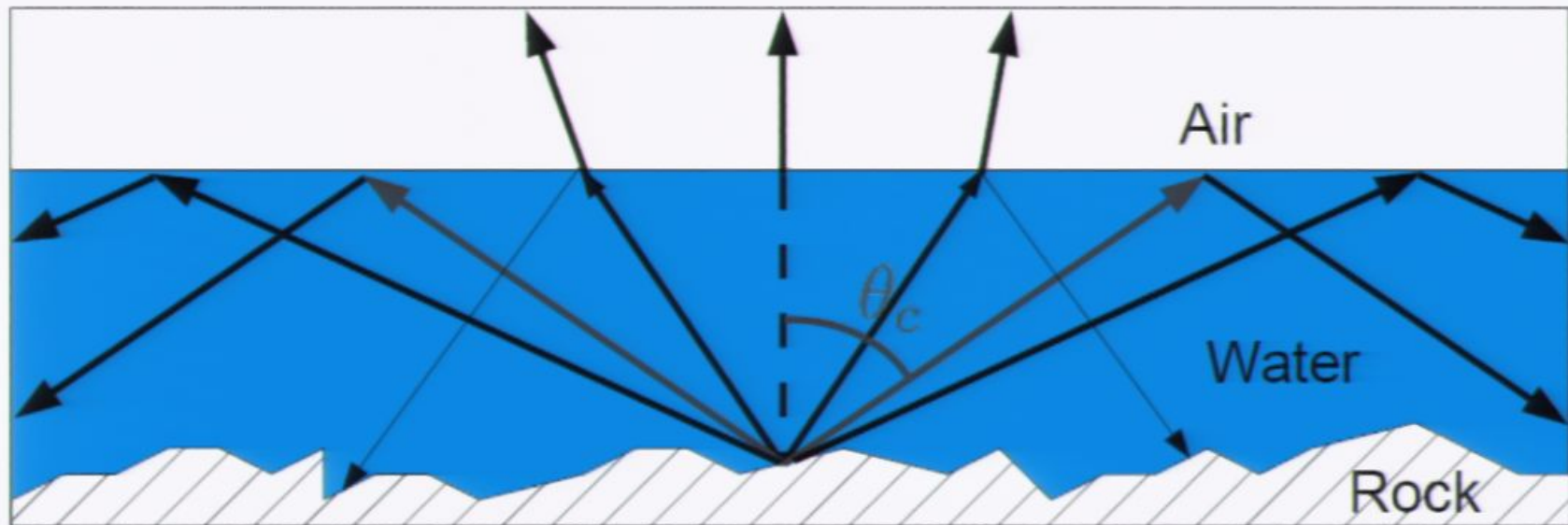
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Rough surface covered with liquid

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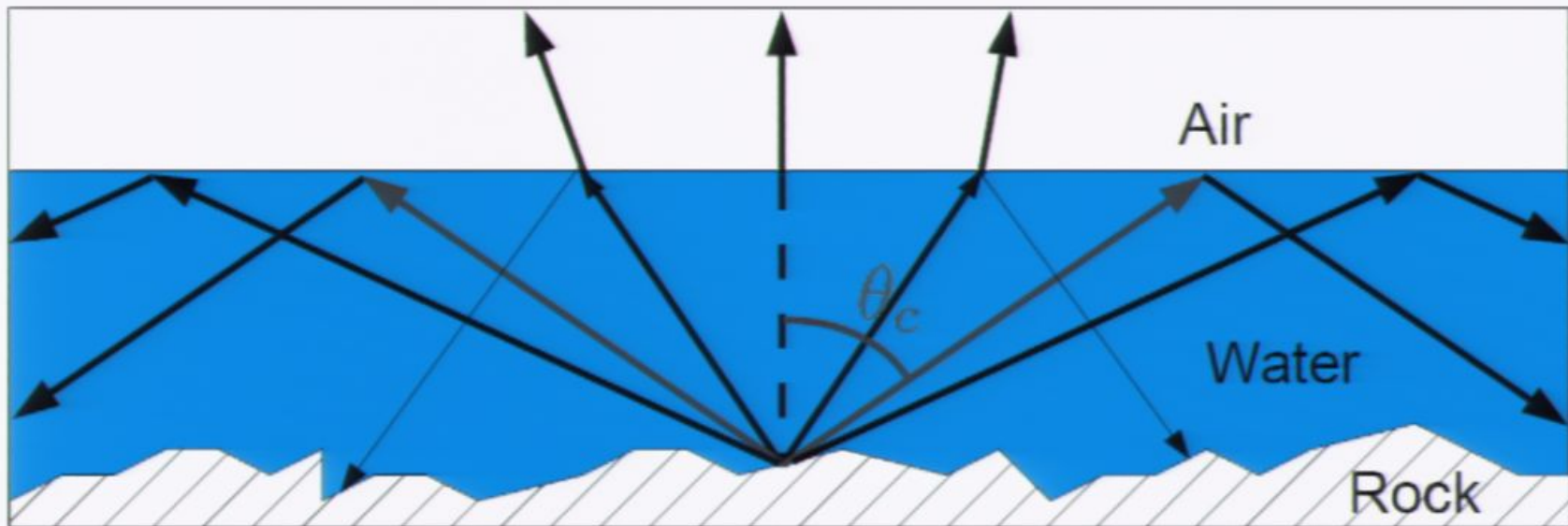


Rough surface covered with liquid



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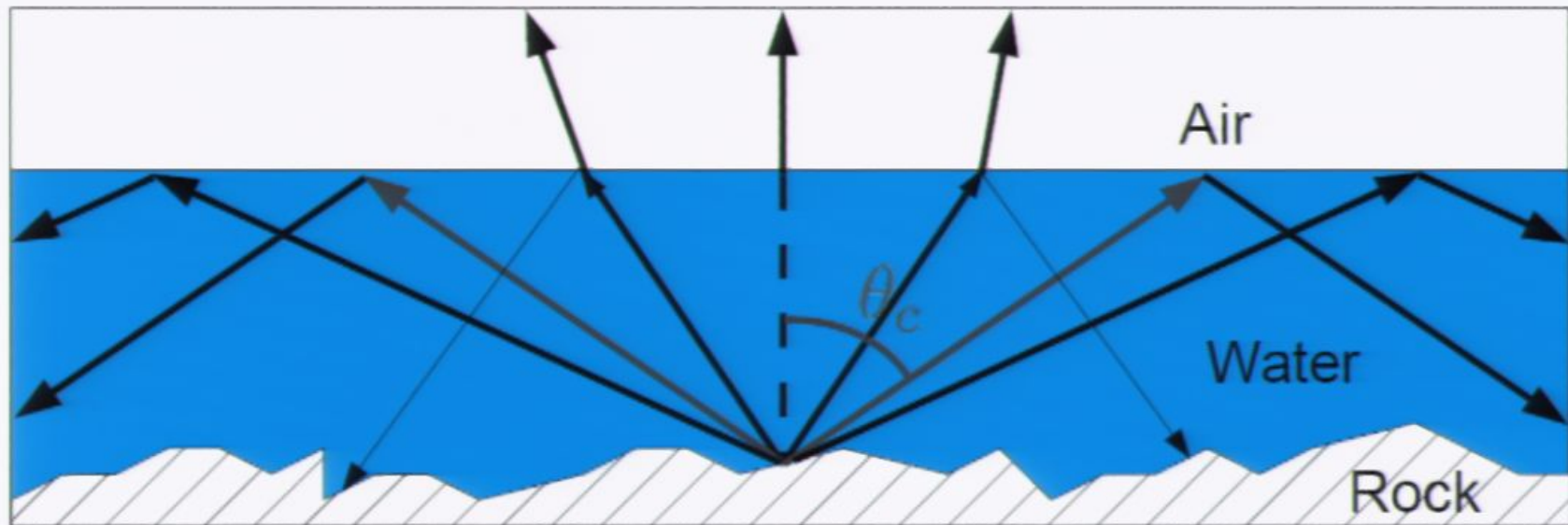
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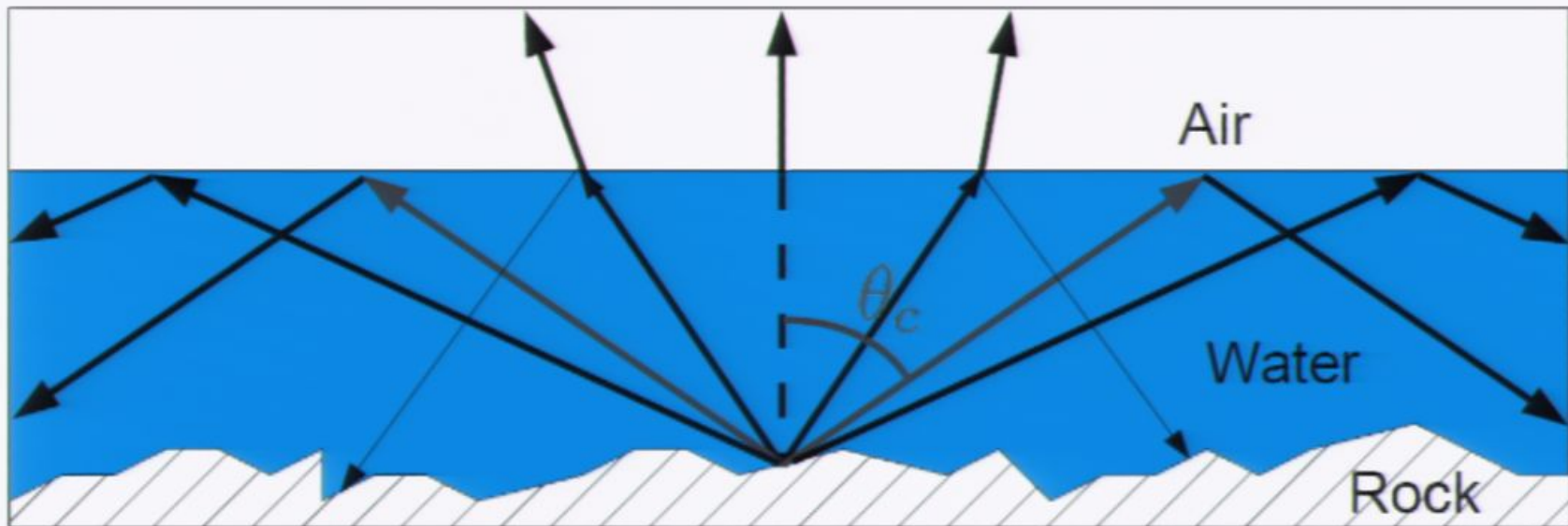
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## Lekner and Dorf, continued

- Ångström underestimated how much light gets trapped in by the water.
- Also, Ångström did not consider that more light will probably be absorbed at water-solid interface than at air-solid interface
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# Conclusions

- Rough surfaces are darker when wet because of:
  - Total internal reflection of light within layer of water
  - Partial reflection of light within layer of water
  - Higher absorption at the liquid-solid interface than there would be at an air-solid interface

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Thank you!



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Thank you!



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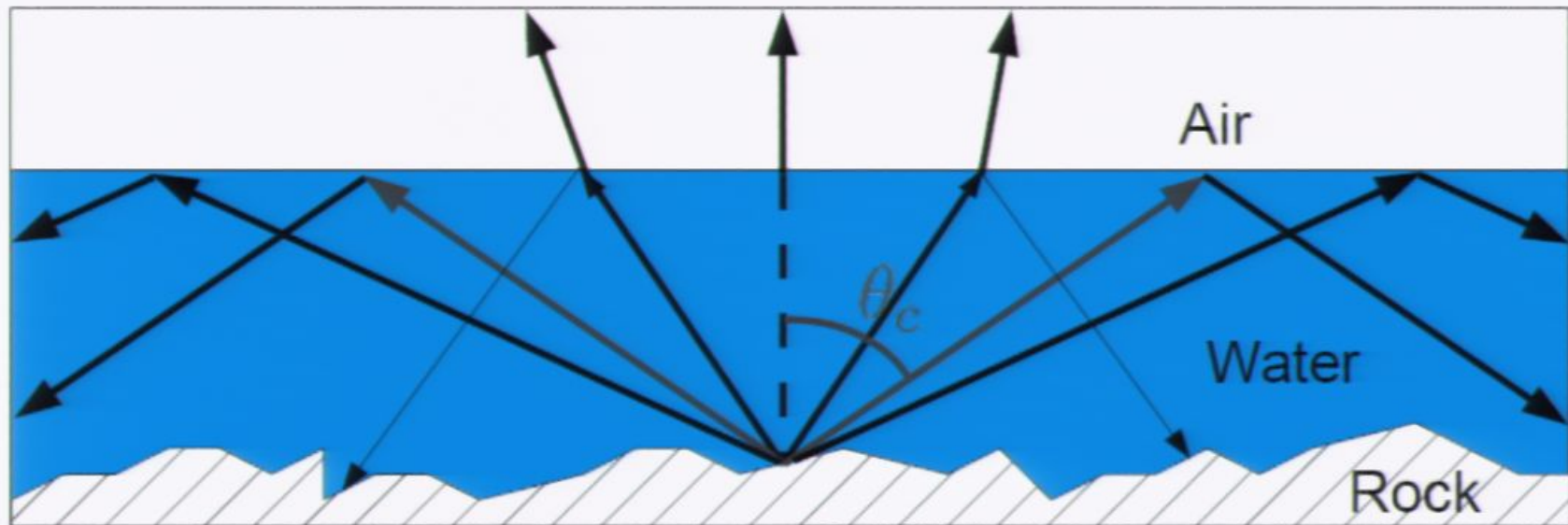
Thank you!



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# Lekner and Dorf Modification

- There is also partial reflection at the water-air interface of beams that are not totally internally reflected

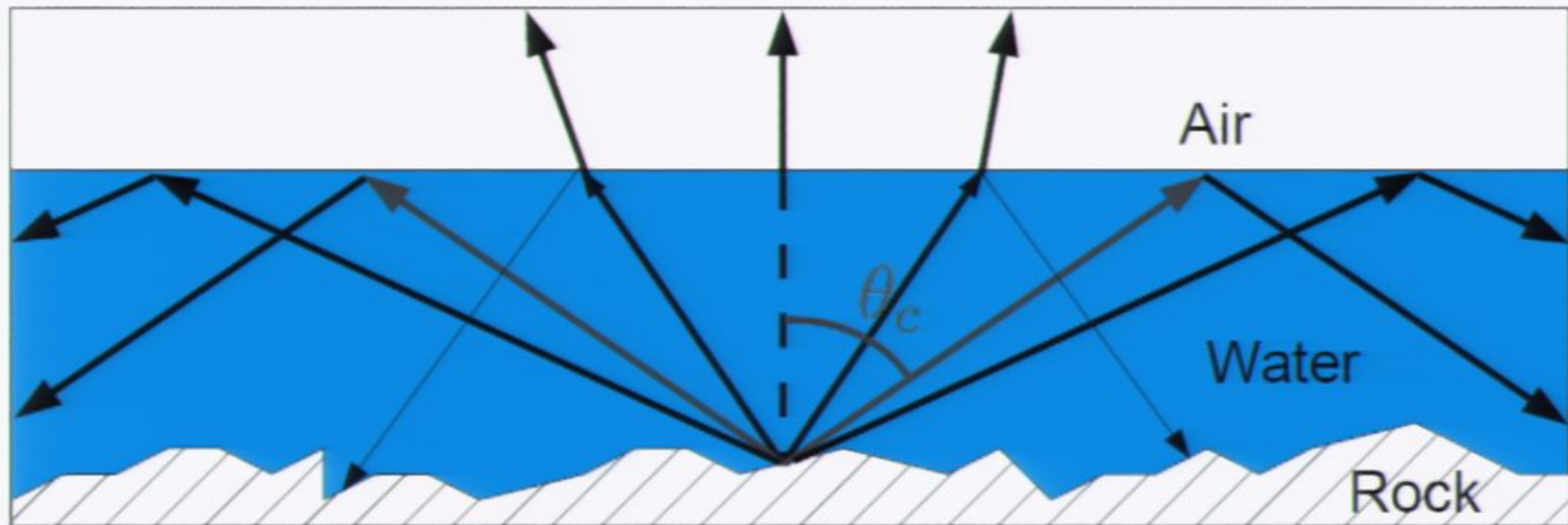


Rough surface covered with liquid



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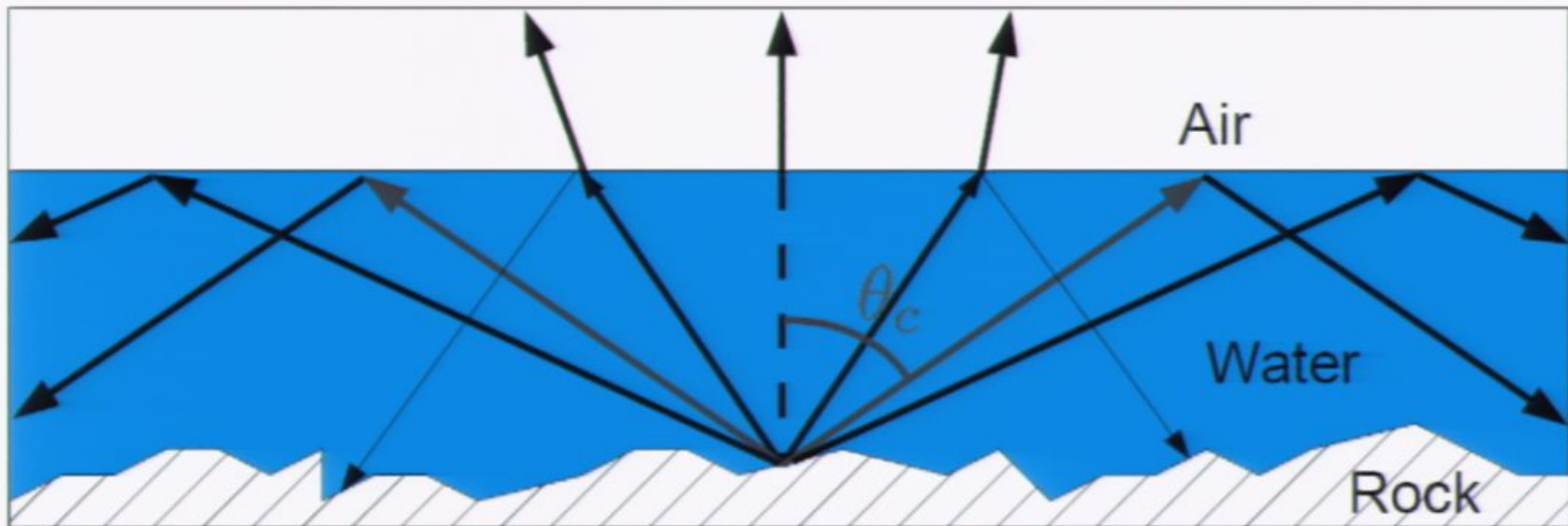
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Rough surface covered with liquid

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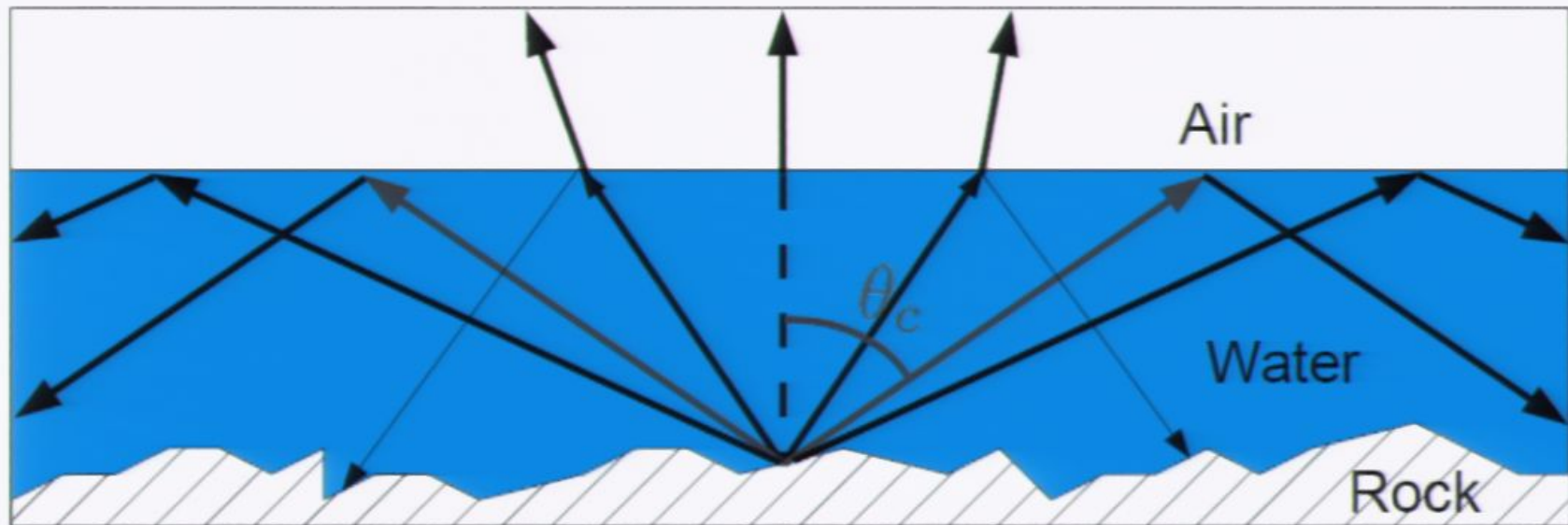
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Rough surface covered with liquid

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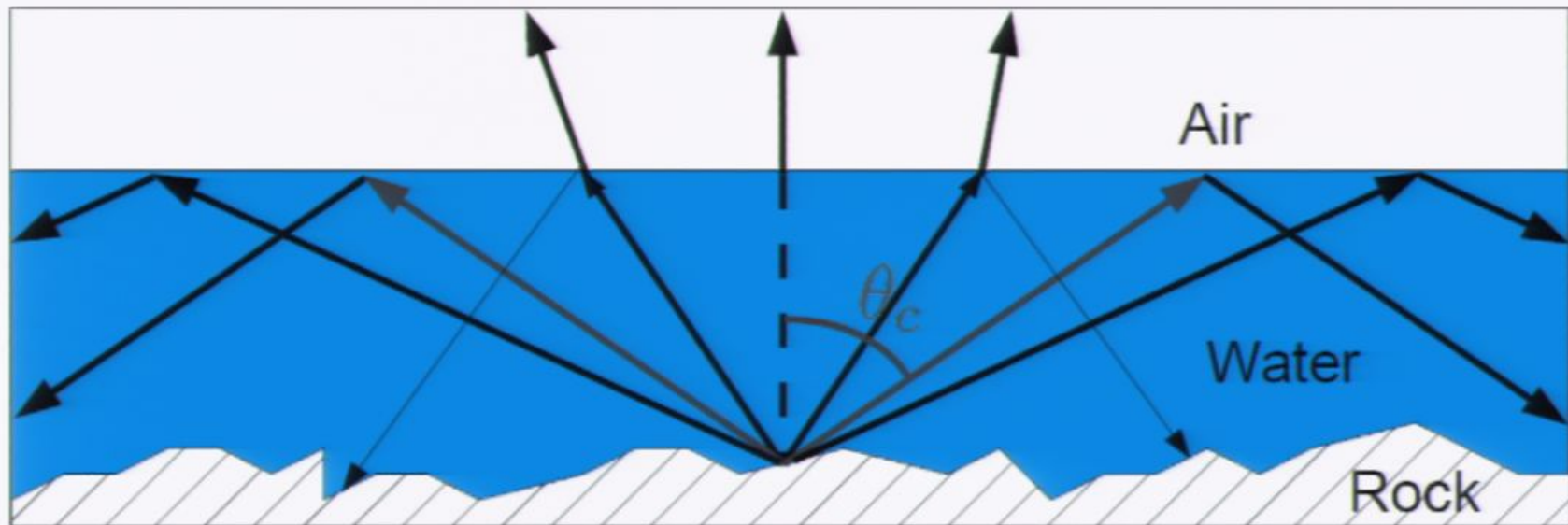


Rough surface covered with liquid



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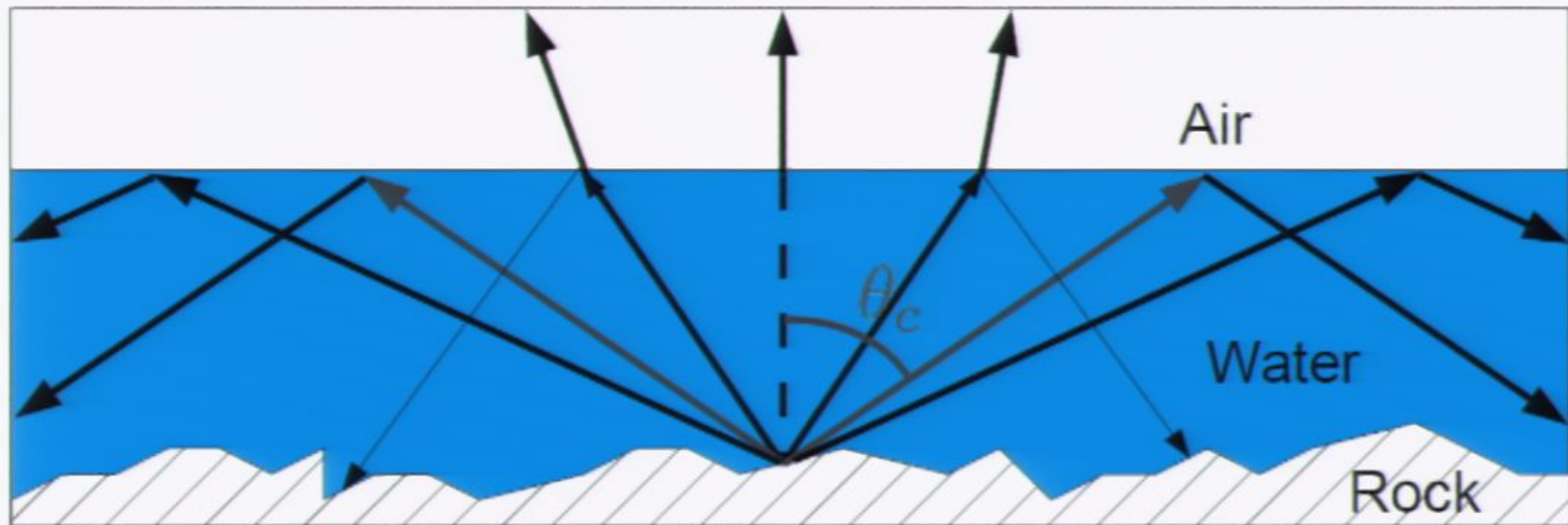
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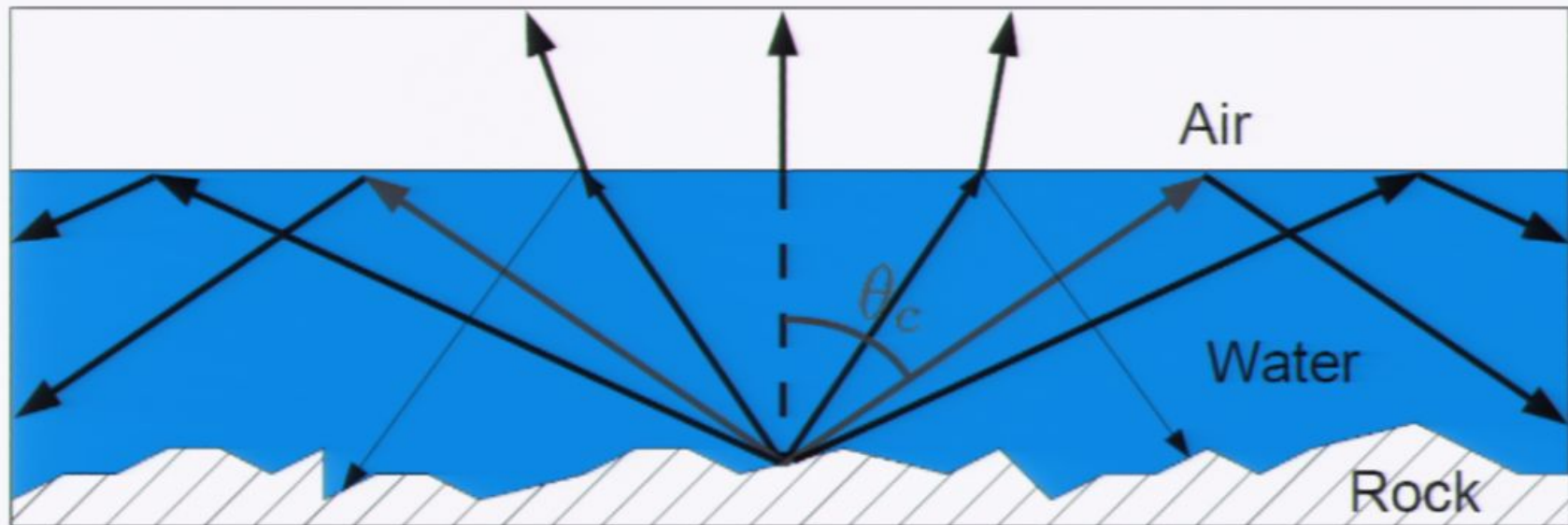
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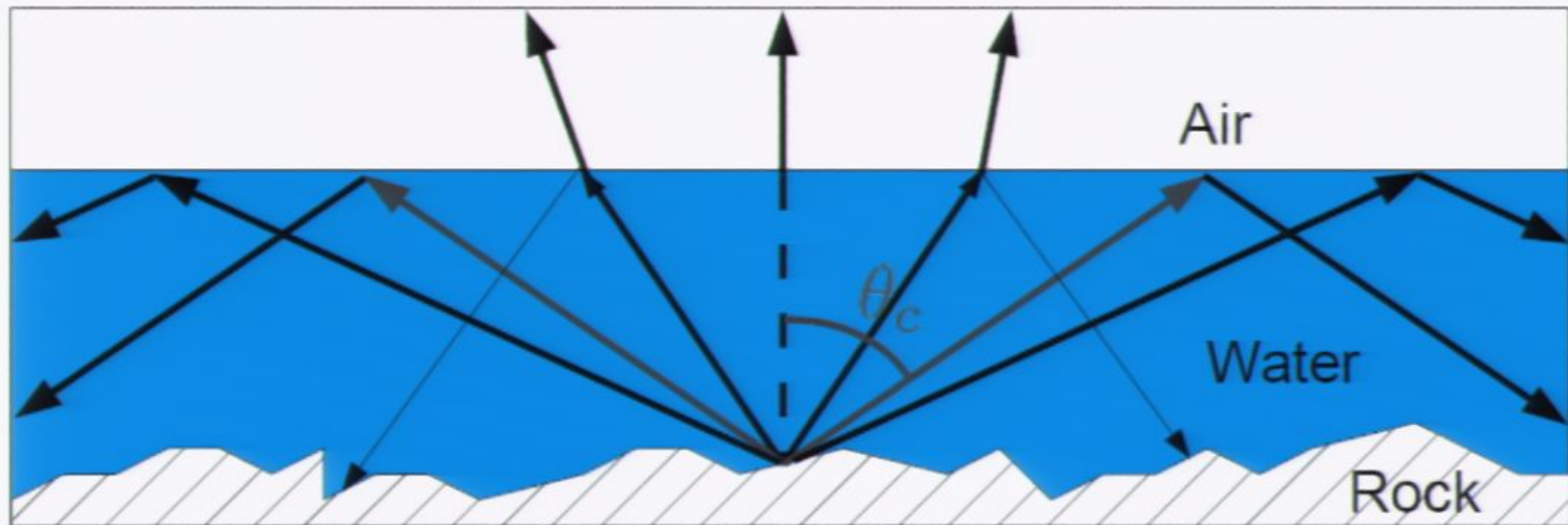


Rough surface covered with liquid



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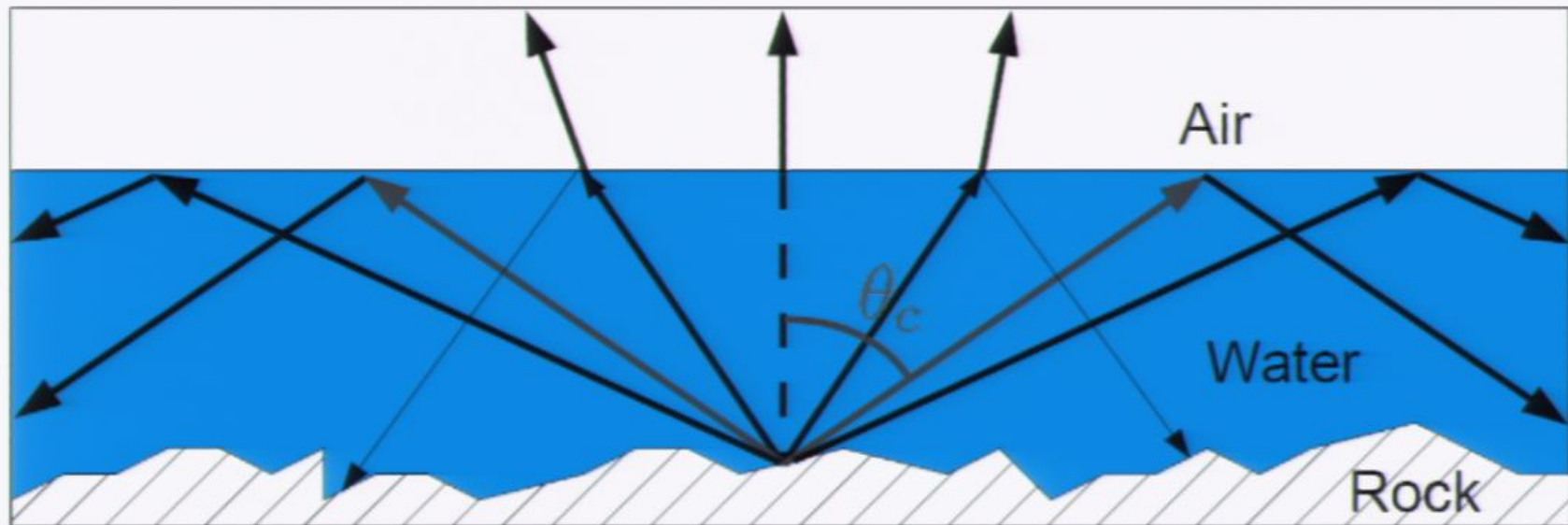
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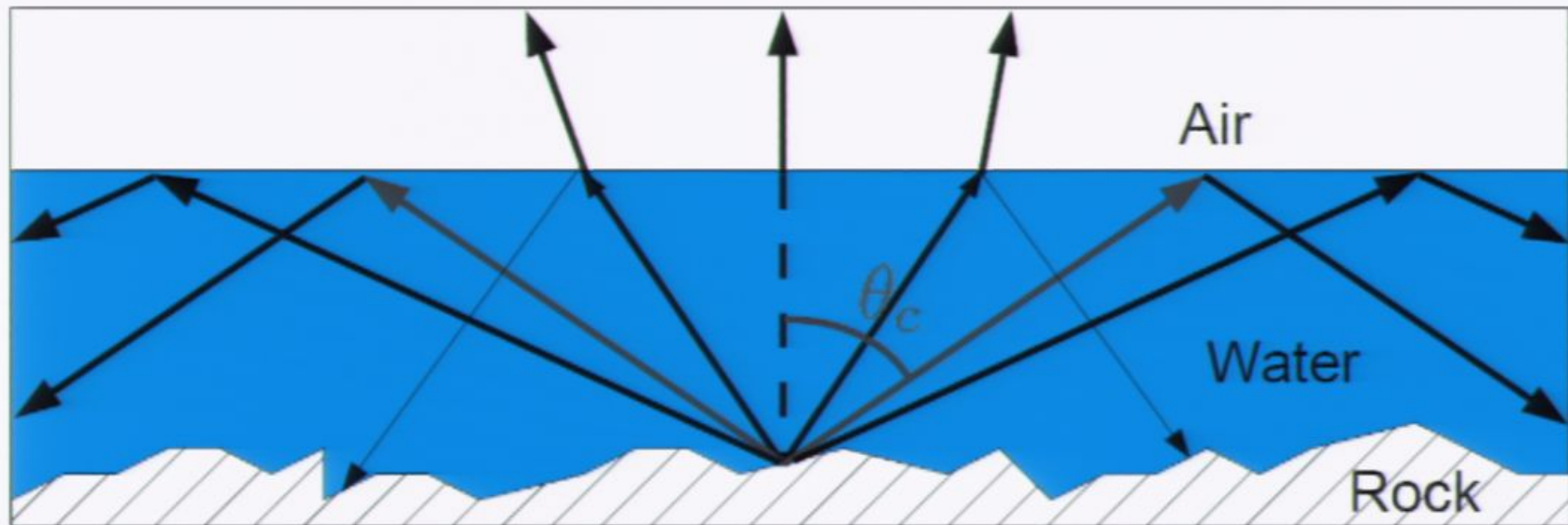
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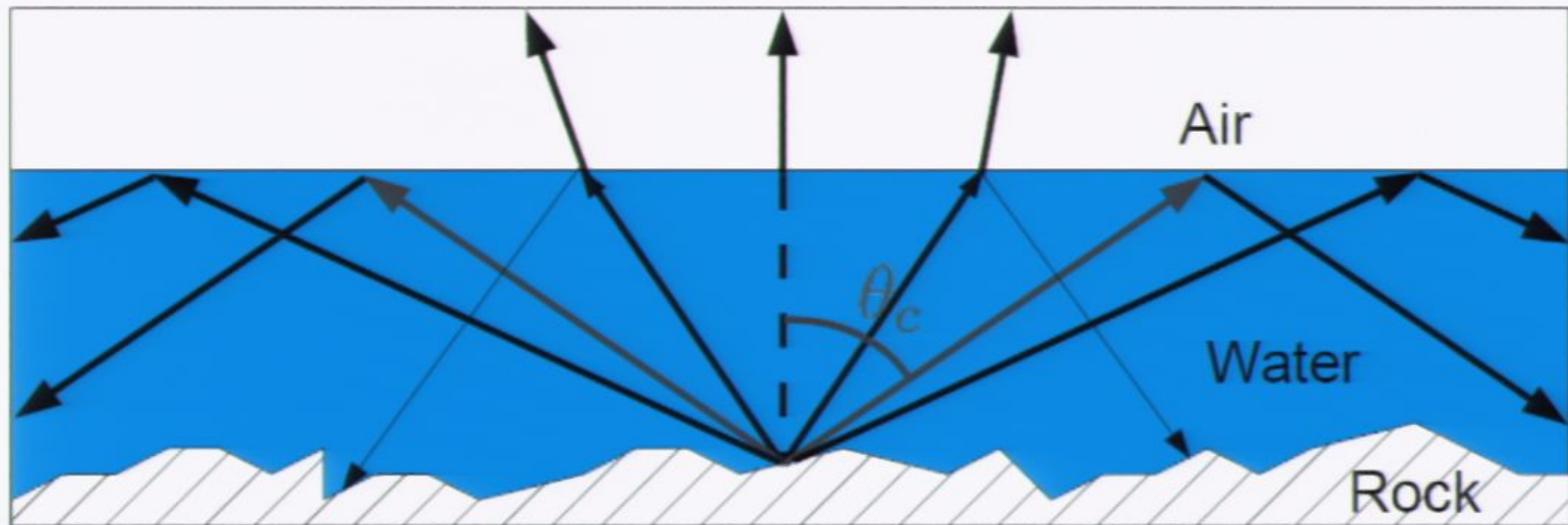


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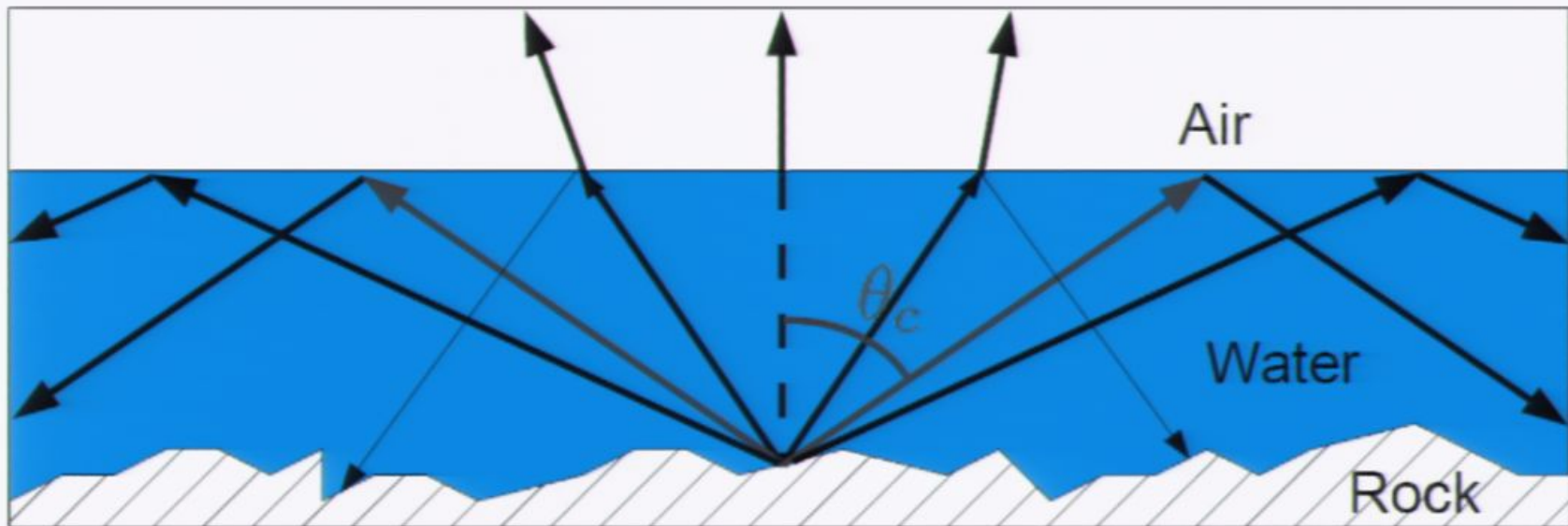
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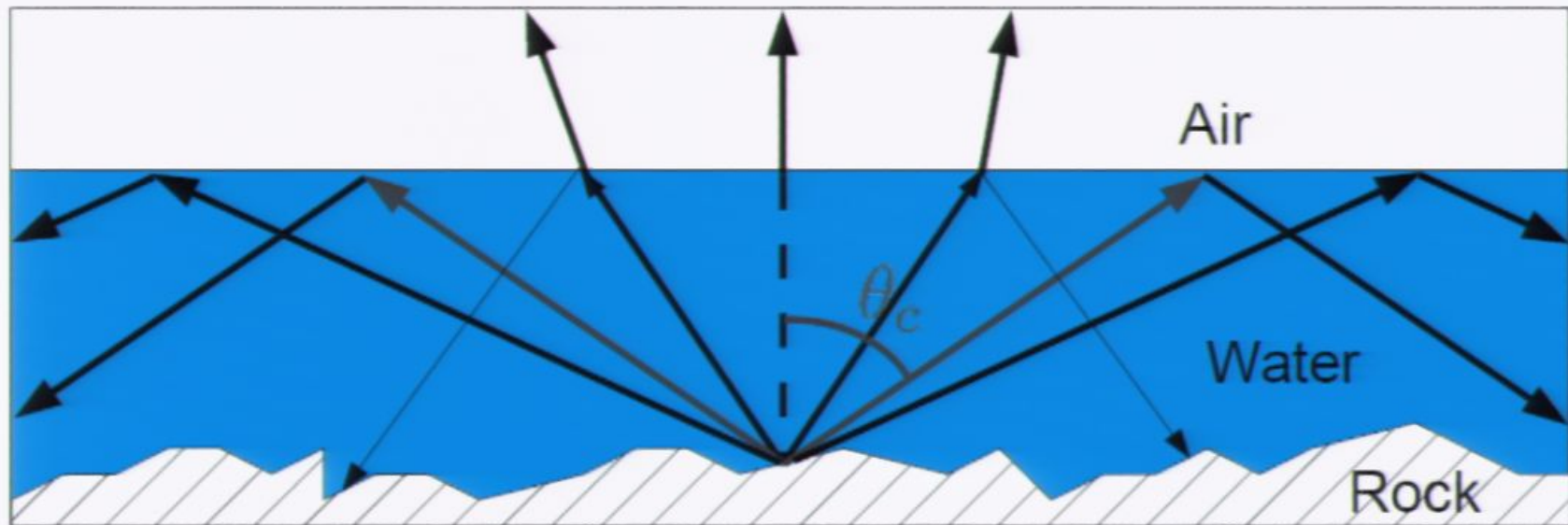
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Rough surface covered with liquid

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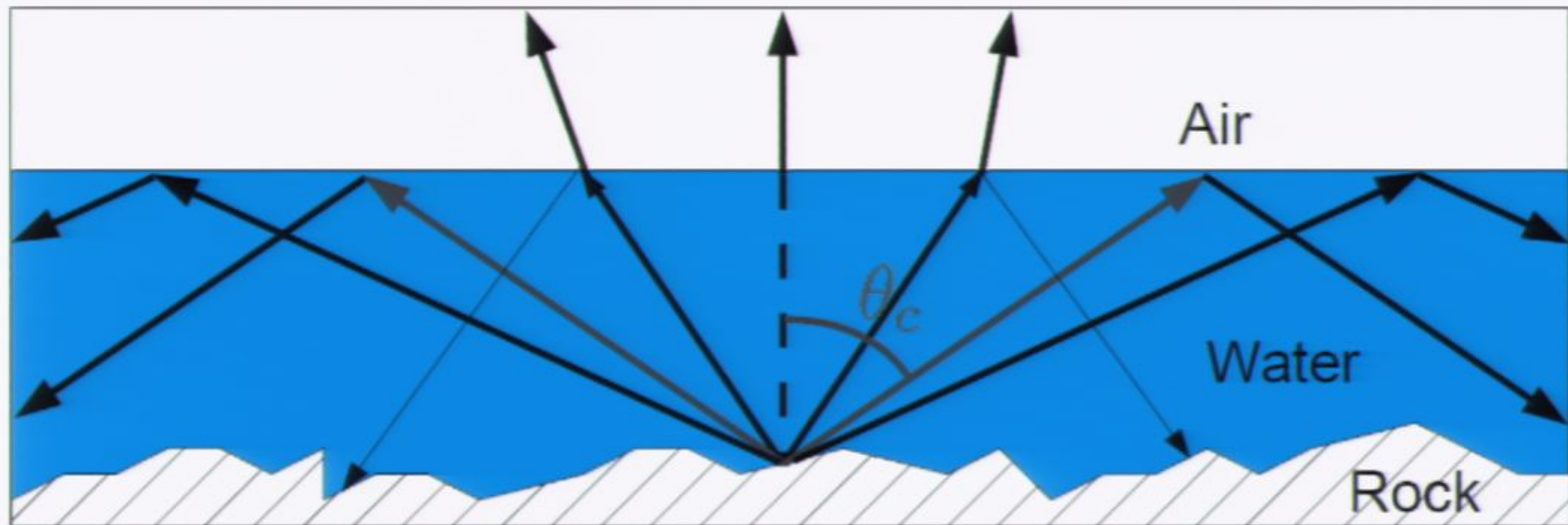


Rough surface covered with liquid



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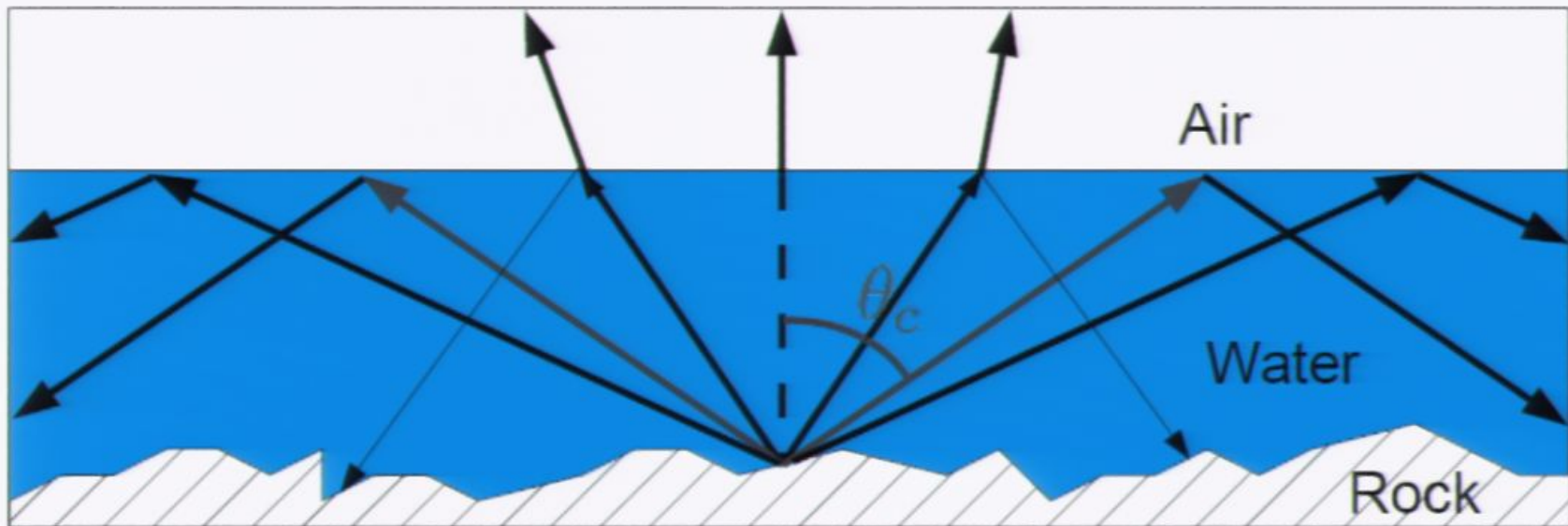
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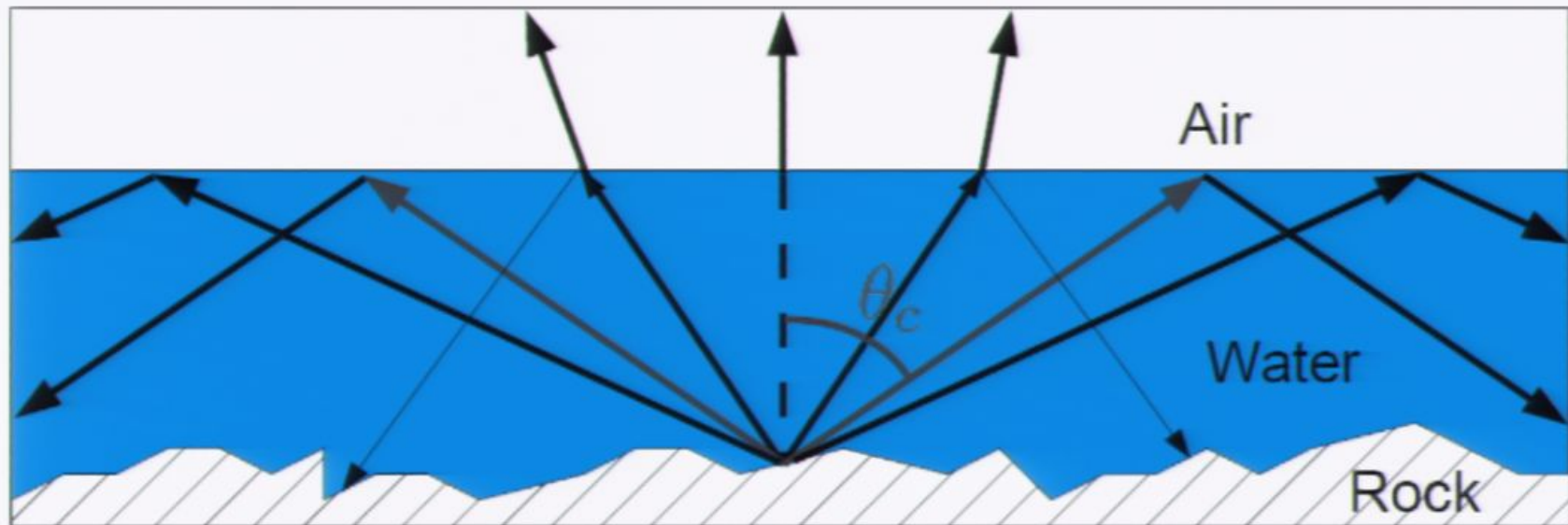
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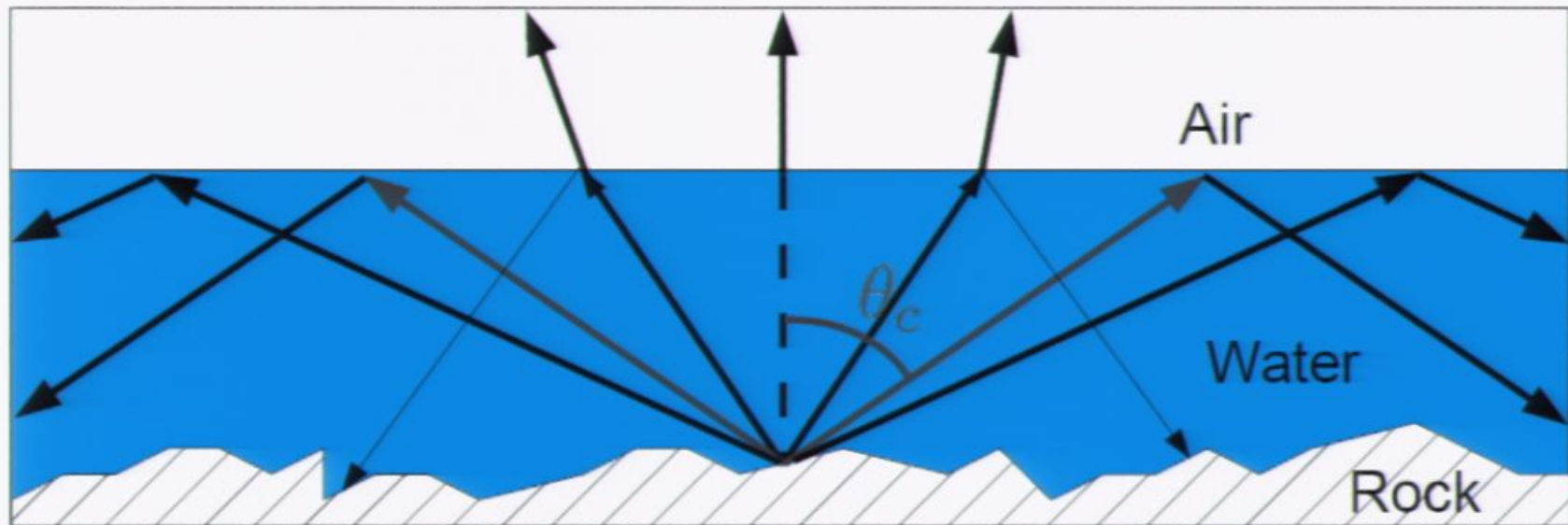


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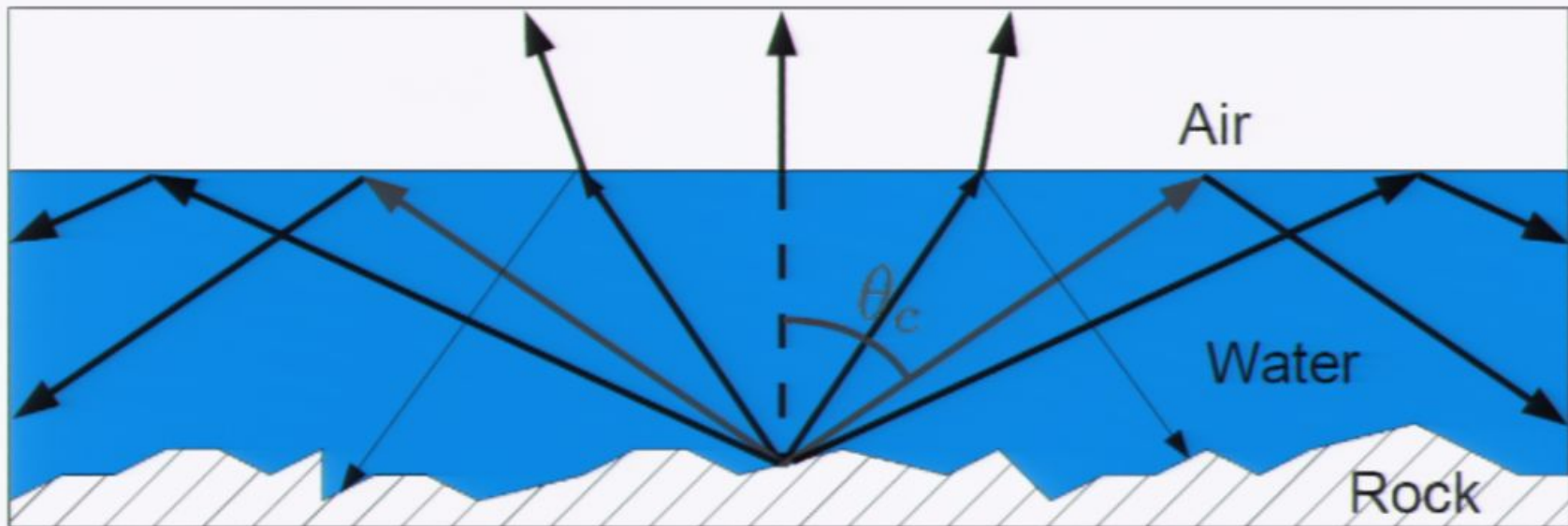
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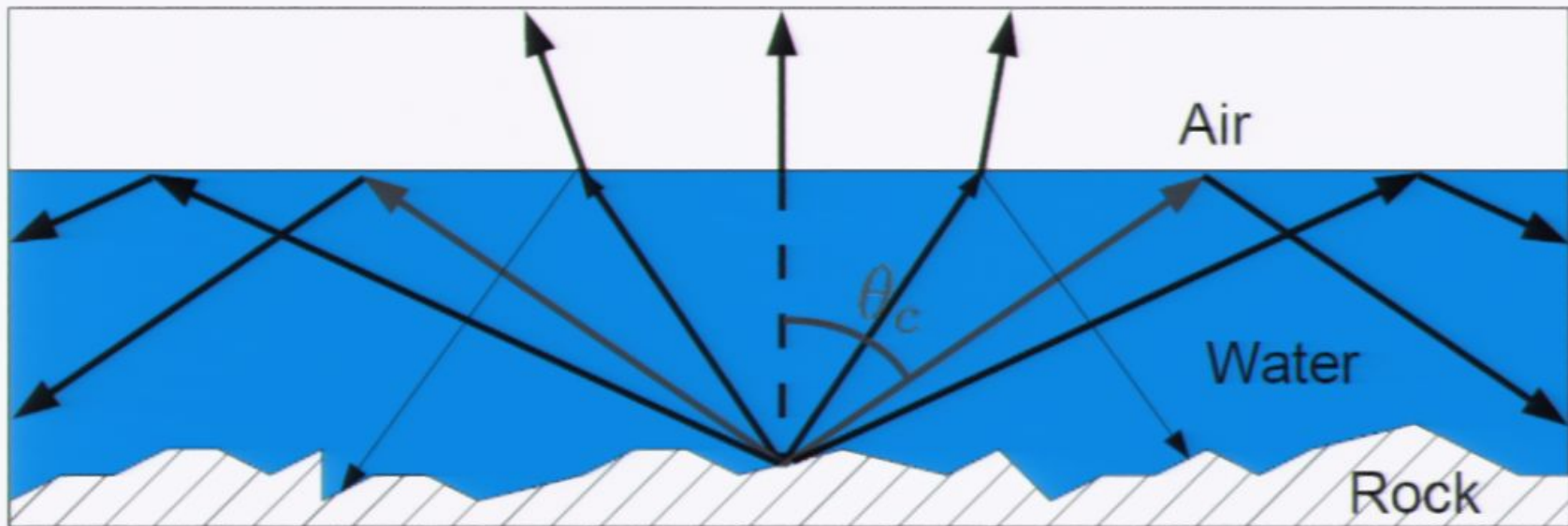
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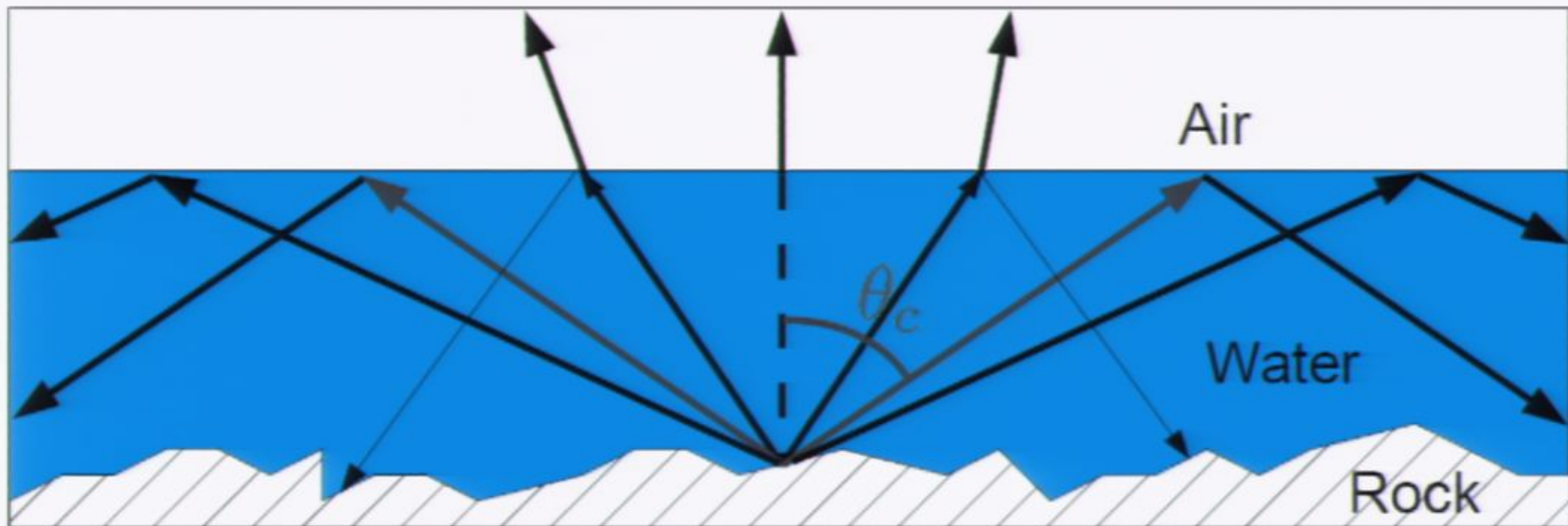


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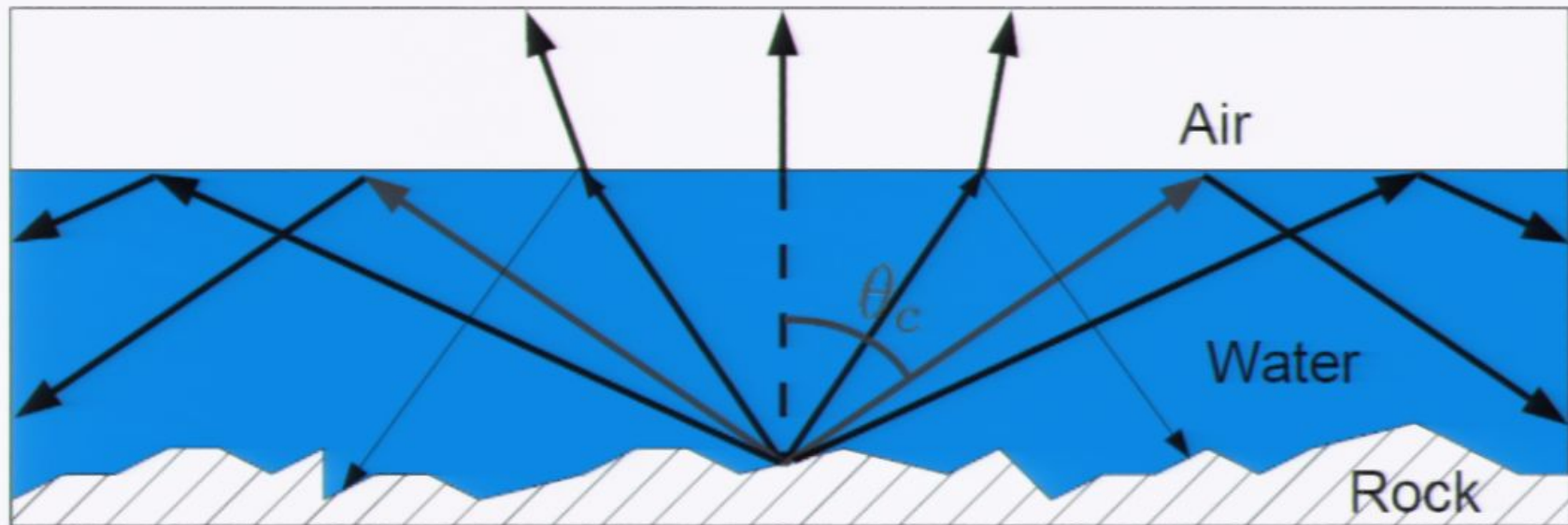
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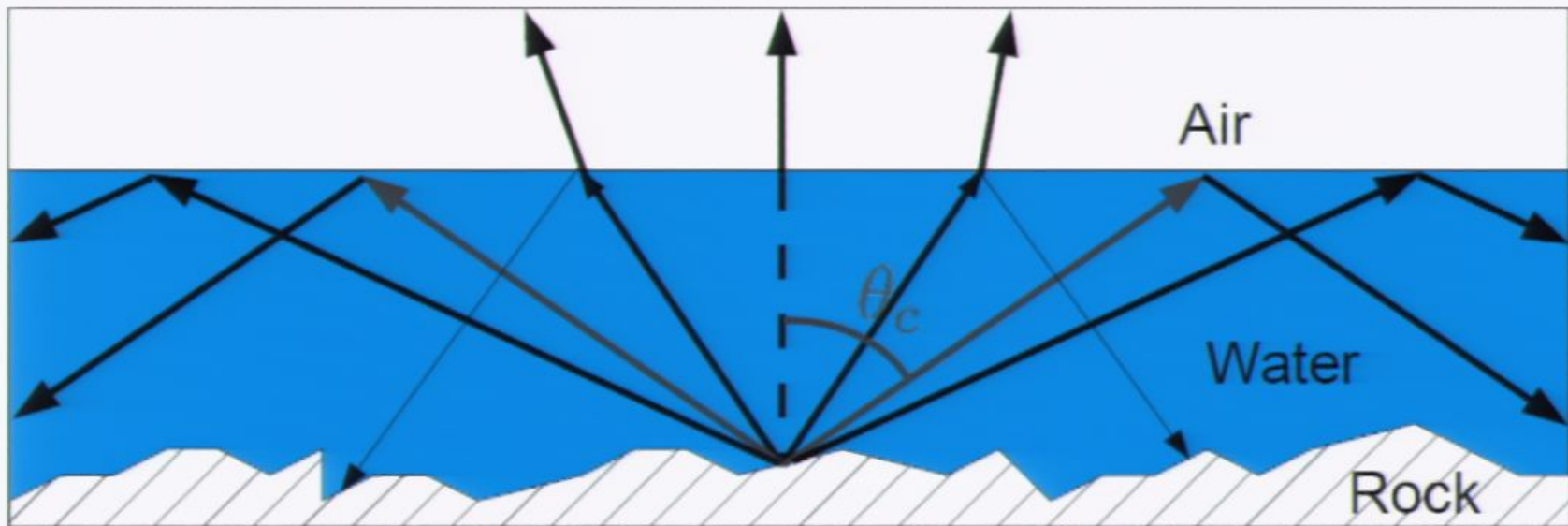
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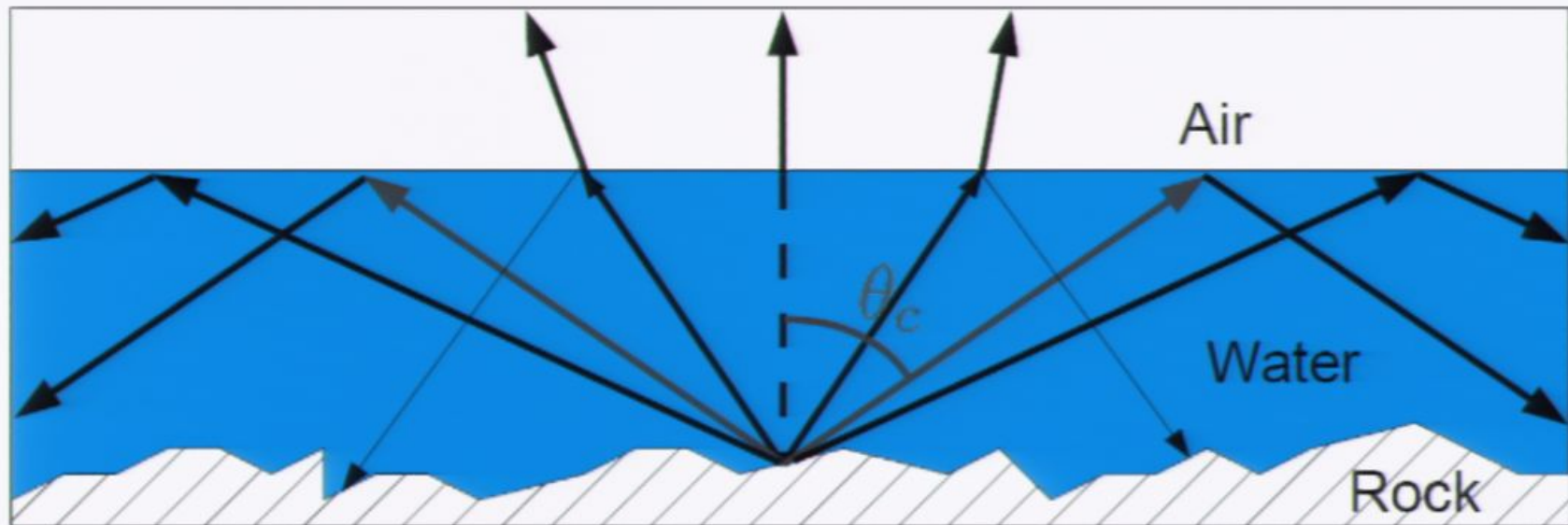


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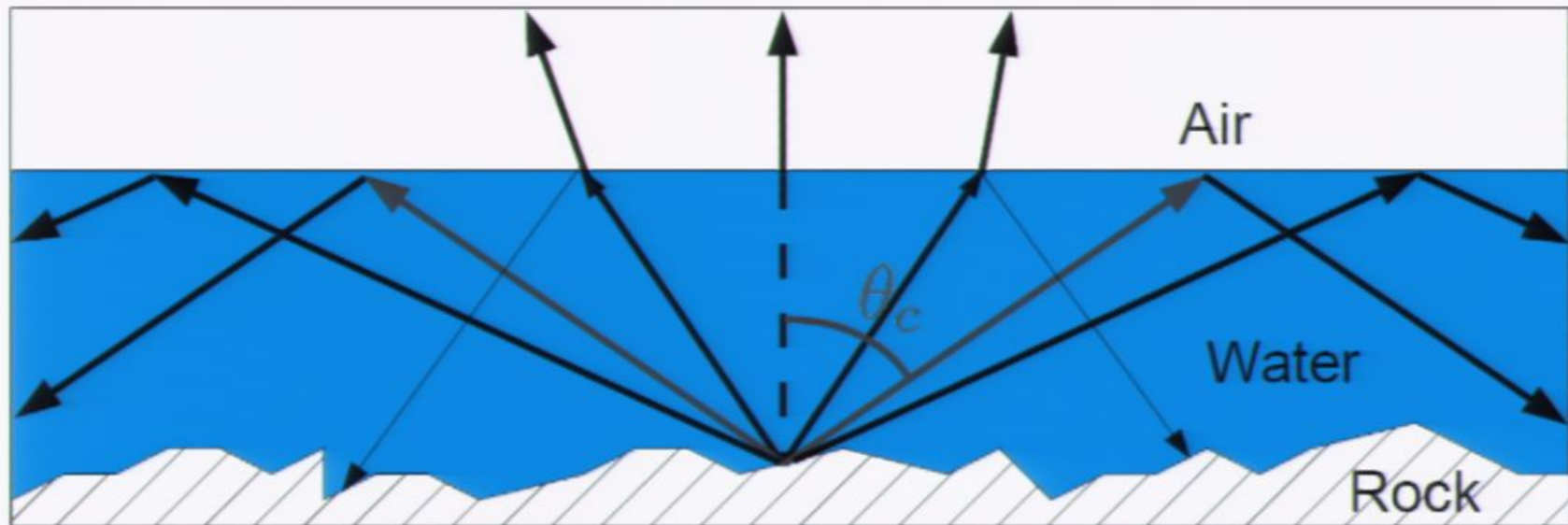
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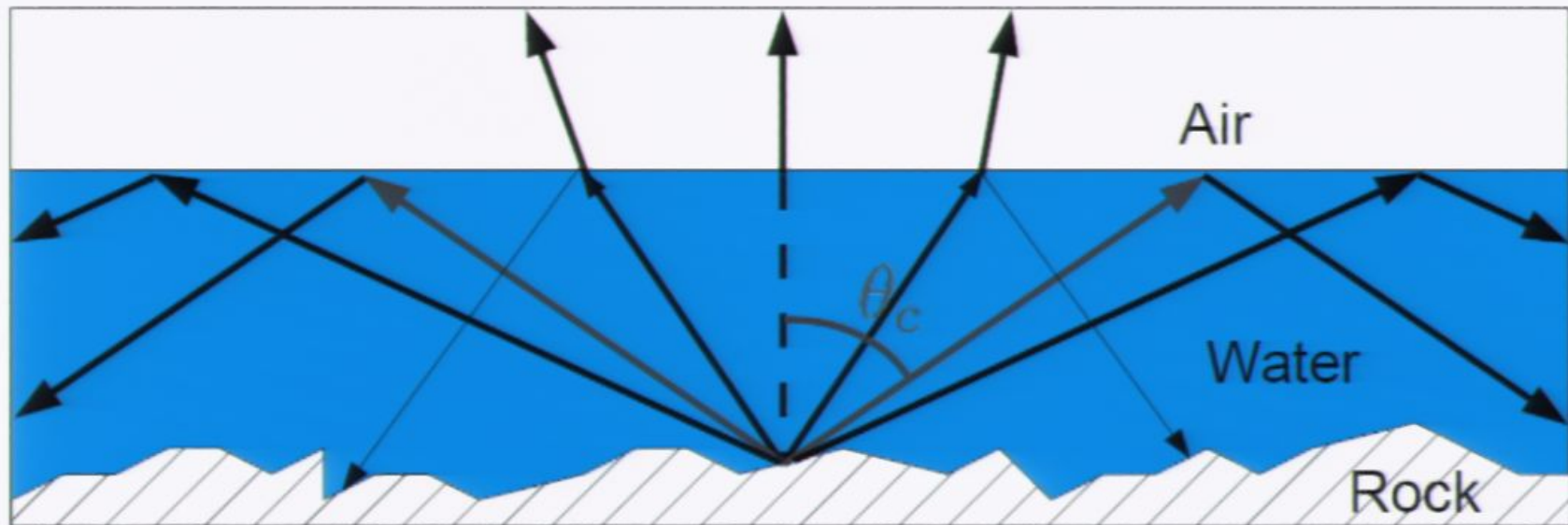
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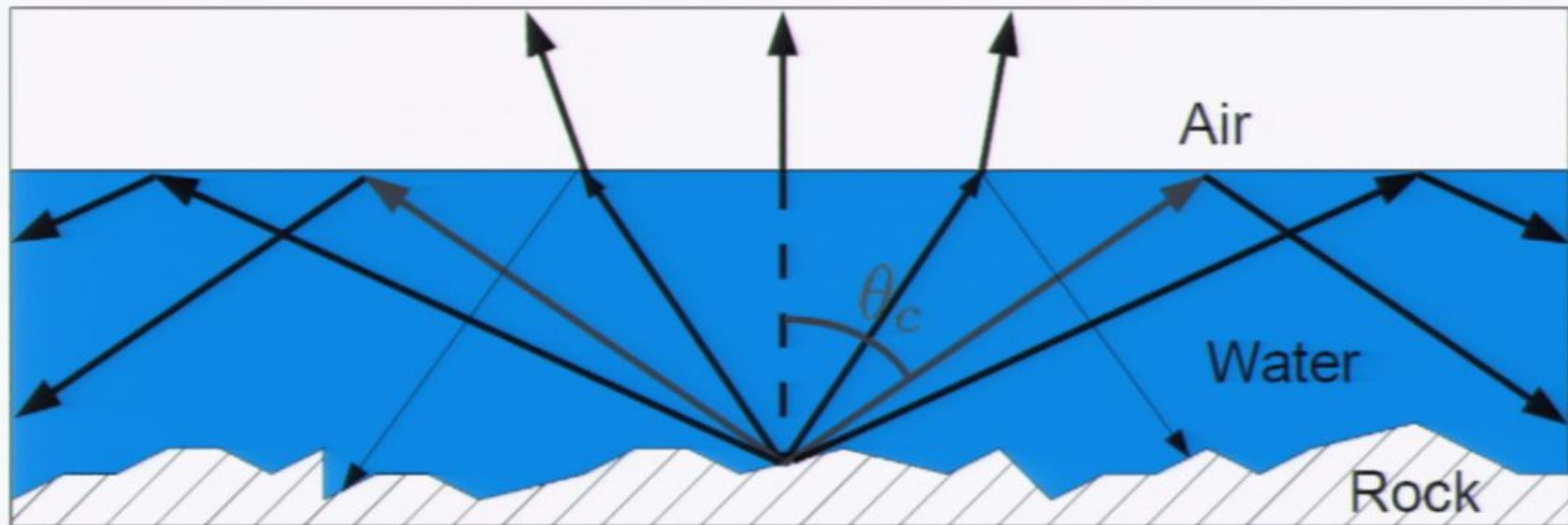


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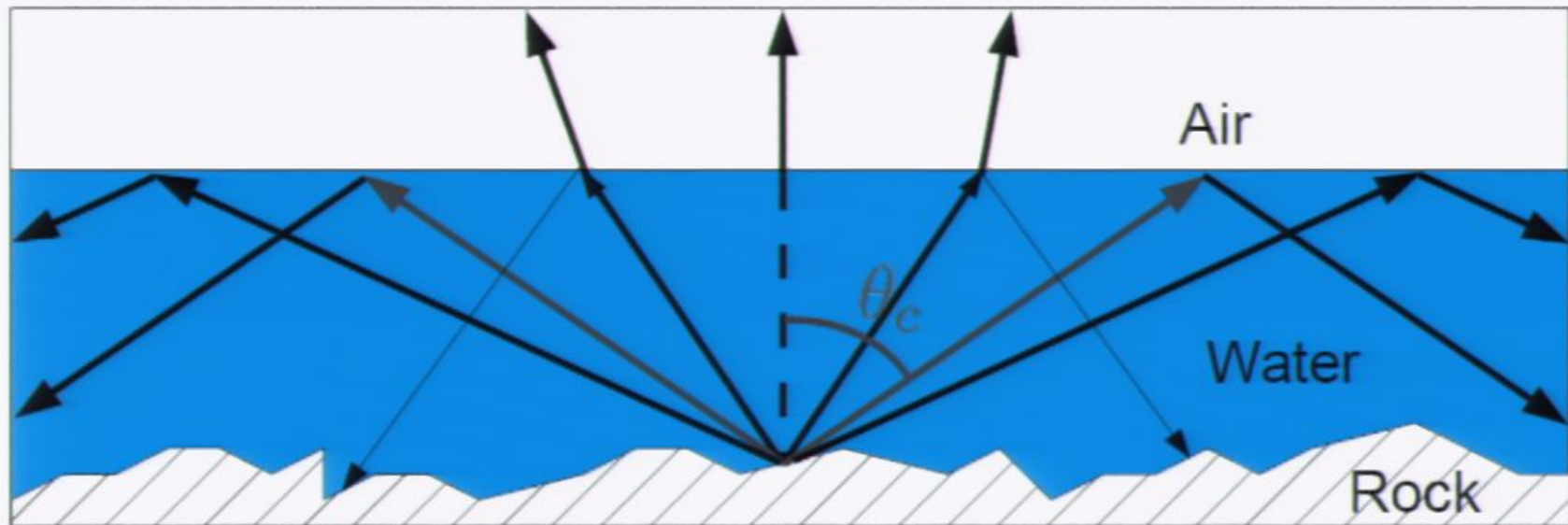
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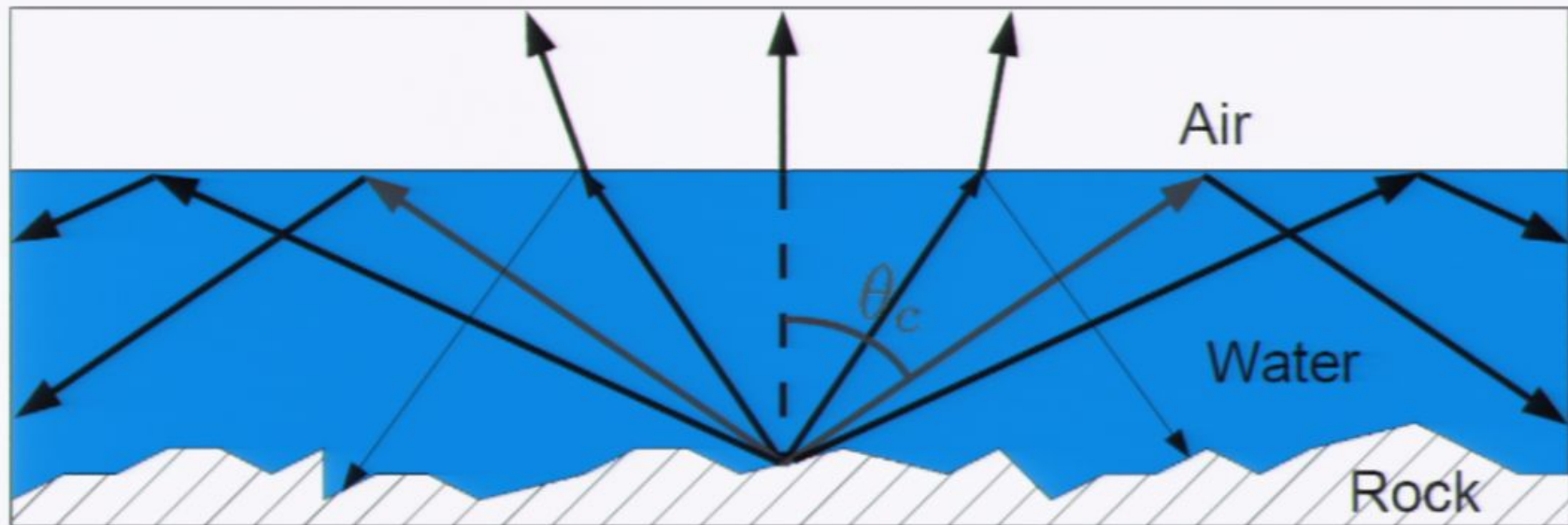
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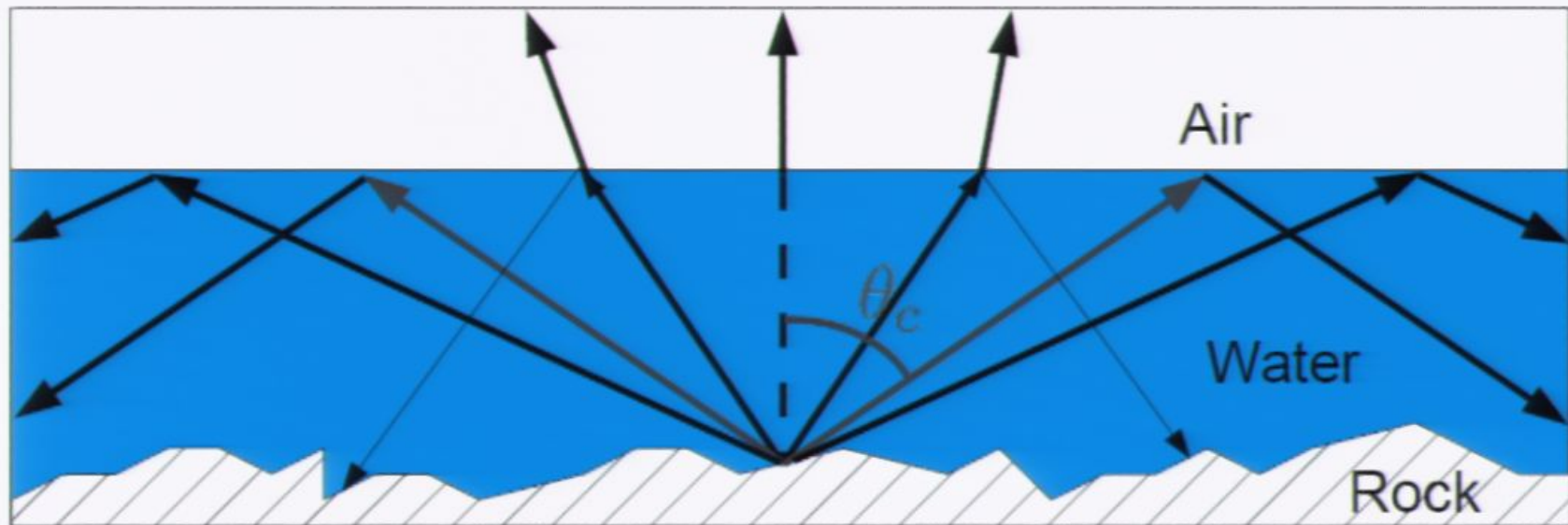


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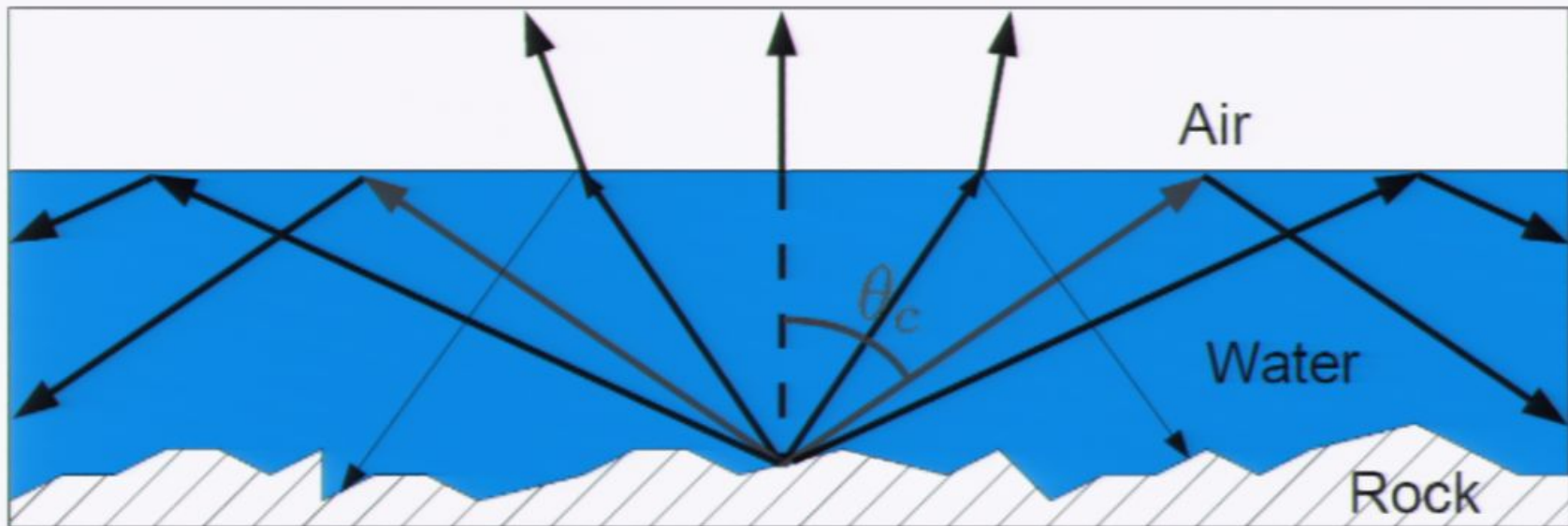
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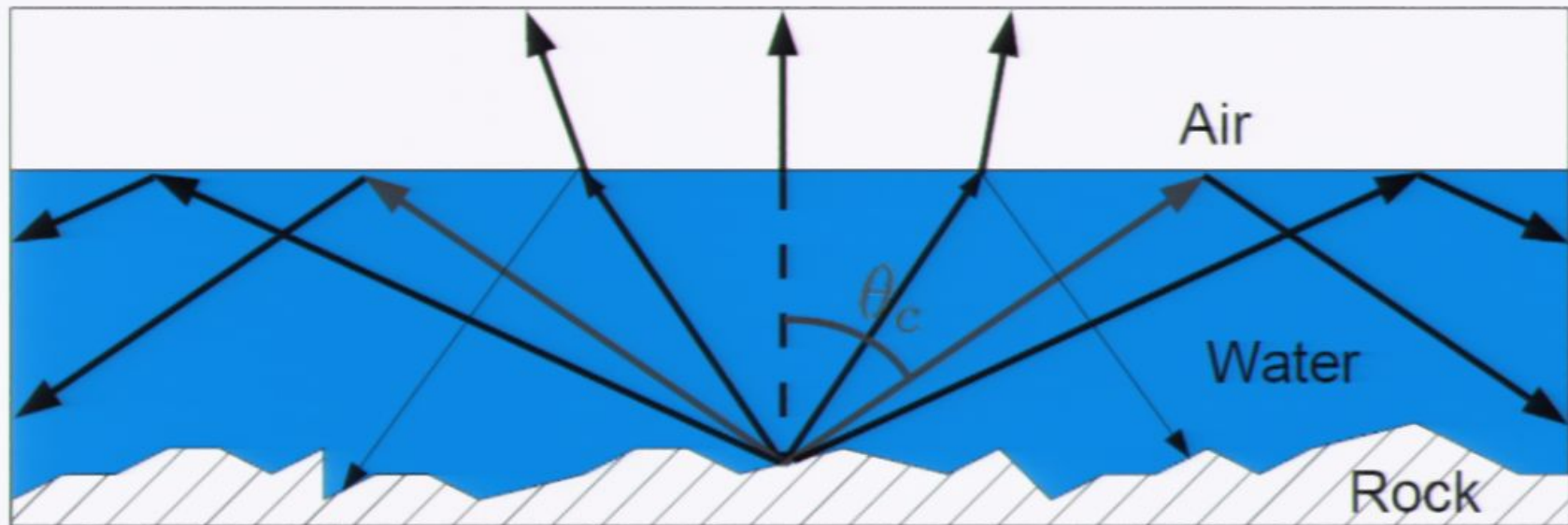
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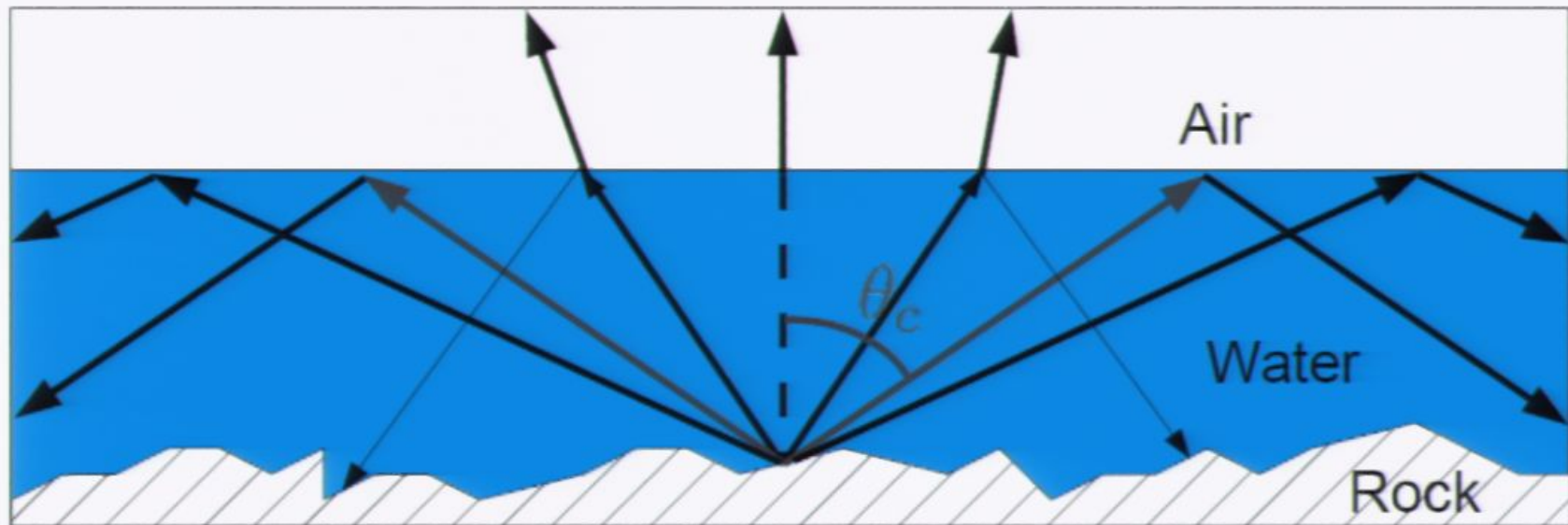


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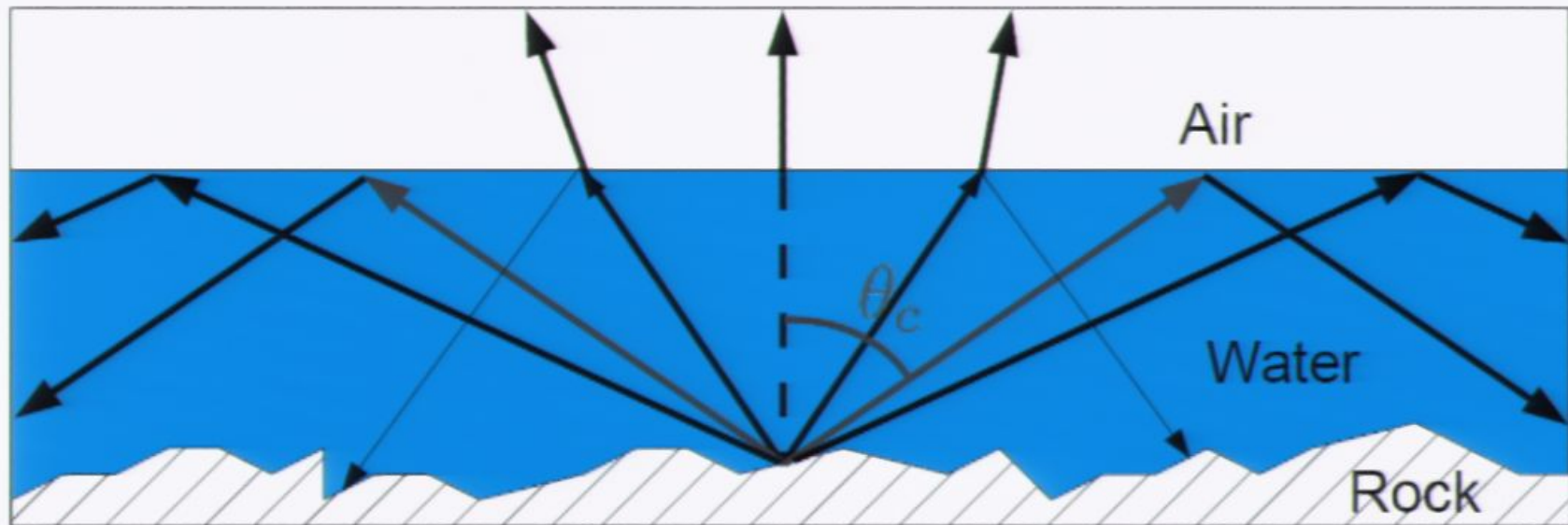
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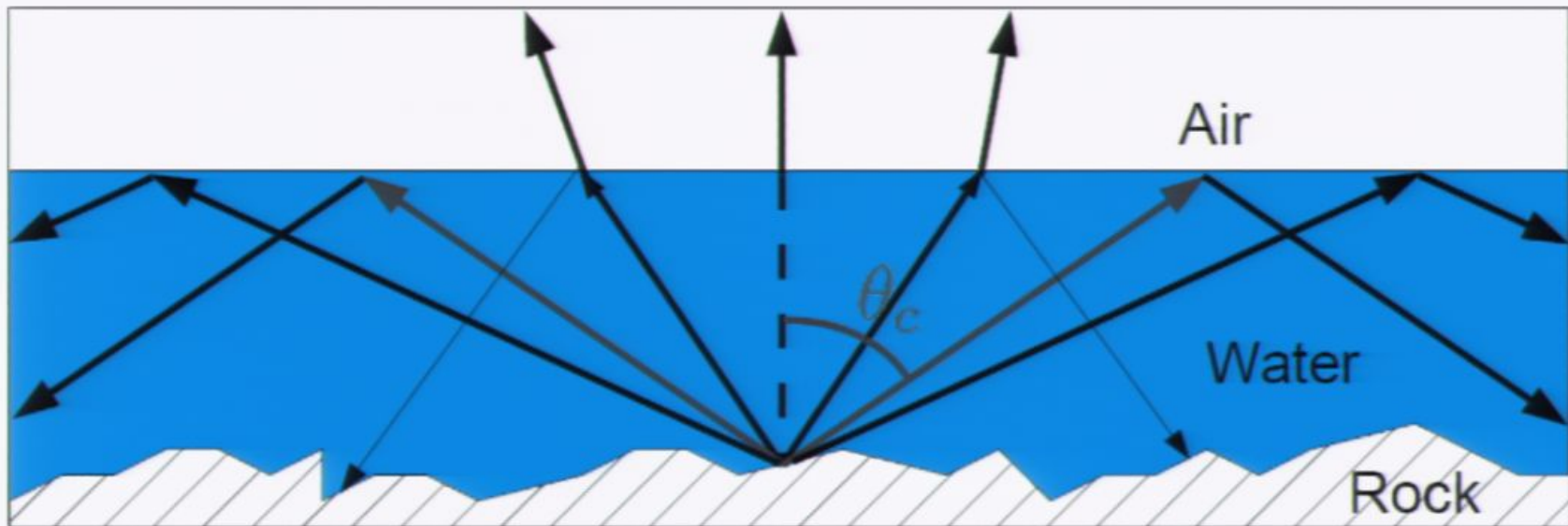
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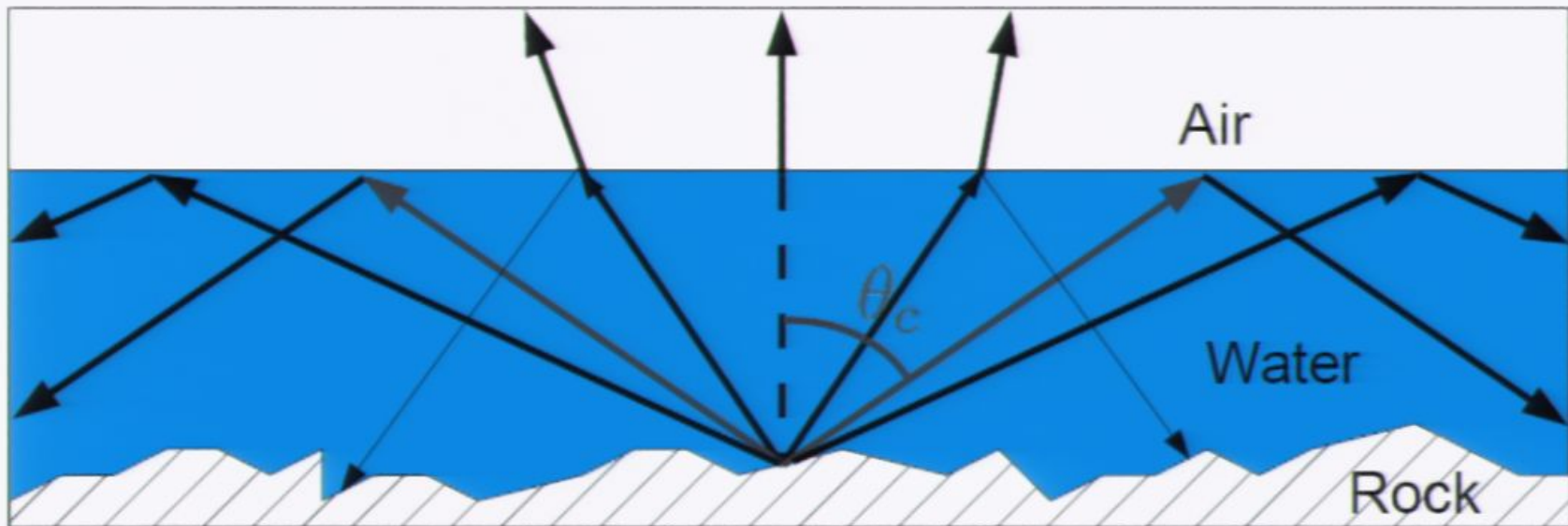


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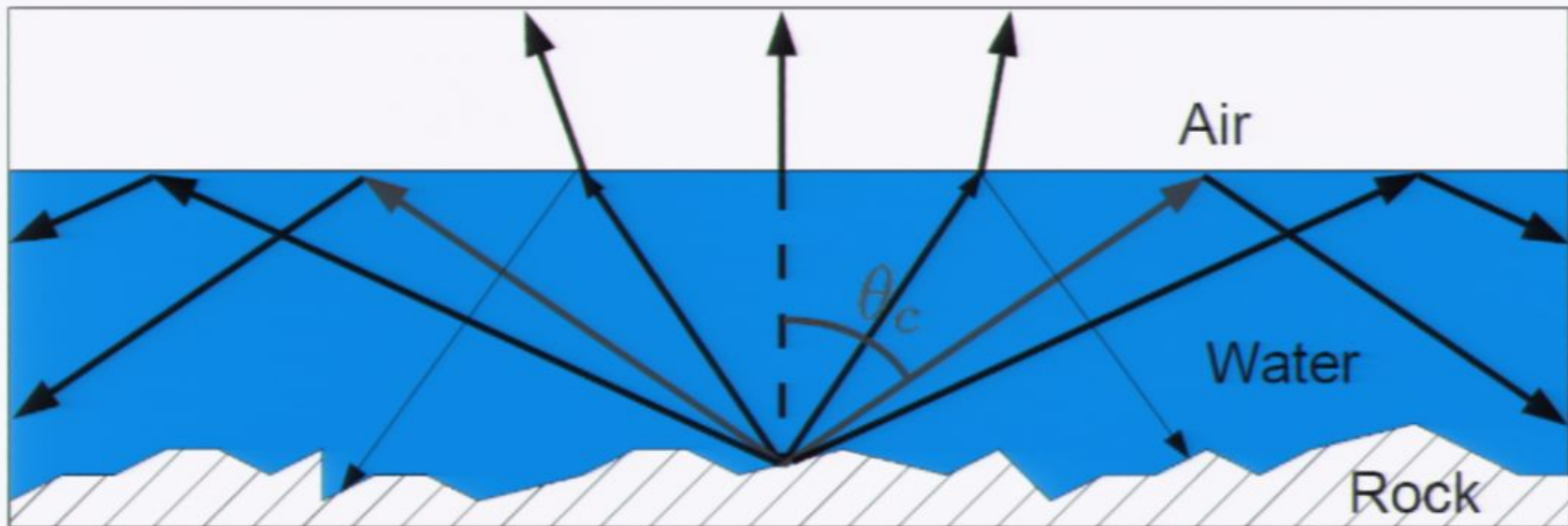
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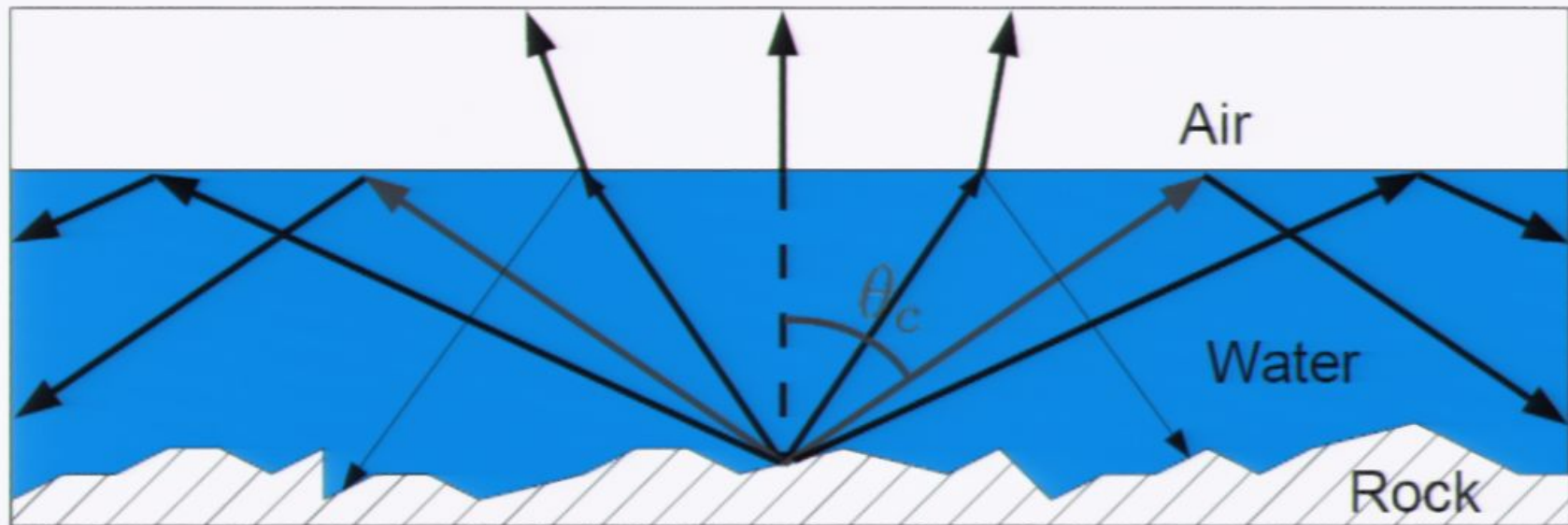
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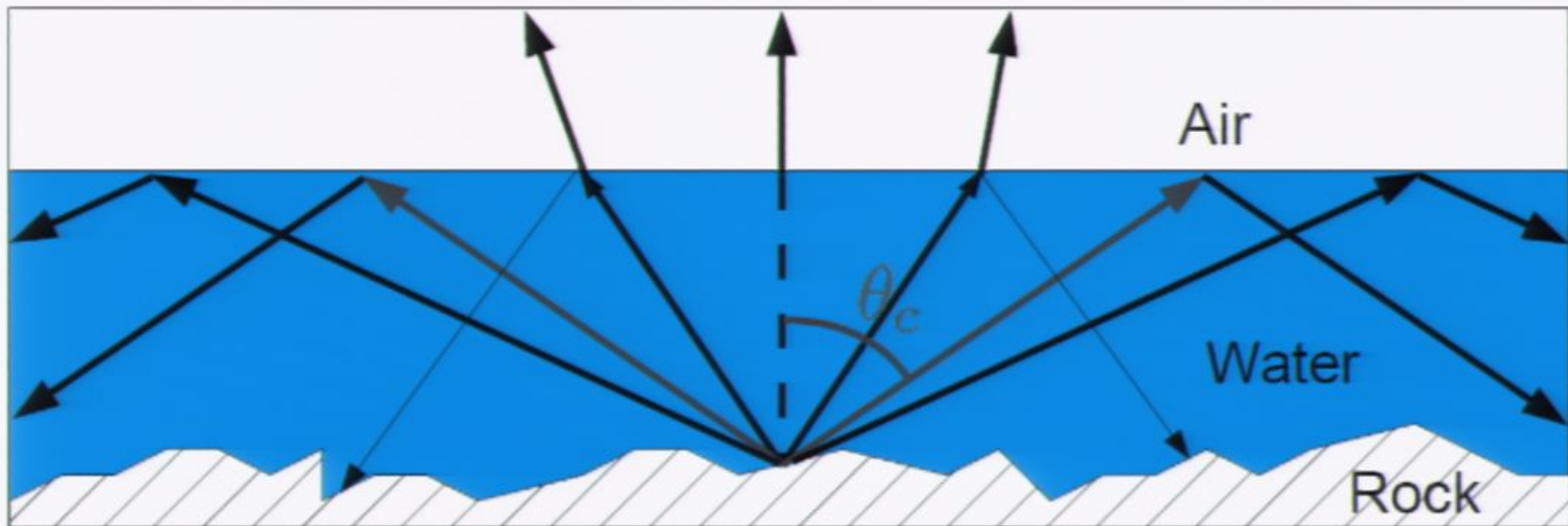


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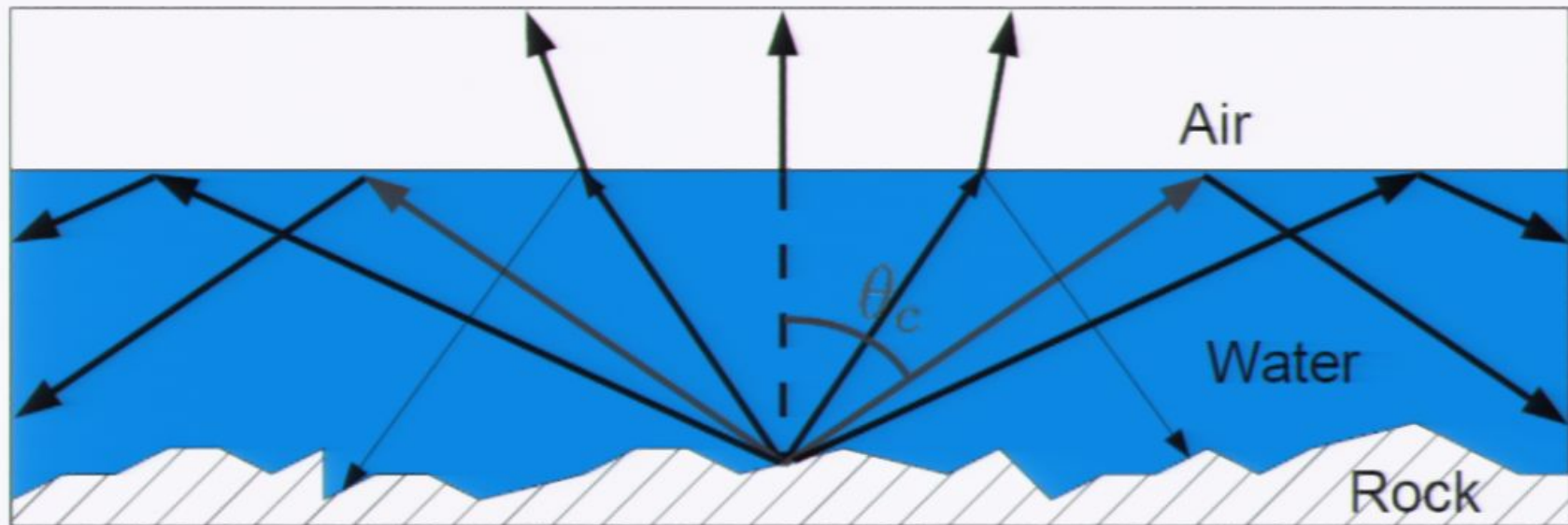
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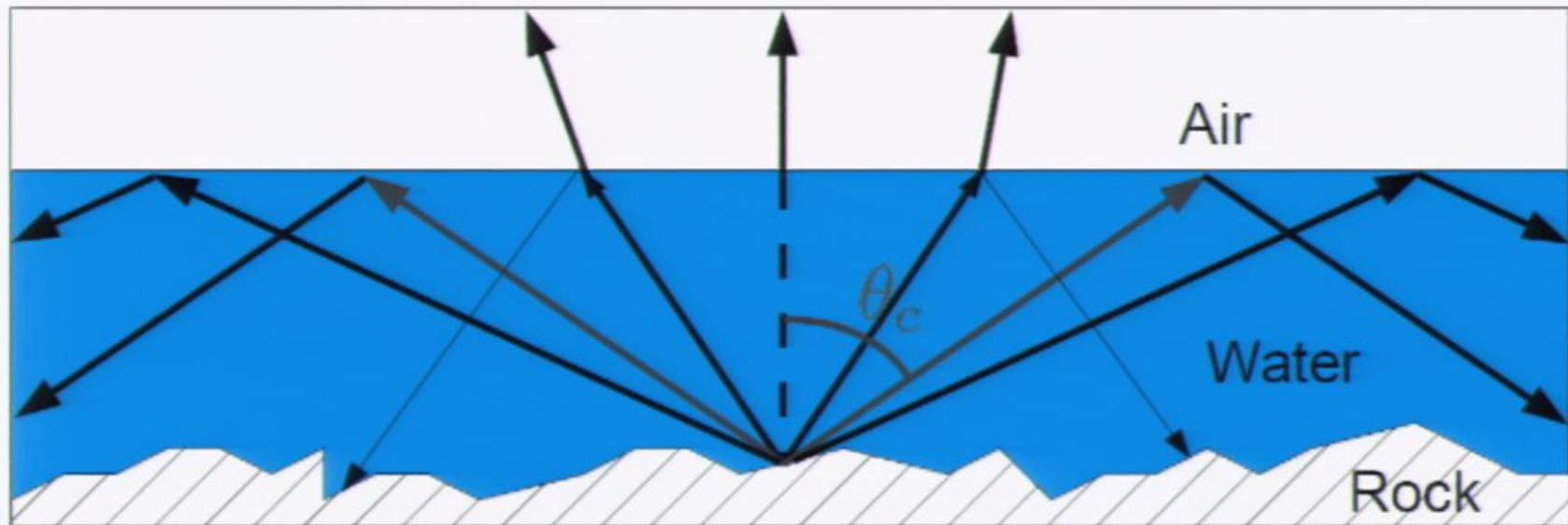
- There is also partial reflection at the water-air interface of beams that are not totally internally reflected



Rough surface covered with liquid

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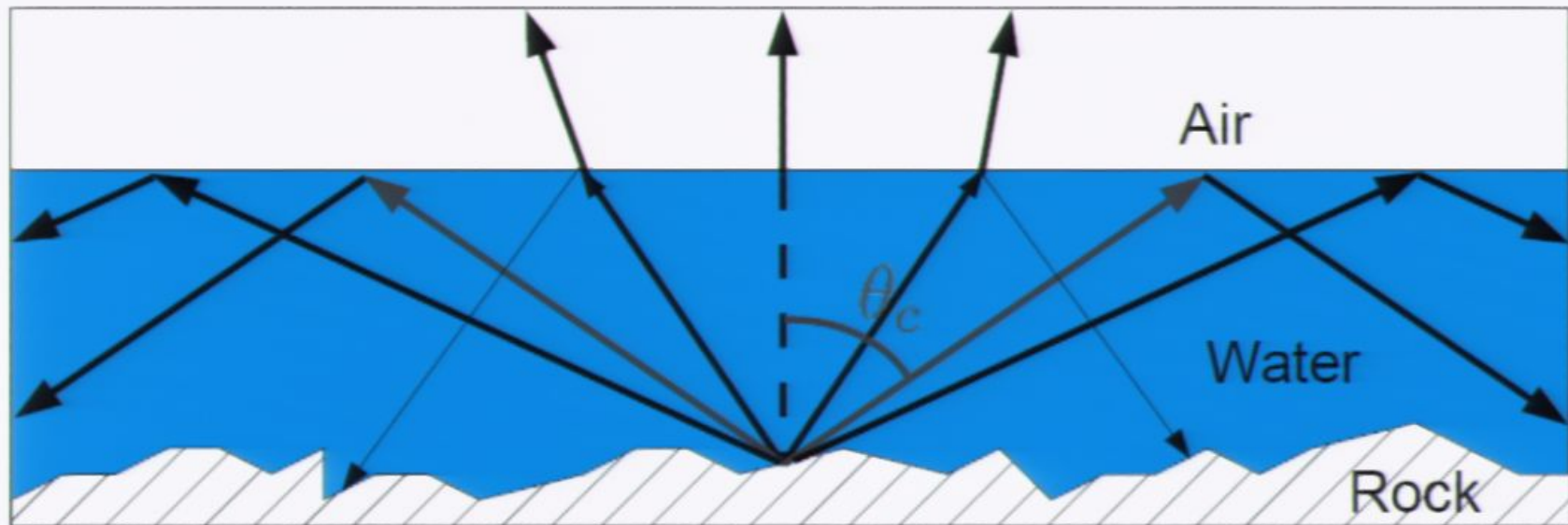


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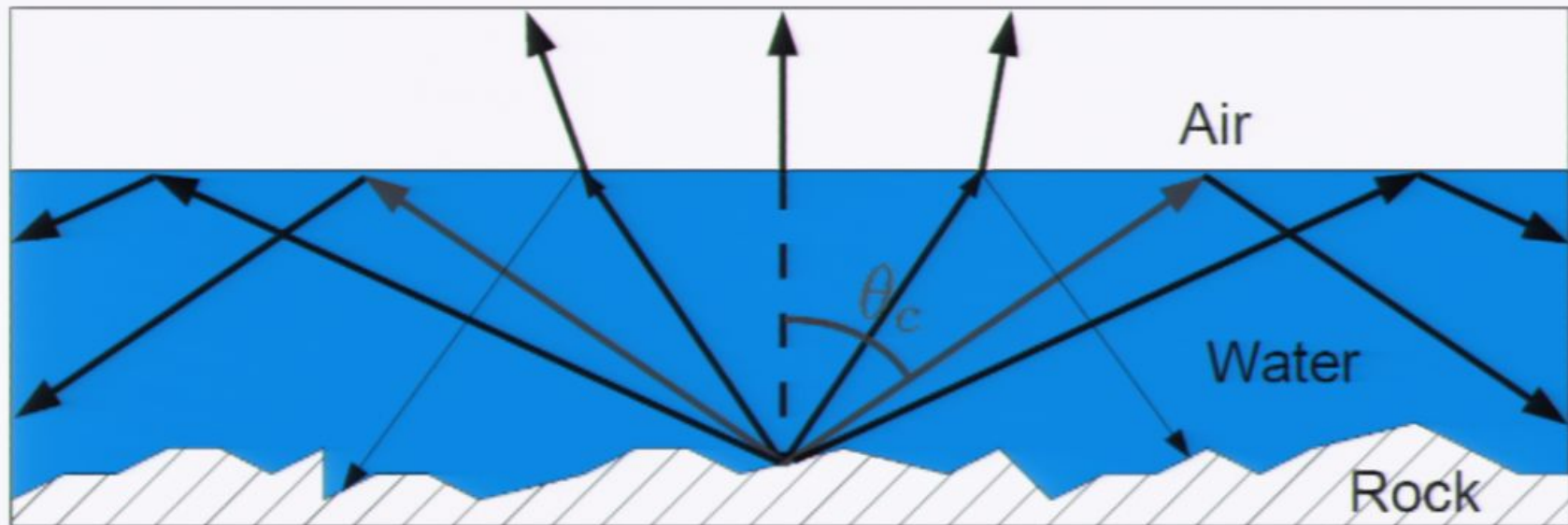
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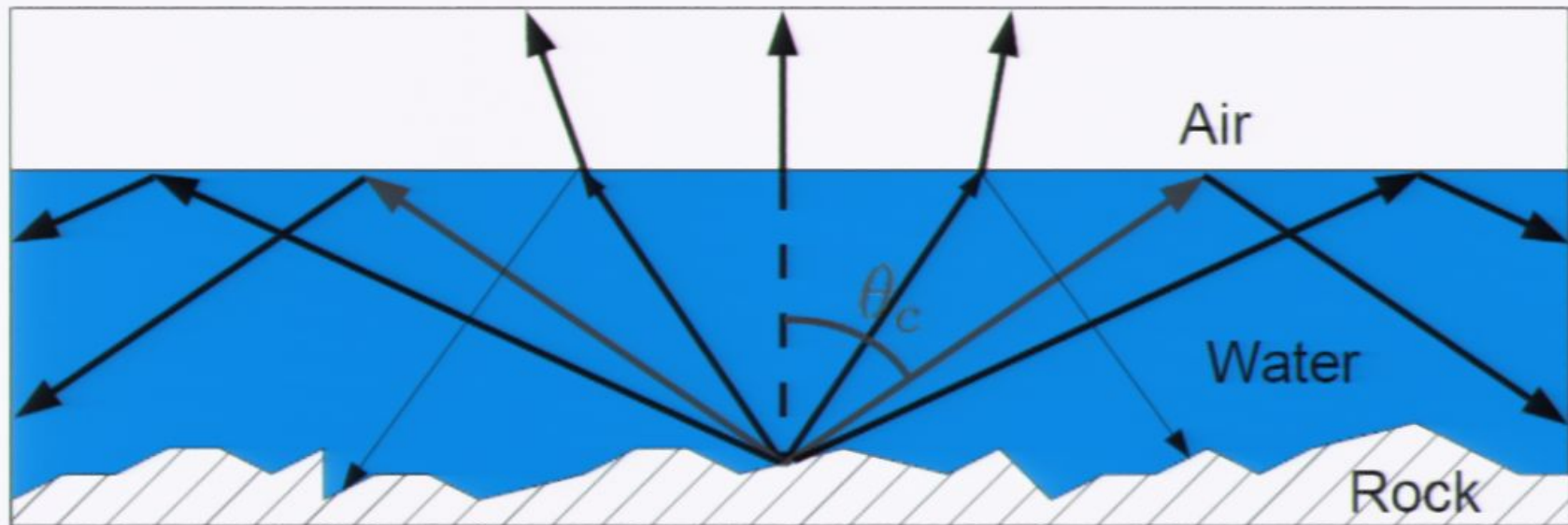
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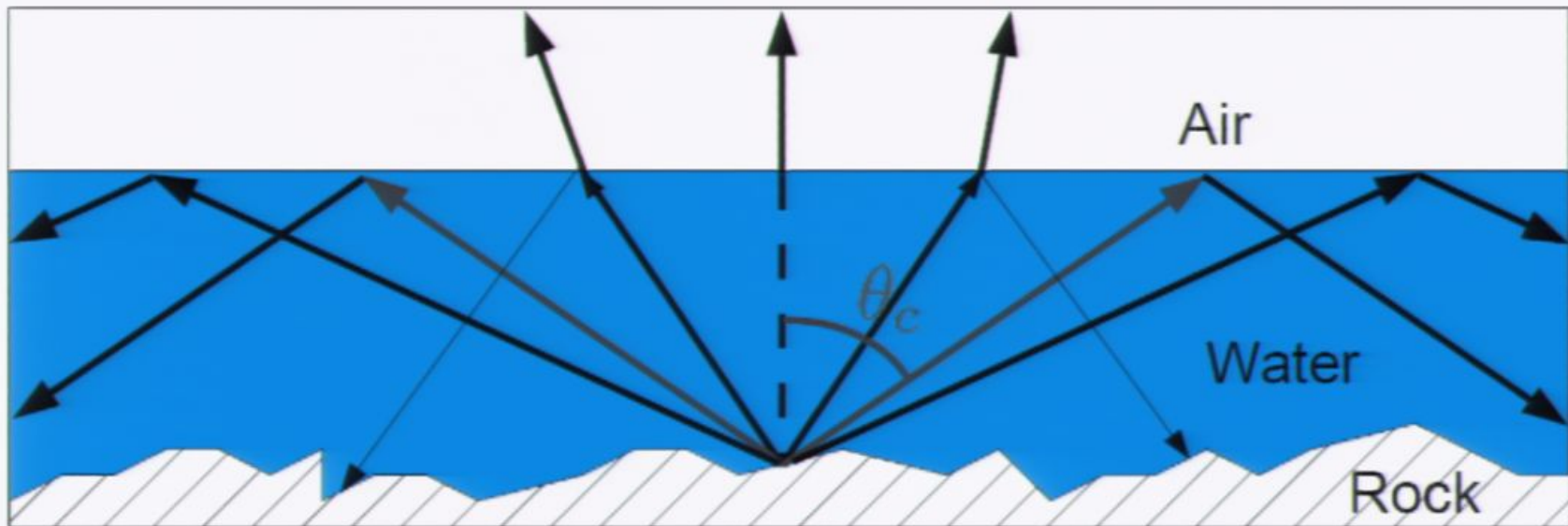


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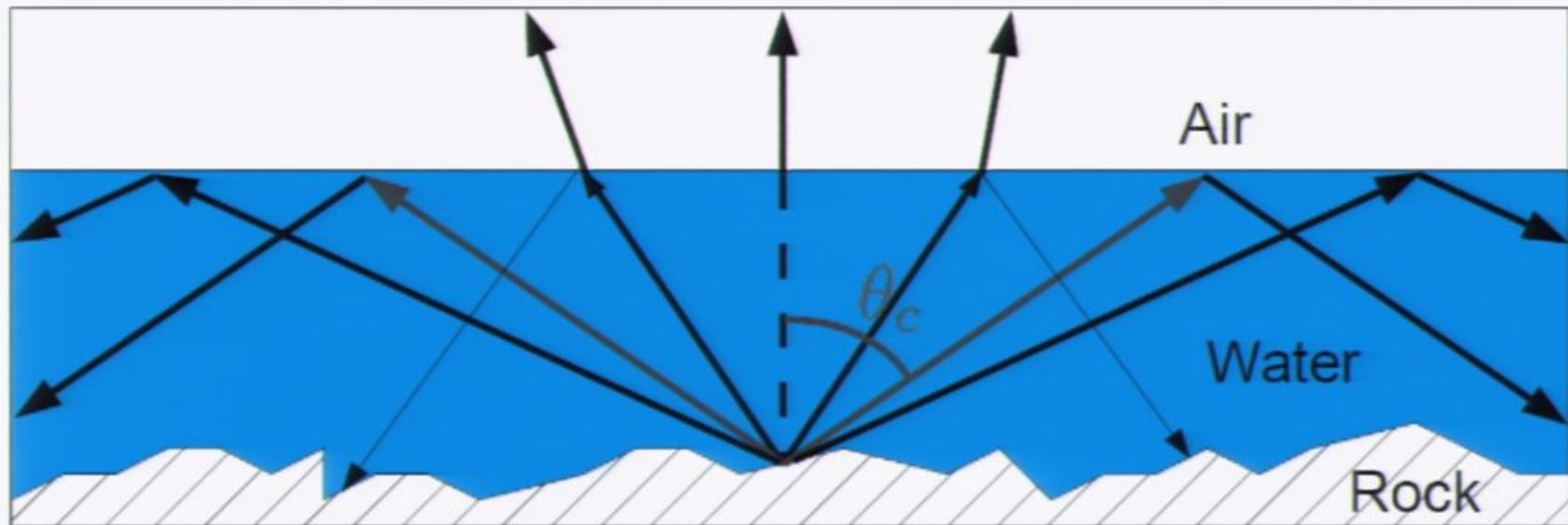
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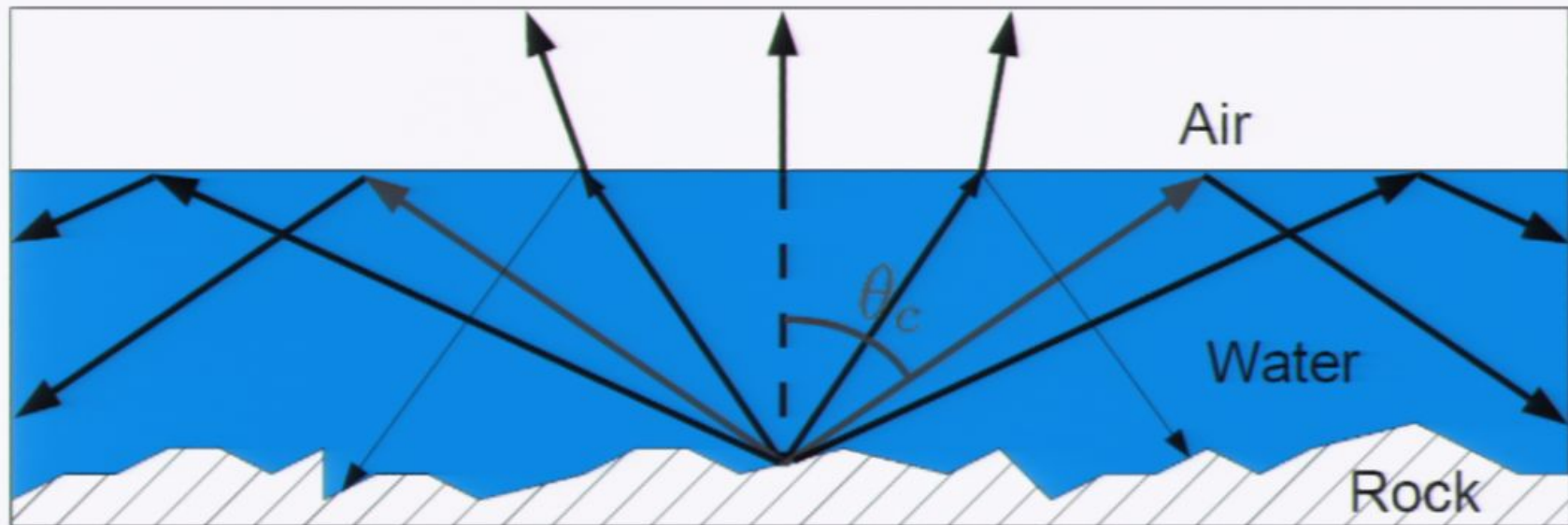
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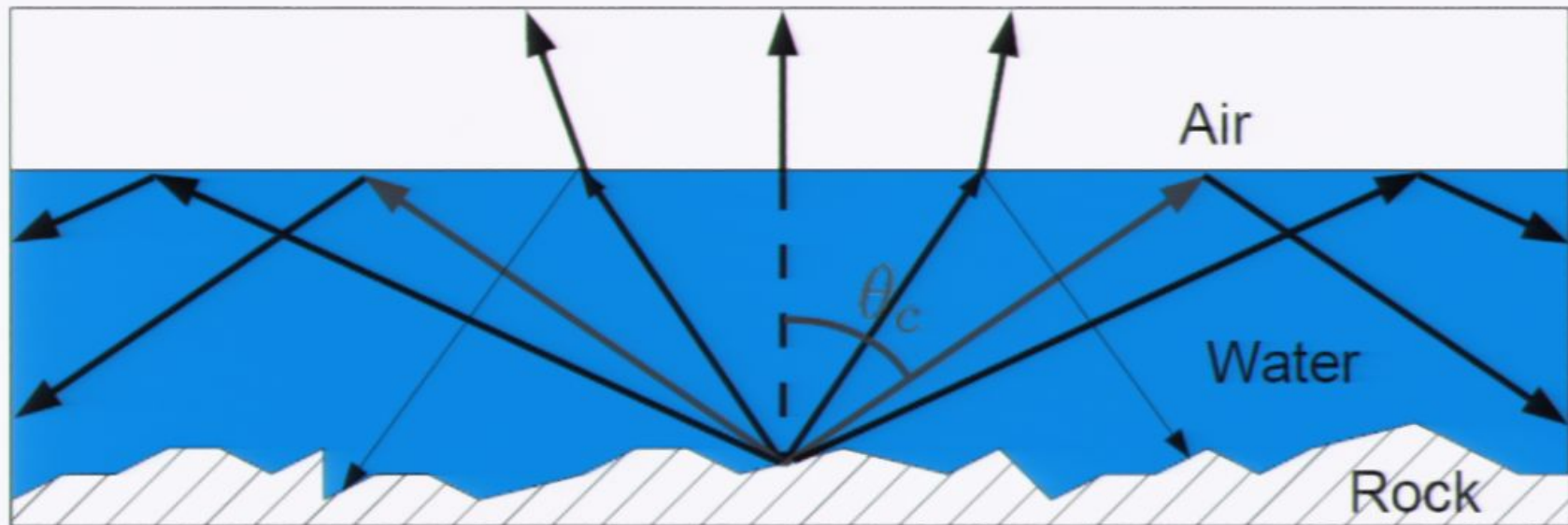


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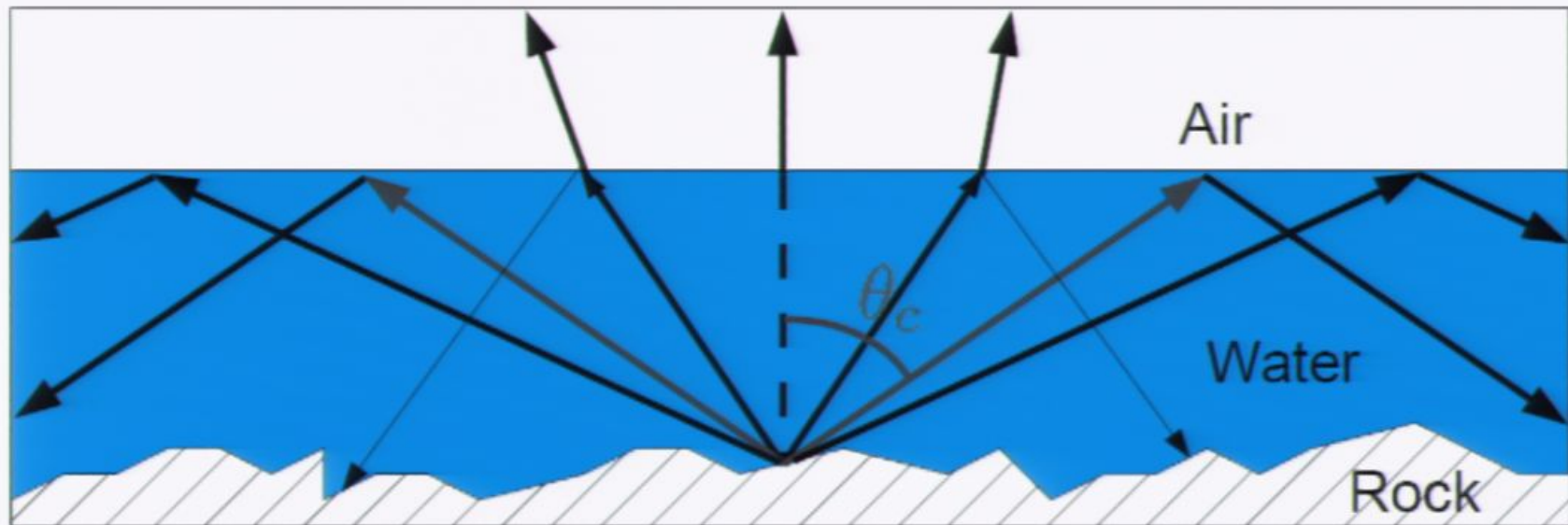
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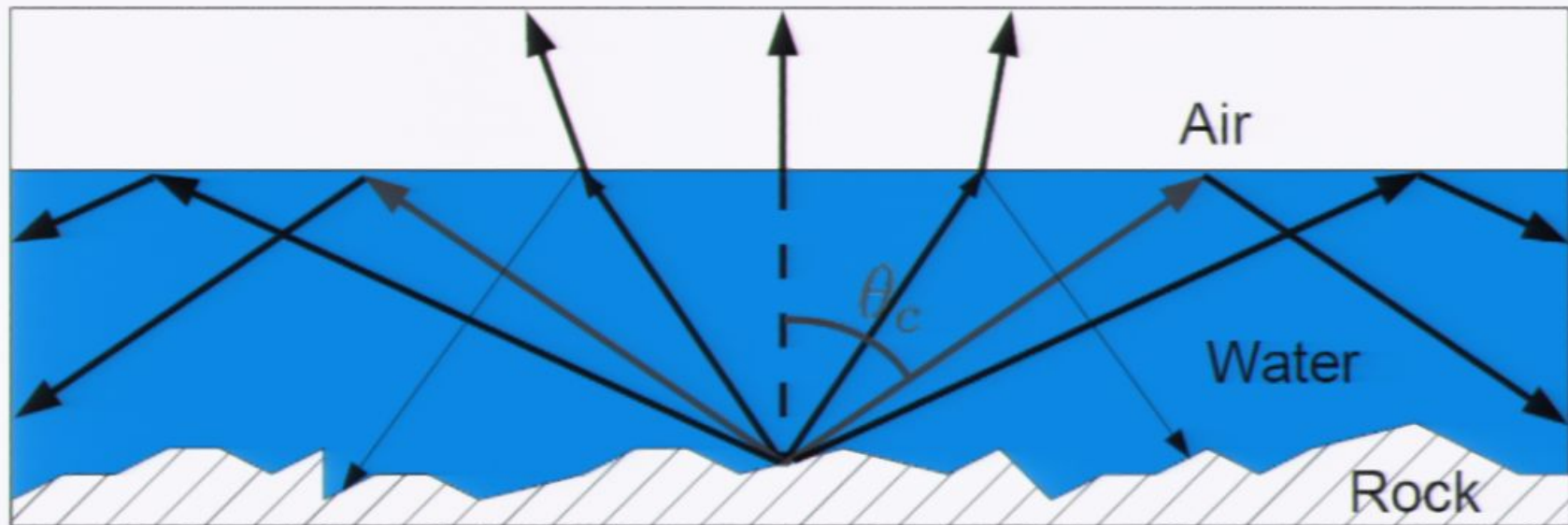
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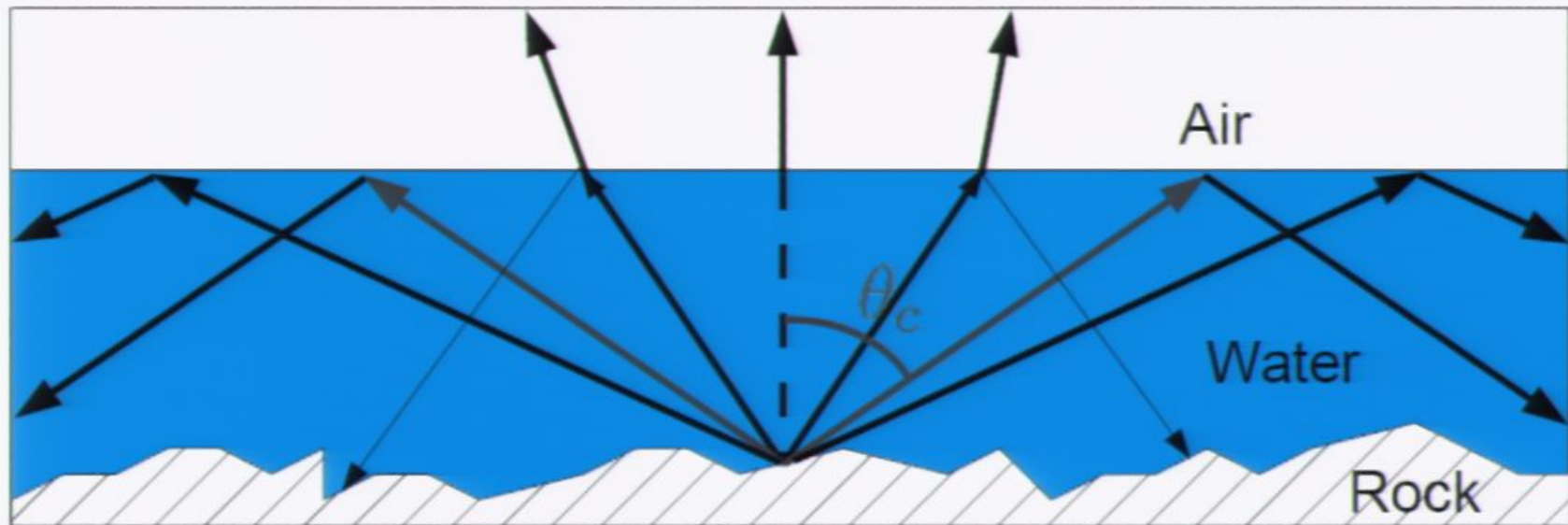


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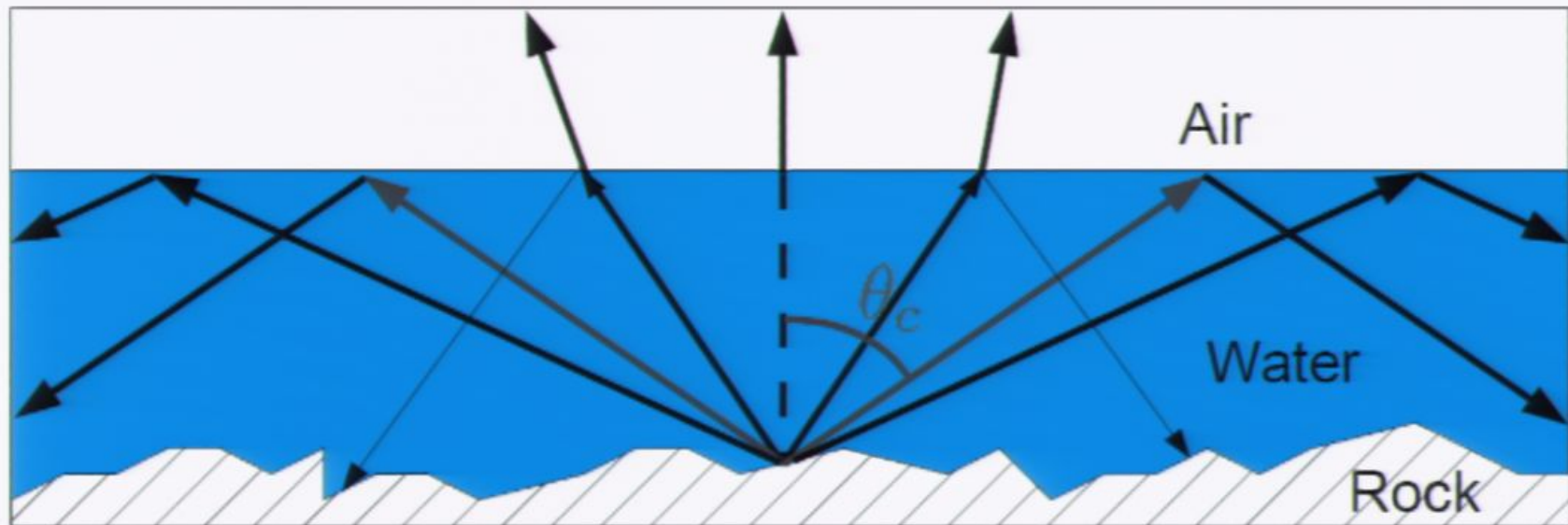
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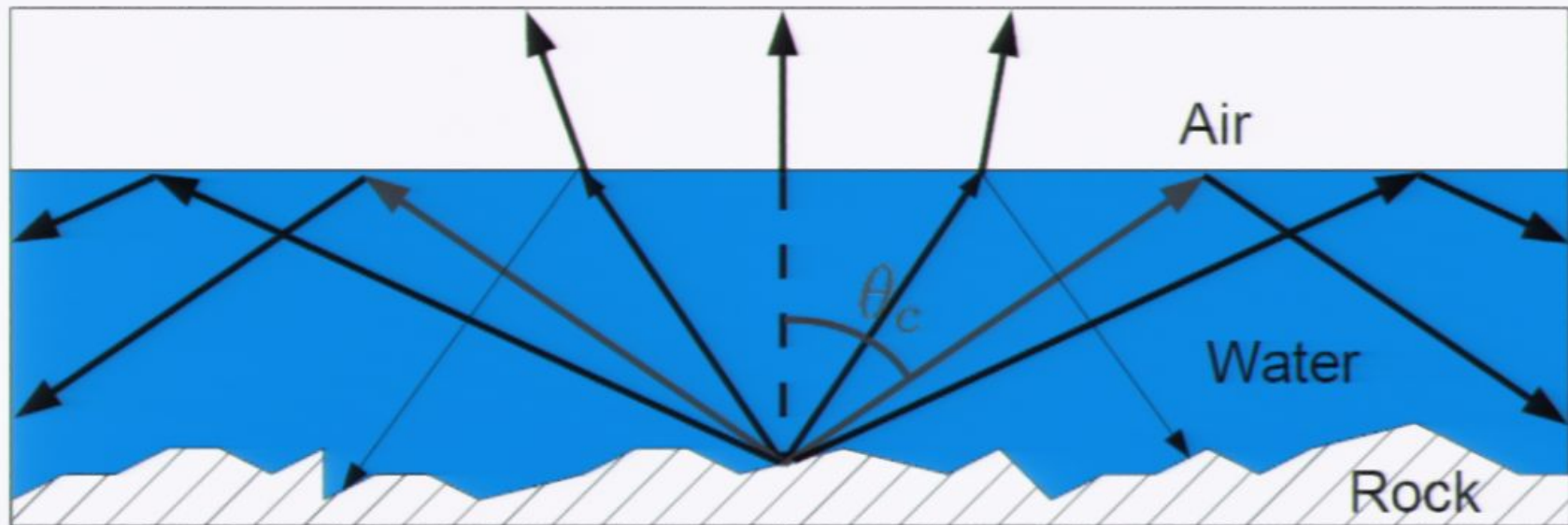
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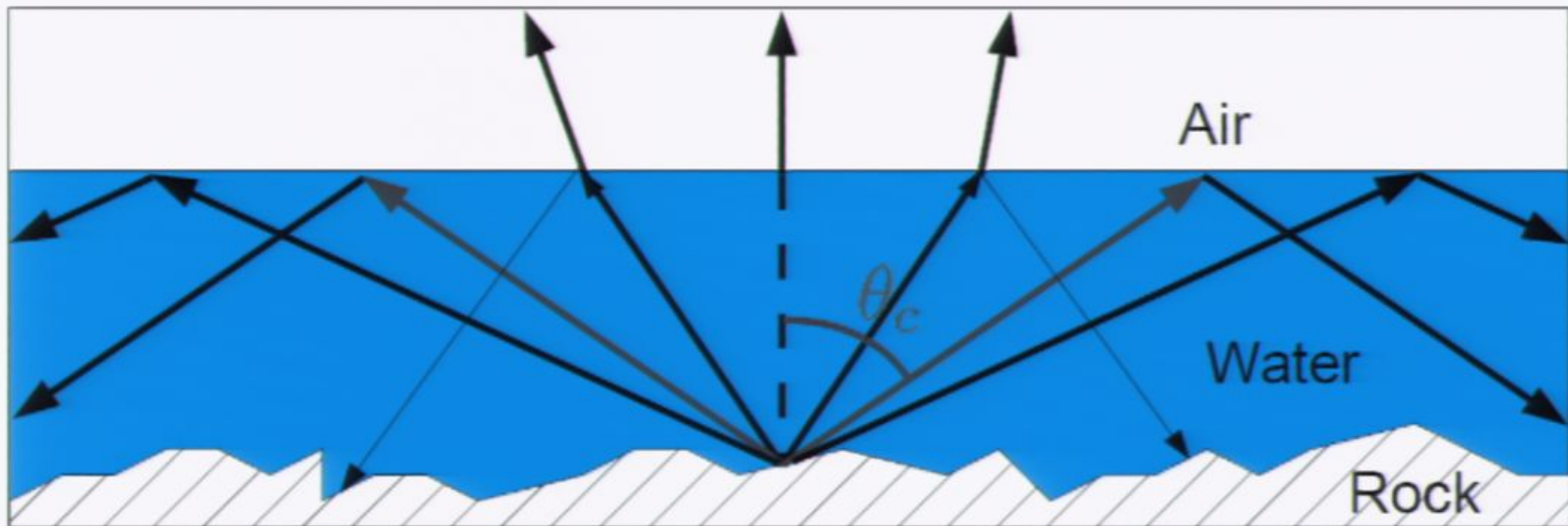


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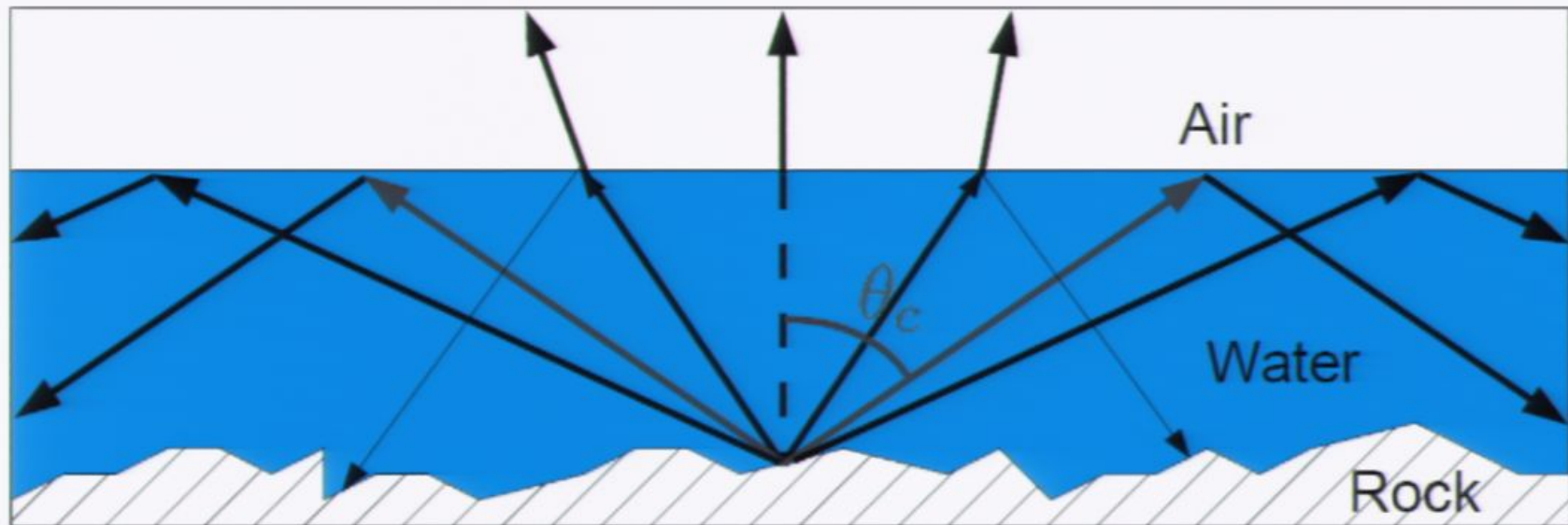
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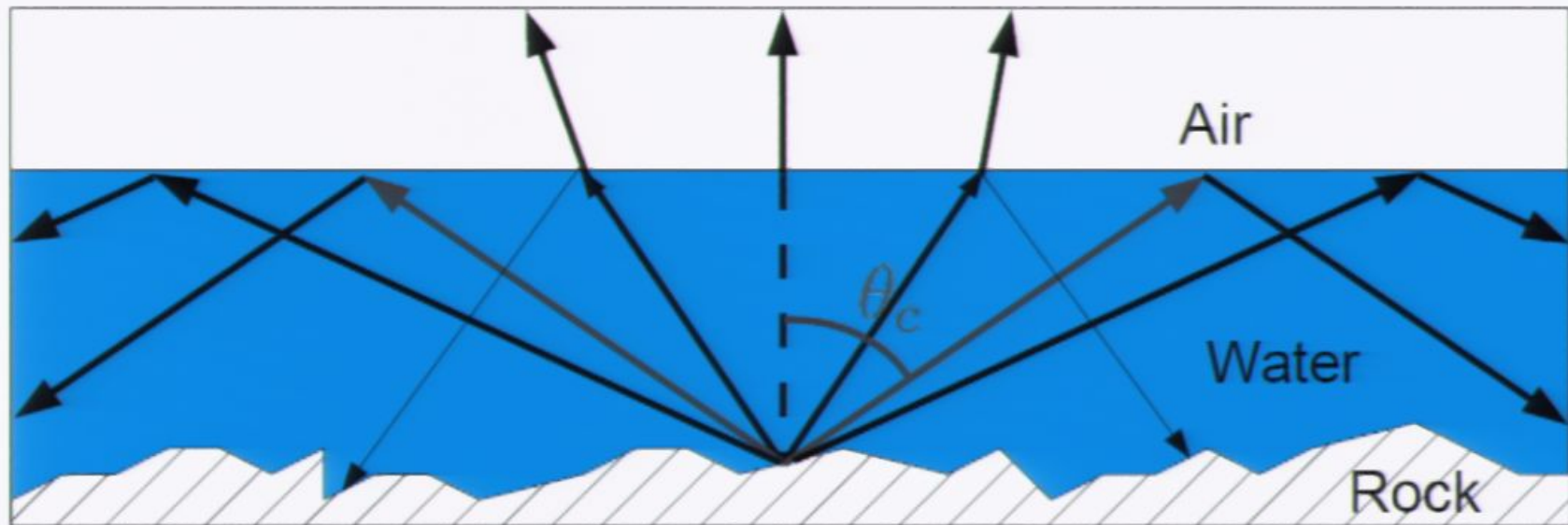
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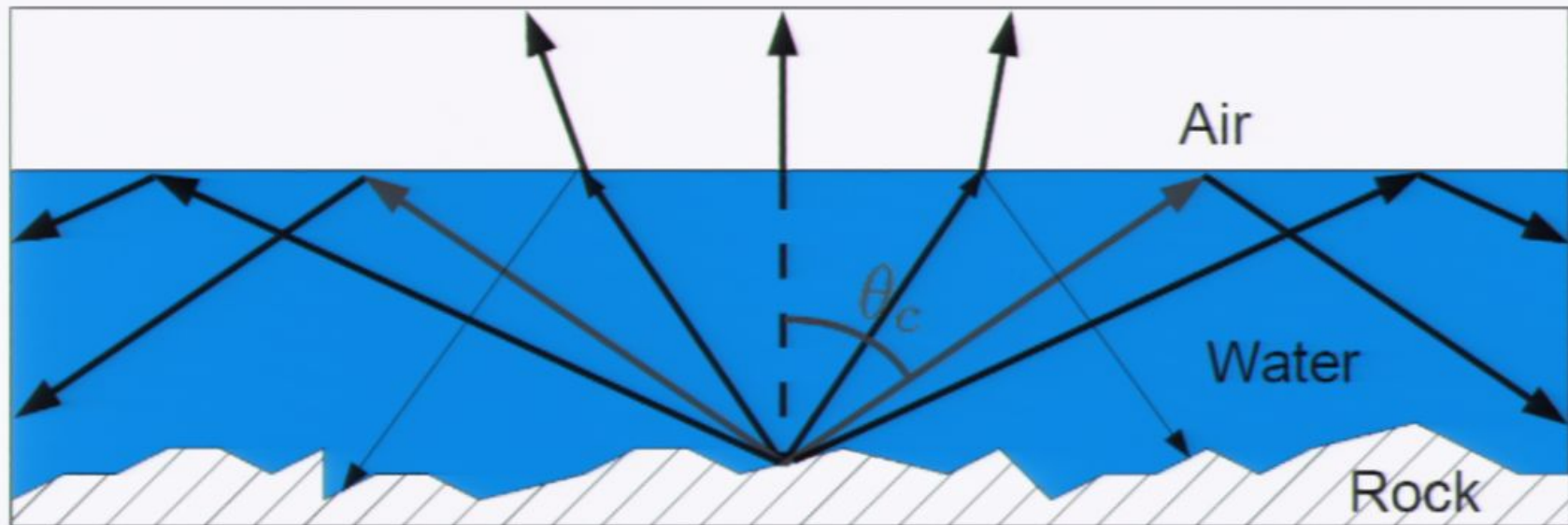


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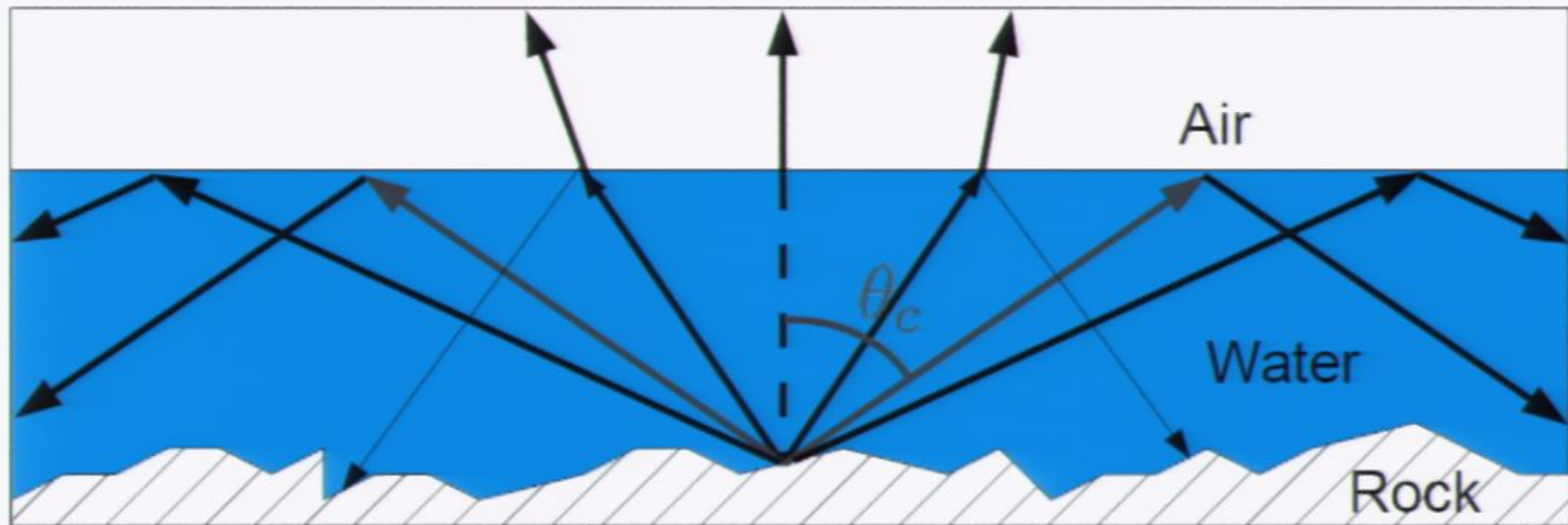
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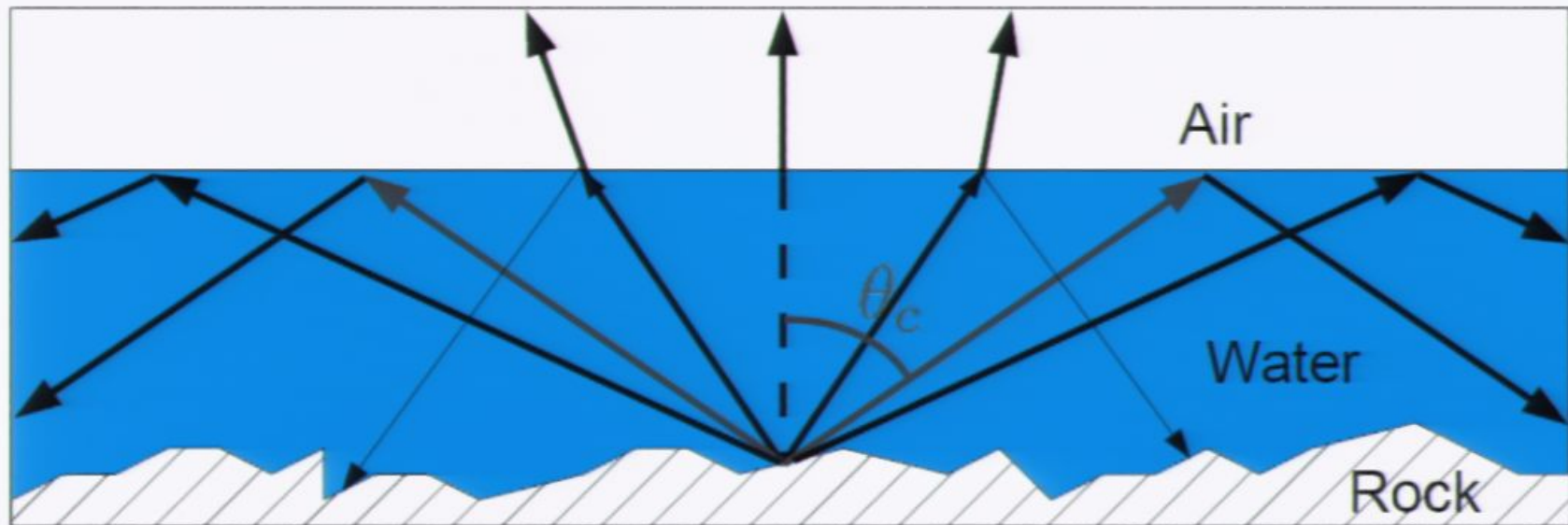
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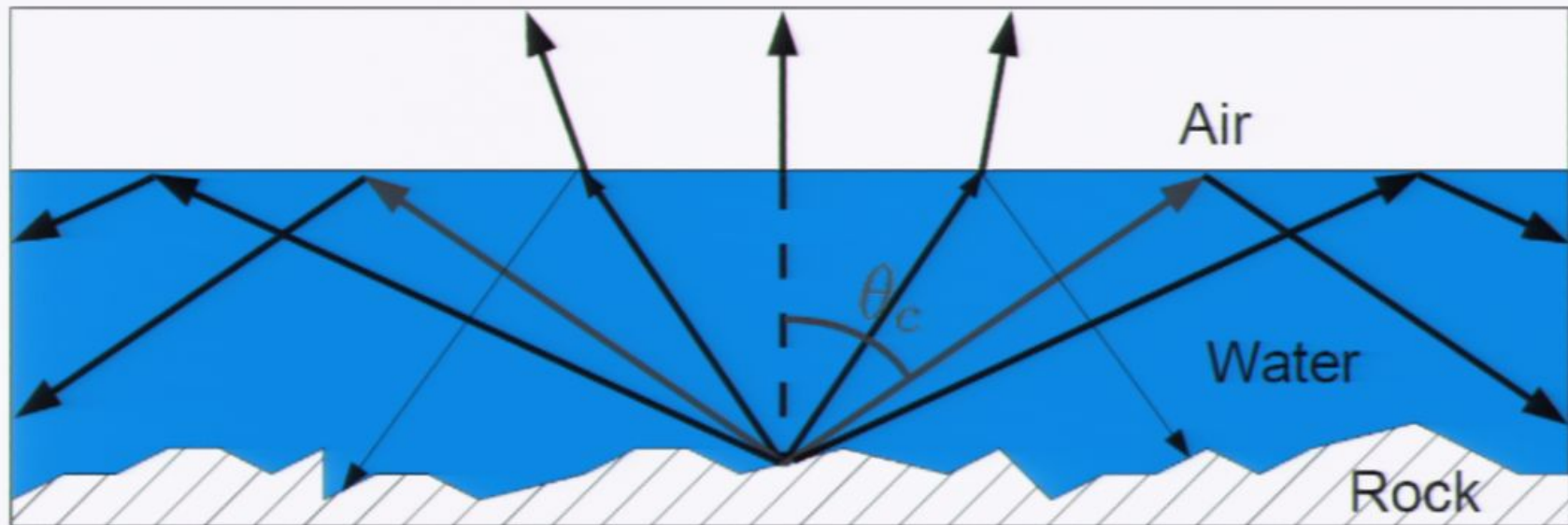


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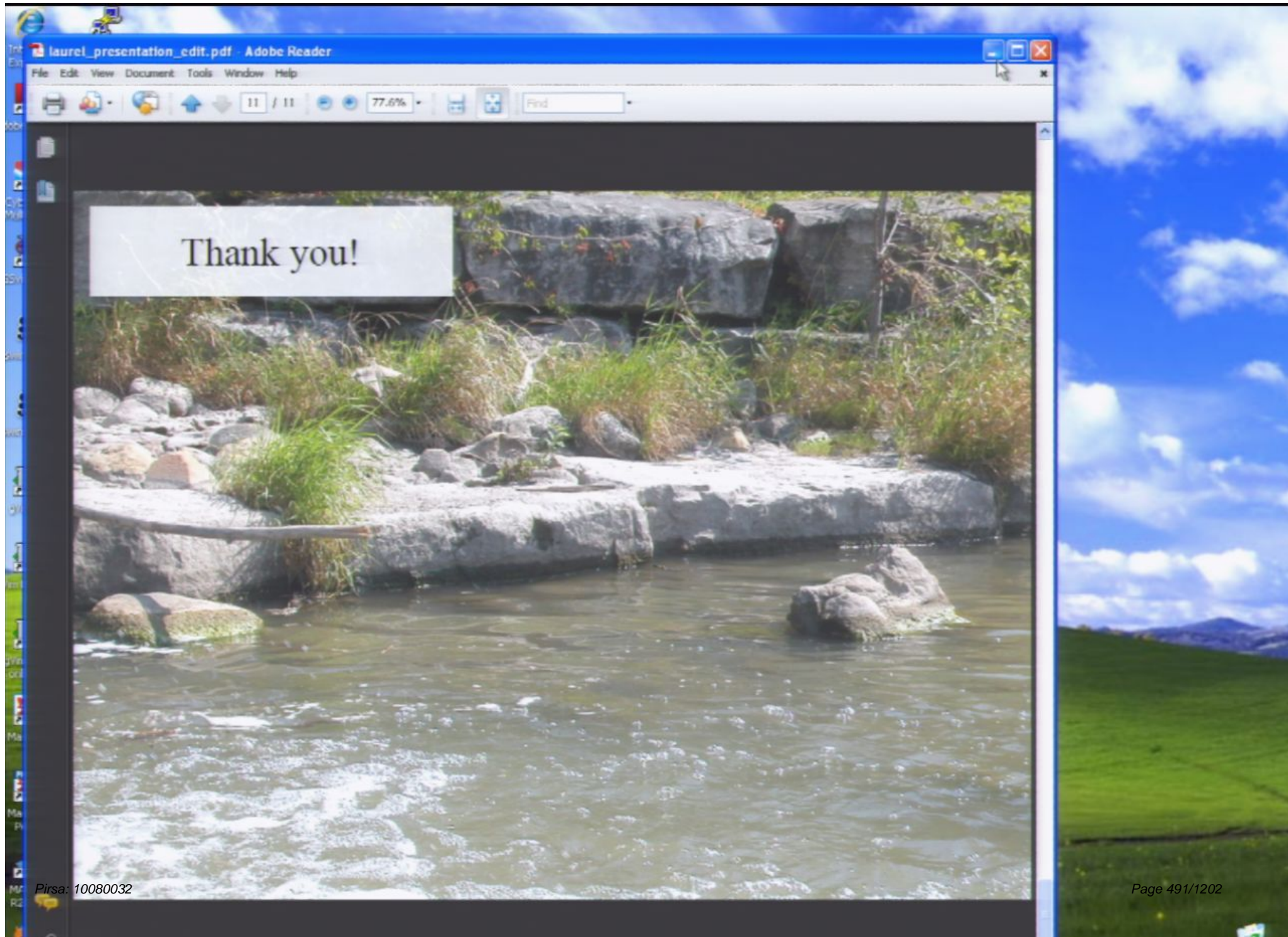
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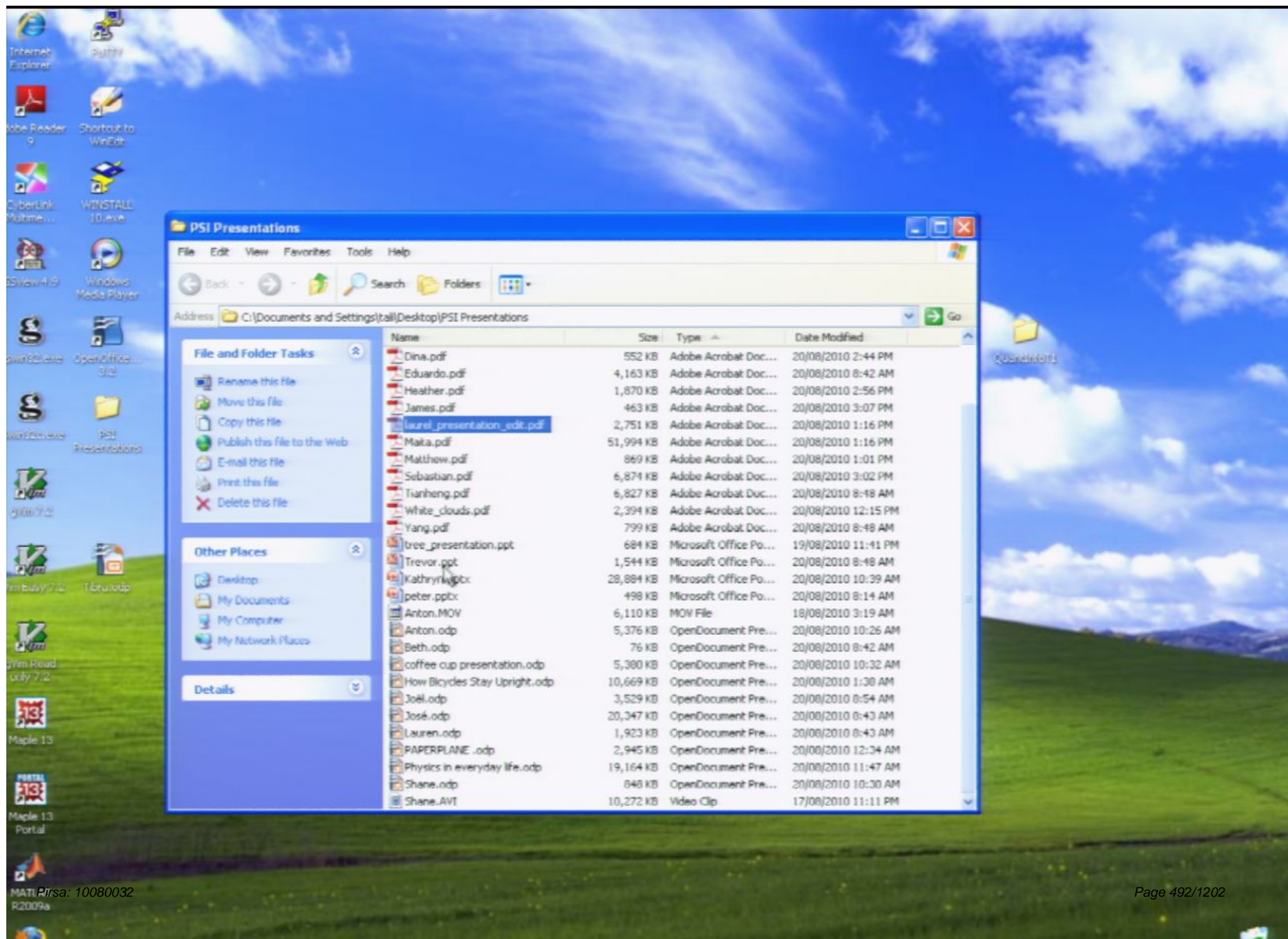


Thank you!













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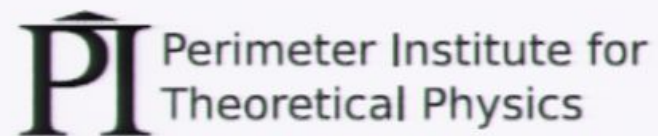


# Instant cooling solutions

Sebastián Montes Valencia

Perimeter Scholars International

20-08-2010



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## Motivation: No AC

- ▶ Put on wet cloths
- ▶ Try minty products
- ▶ Eat spicy food
- ▶ ...
- ▶ Use a fan
- ▶ Pucker your lips and blow

(<http://www.wikihow.com/Cool-Yourself-Without-Air-Conditioning>)

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# Outline

Fans

Blowing cool air



## What is a fan?

Any flat, broad and lightweight surface can be used as a fan. Just wave it back-and-forth!

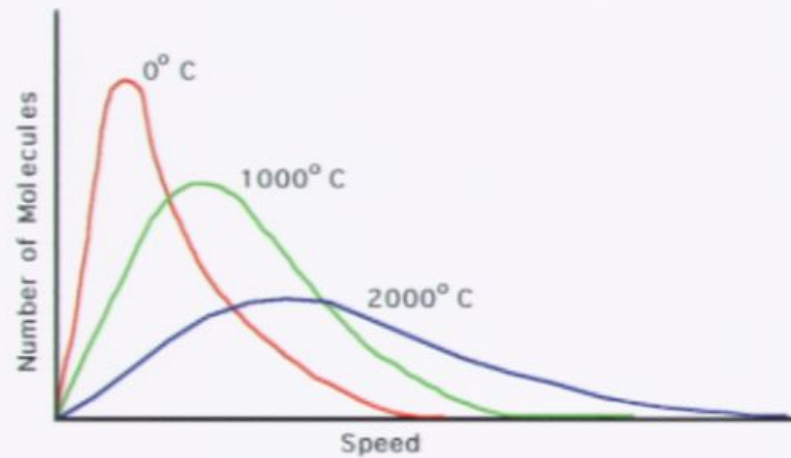


## How does the fan work?

- ▶ A fan doesn't actually cool the air!
- ▶ It increases the airflow over the skin
  1. Helps natural evaporation
  2. Convection



## Fans: Evaporation



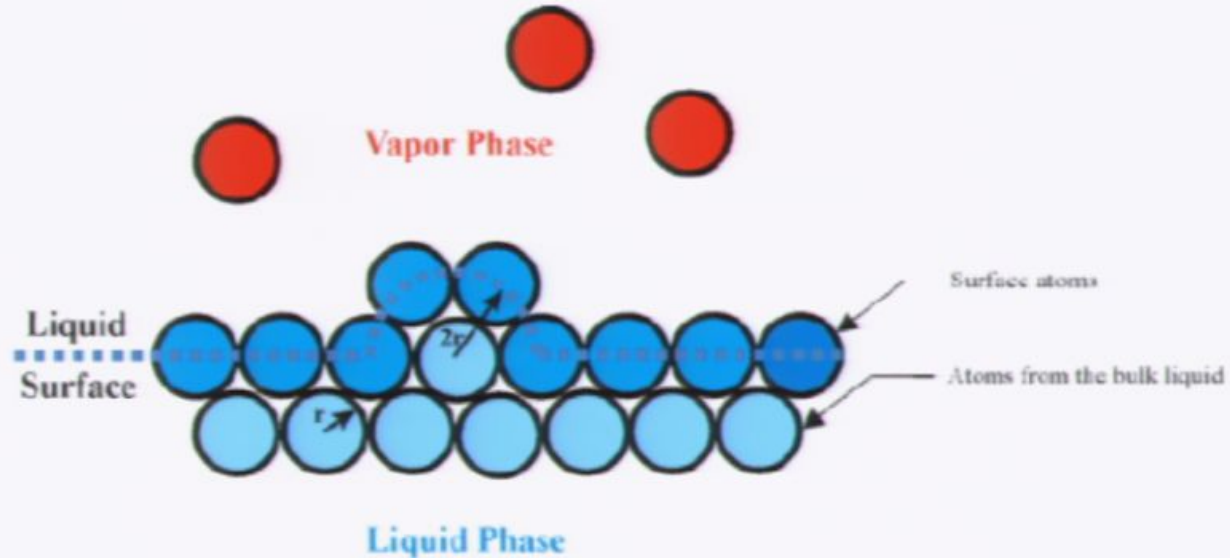
Maxwell-Boltzmann distribution

$$f(v) \propto v^2 e^{-\frac{mv^2}{2k_B T}}$$

$$T \propto \langle K \rangle$$

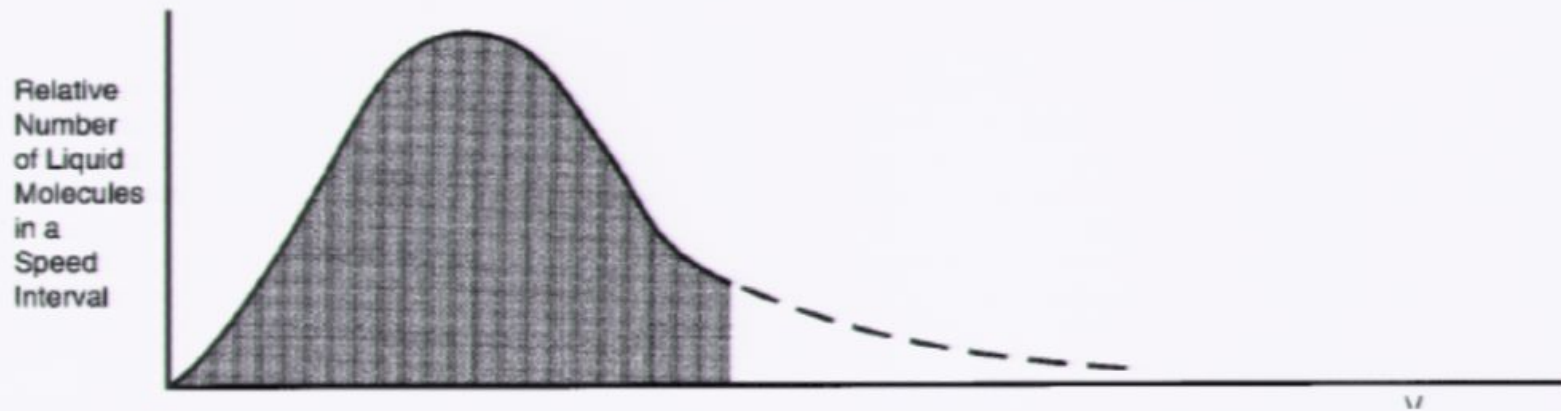


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(J. Garai (2009) Physical model for vaporization, Fluid Phase Equilibria, 283, 89-92 (IF: 1.506))

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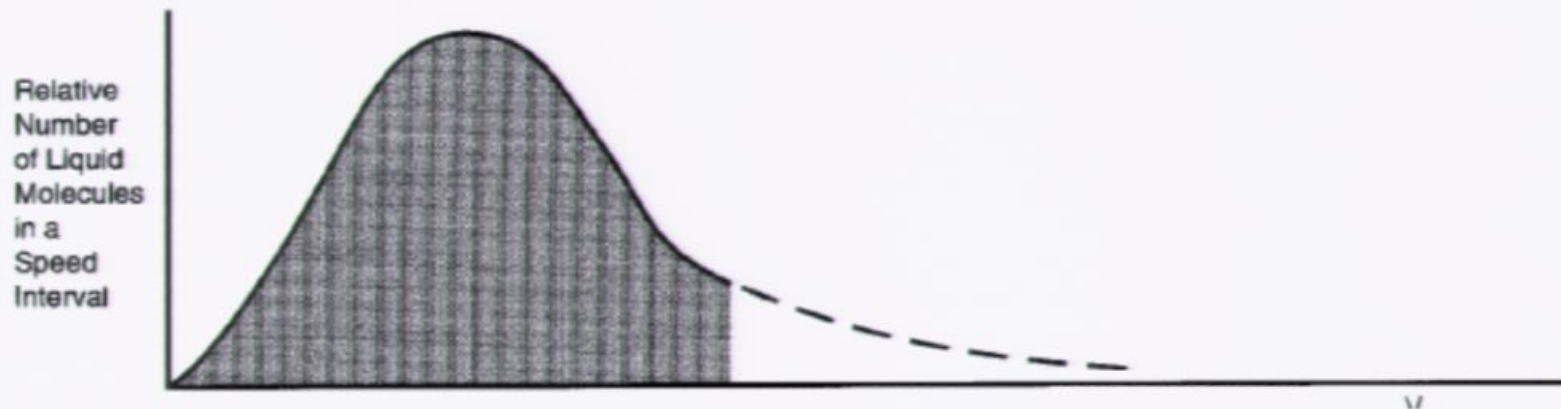


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The faster molecules leave before equilibrium. The average molecular velocity decreases, reducing the temperature.

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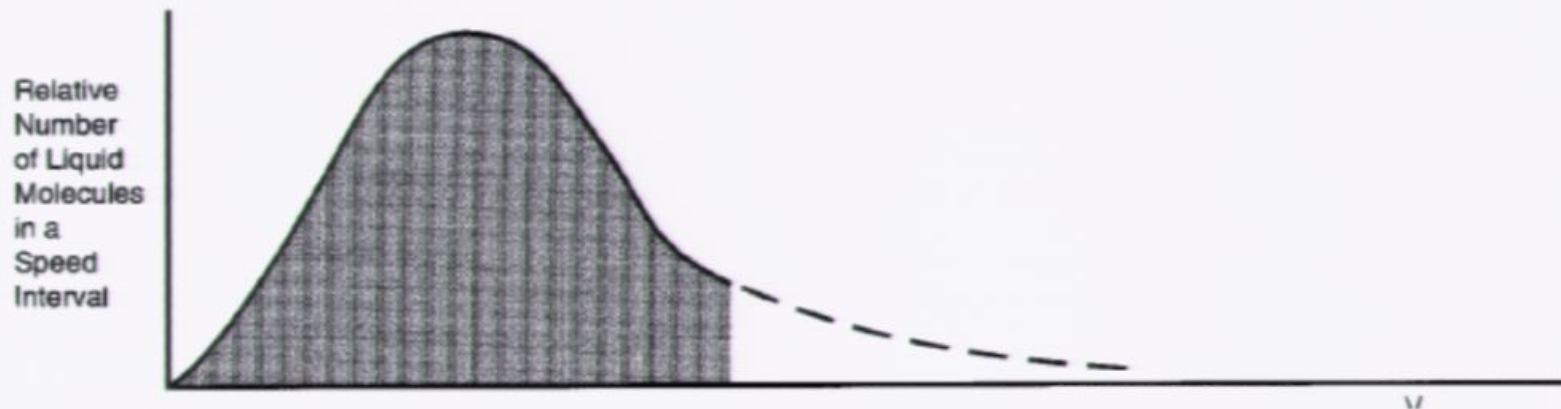
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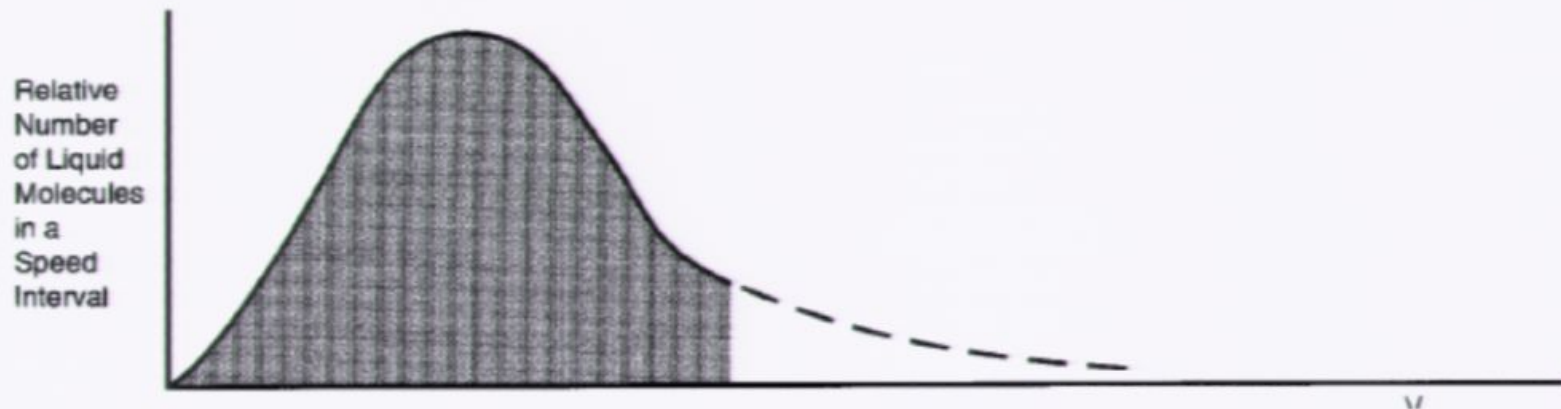


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The airflow produced by fans **reduces the concentration of water** in the air surrounding the skin. In this way, sweat evaporates much faster and temperature drops.

Sweat has a large heat capacity. Therefore these temperature changes cool the body rapidly.





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Blowing cool air

# Outline

Fans

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Blowing cool air

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## Blow cold: misleading (false) explanation

When you pucker your lips and blow hard, air expands adiabatically and cools down.

$$T_2 = T_1 \left( \frac{P_1}{P_2} \right)^{\frac{\gamma-1}{\gamma}}$$

### Problem

Human beings usually don't blow that hard. You would need a pressure greater than 1 atm.

([http://www.last-word.com/content\\_handling/show\\_tree/tree\\_id/3121.html](http://www.last-word.com/content_handling/show_tree/tree_id/3121.html))

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- ▶ Key word: forced convection
- ▶ Faster moving air **entrains (moves) room air** in its flow, thus providing a drier air stream
- ▶ The airflow increases the liquid's rate of evaporation
- ▶ Air stream: 40 % body warmth, 60 % ambient
- ▶ Distance from the mouth

(boards.straightdope.com/sdmb/archive/index.php/t-244600.html)

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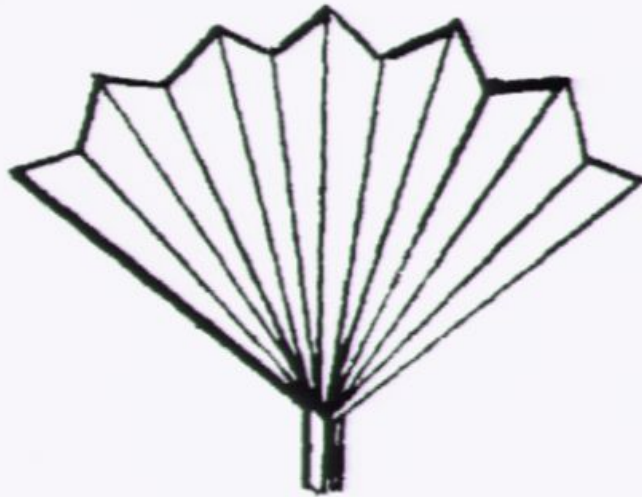
## Conclusions

There are simple and handy solutions when you need to cool yourself. Induced airflows can create an effective cooling sensation by reducing the rate of evaporation of your sweat.



## Conclusions

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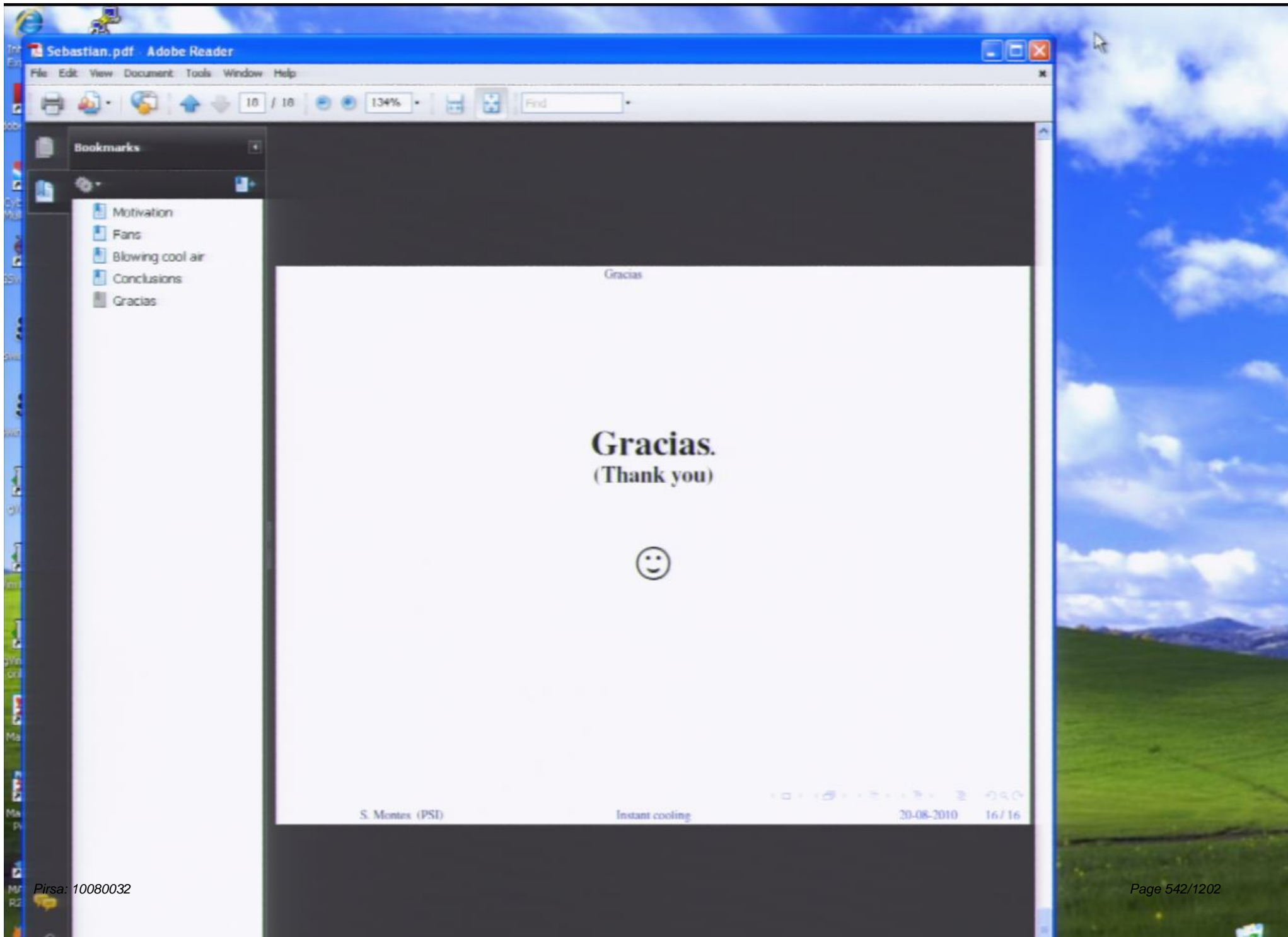


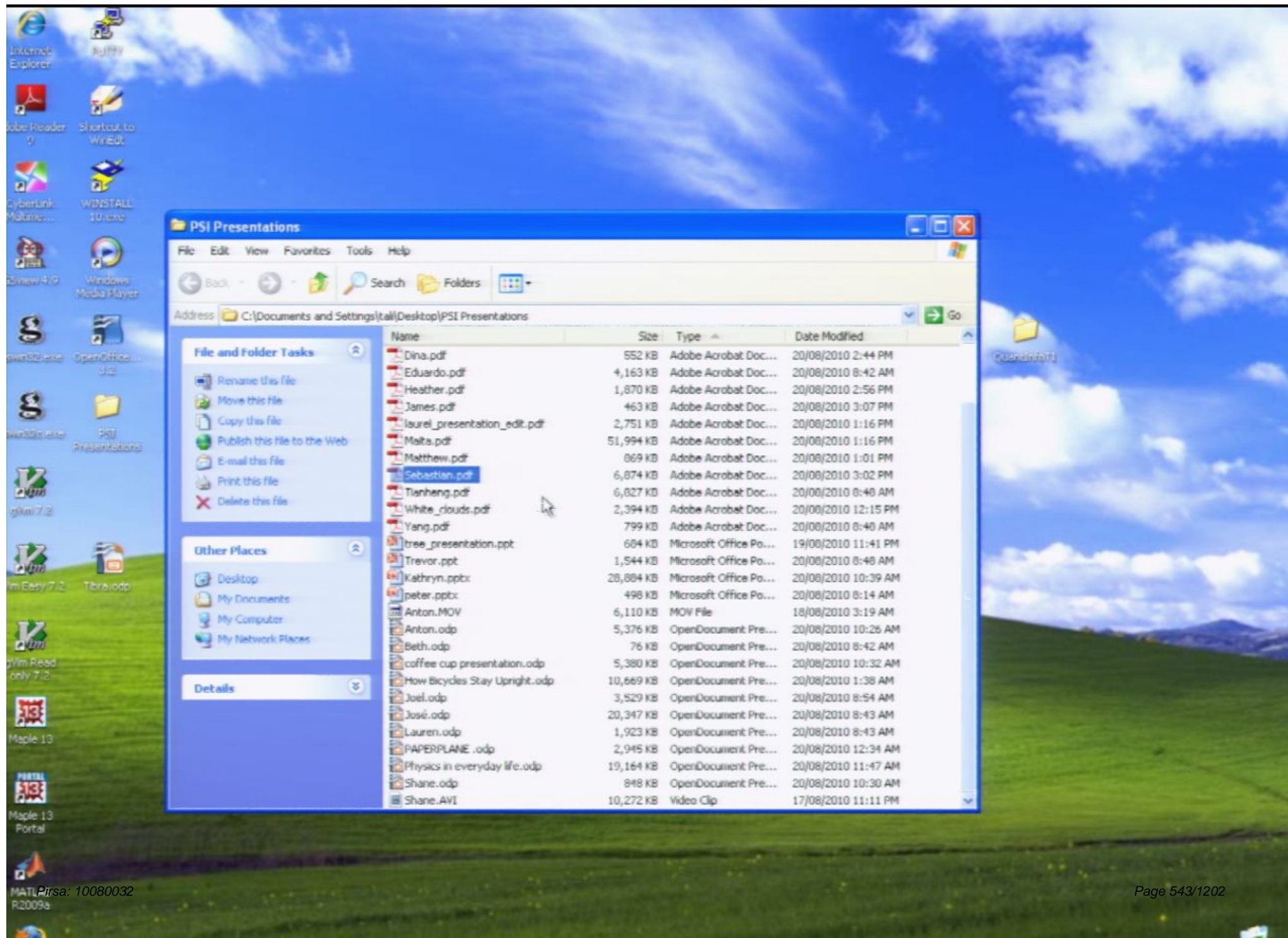
Gracias

**Gracias.**  
(Thank you)

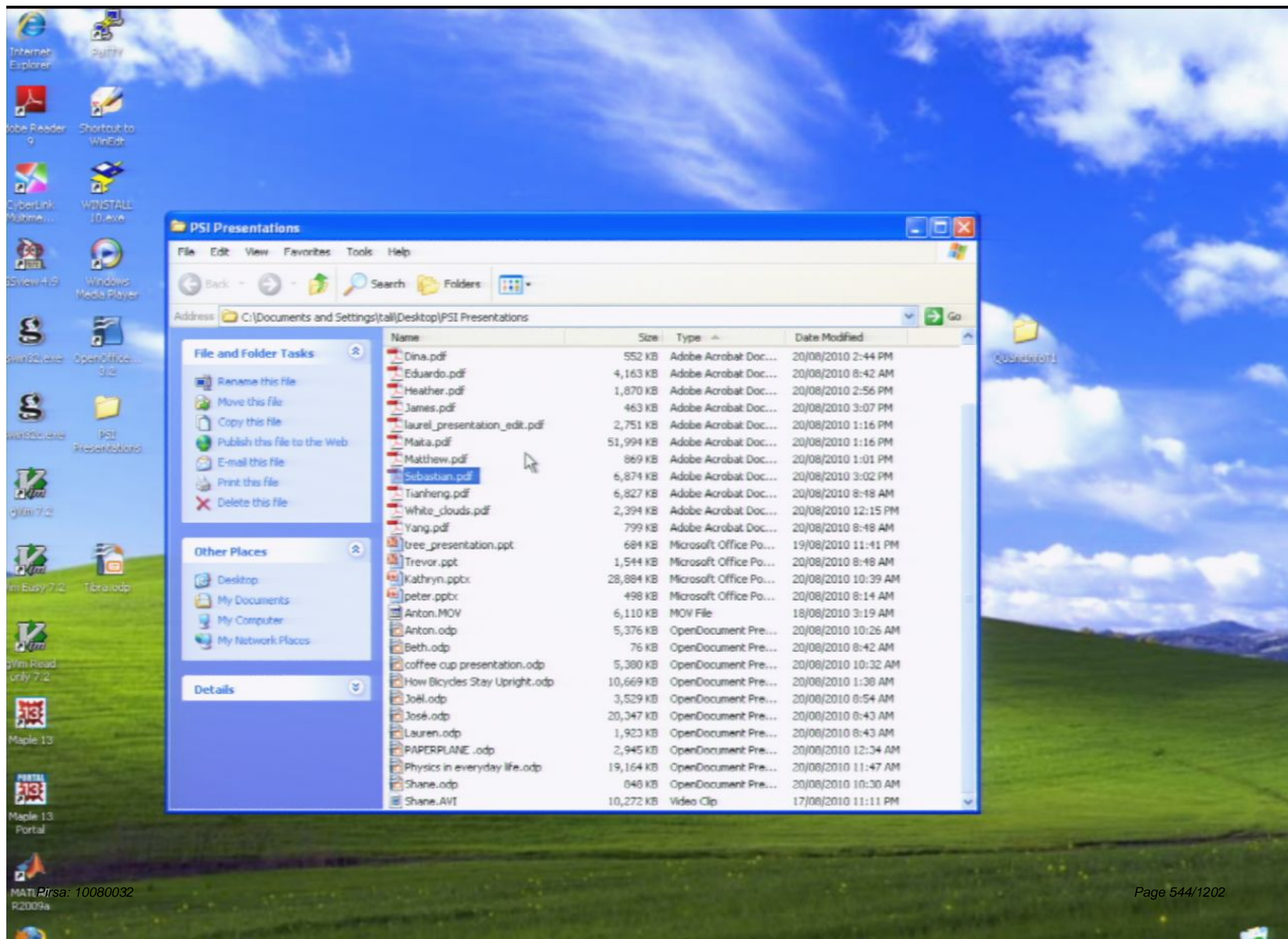
















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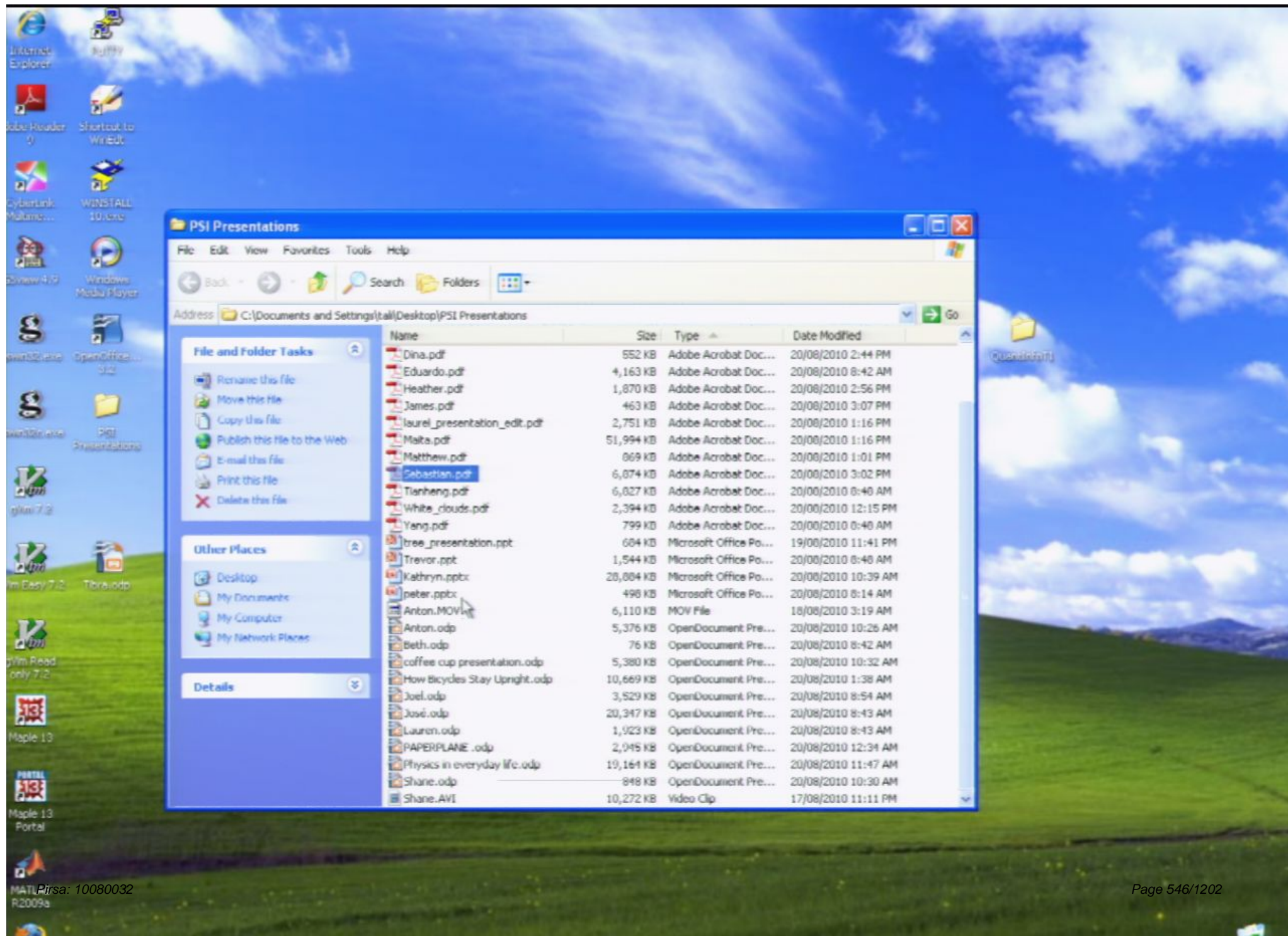
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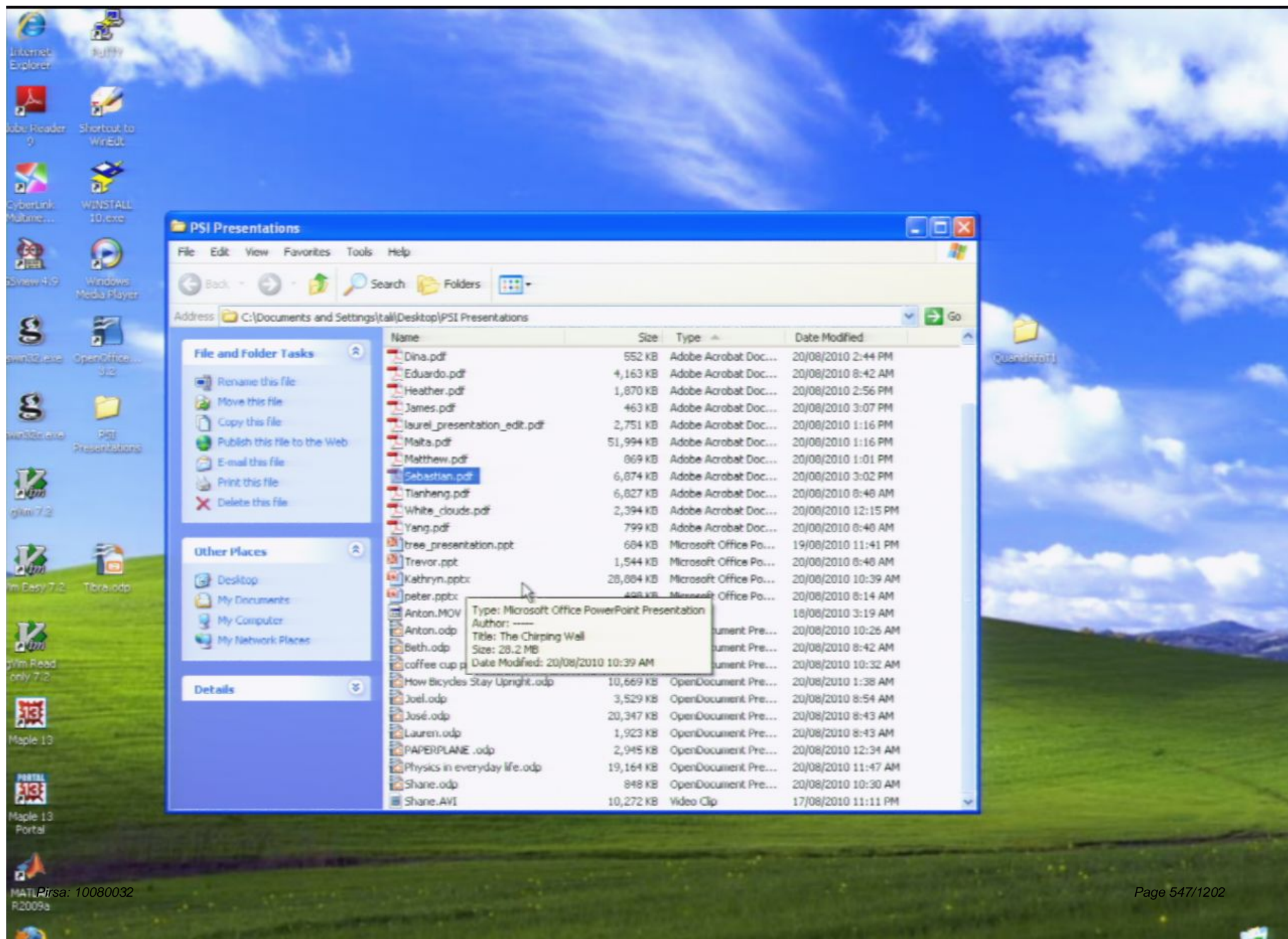
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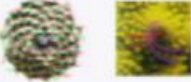
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Outline

Nature Knows Number Theory!

Fibonacci sequence:  
1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, ...




Connection  
Number of LH vs RH (as discussed) equals a pair of consecutive Fibonacci numbers (as (8, 13), (34, 55))


Name: Phyllotaxis

Question: Why does this happen?

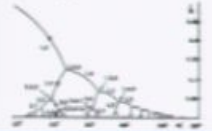
Lattice on Cylinder  
 $A_n = An$ ,  $B_n = an \pmod{2\pi}$



Cayley Tree



Cayley tree for lattice



Change lattice  
 $R_{m,n} = ((m + ni)/\sqrt{2}, (m - ni)/\sqrt{2})$ ,  $m, n \in \mathbb{Z}$

Define energy function:  
**Pirsa: 10080032**

For calculations:  $\Omega(L) = \exp(-L^2)$

# Nature Knows Number Theory!

Peter Lunts  
Aug. 20, 2010  
PSI Talk

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Nature Knows Number Theory!

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Lattice on Cylinder  
 $A_0 = A_0$ ,  $A_1 = a_1$  (mod 2 $\pi$ )

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# Nature Knows Number Theory!

Peter Lunts  
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Page 550/1202

# Nature Knows Number Theory!

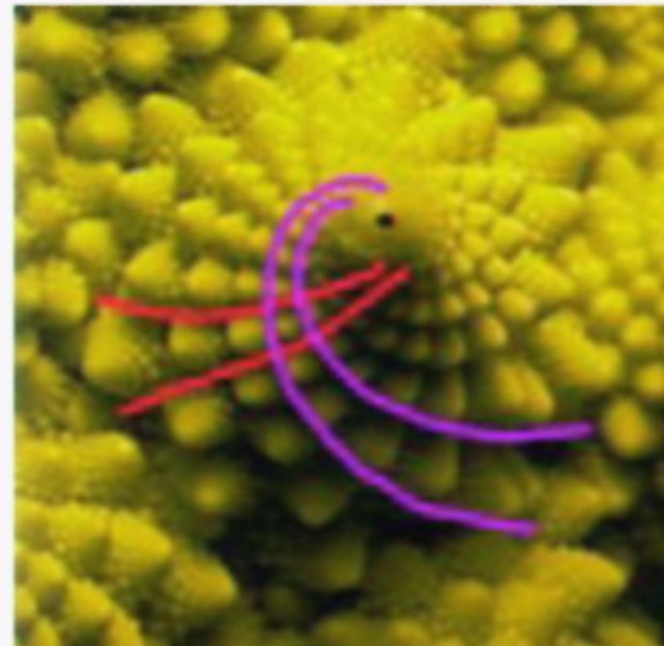
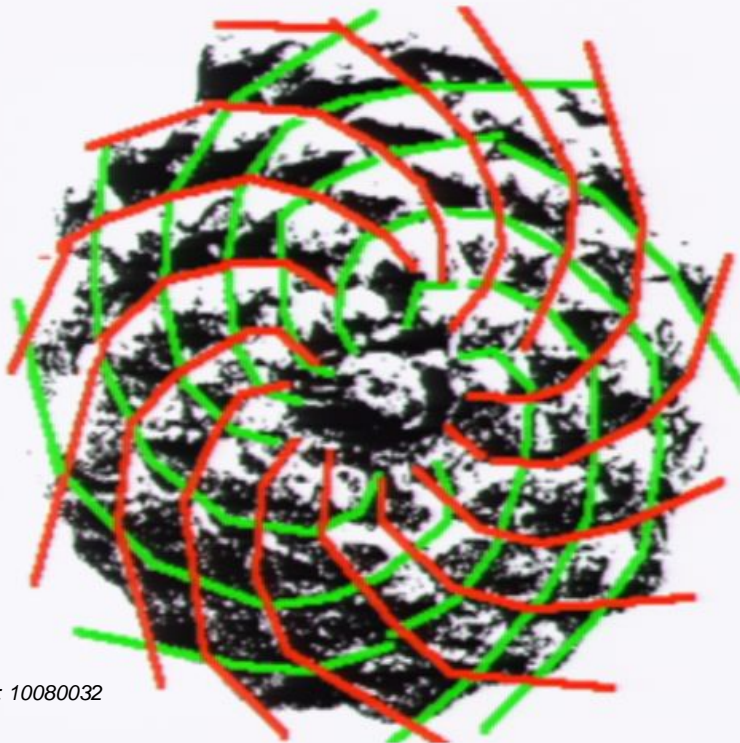
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Fibonacci sequence:

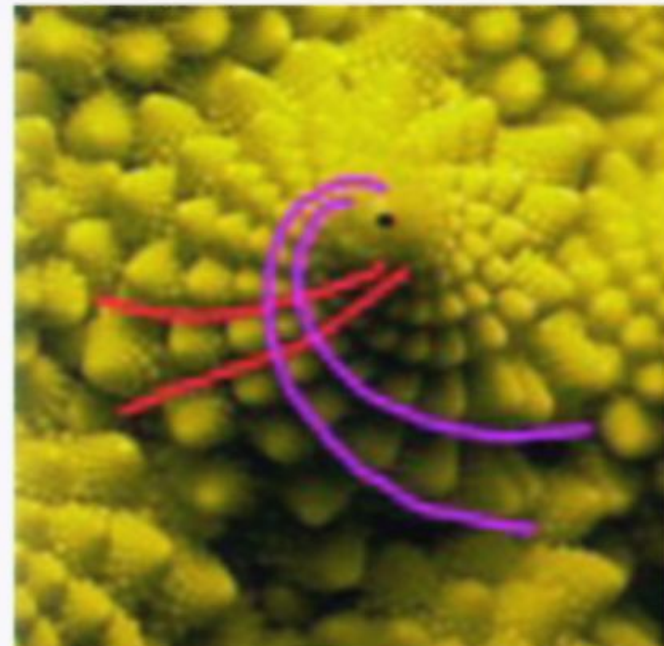
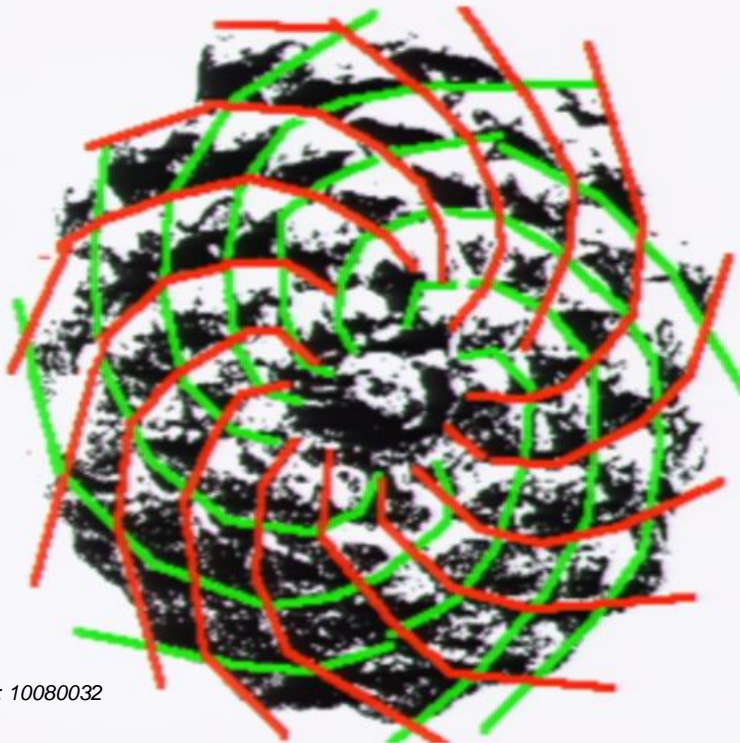
1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144...





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# Connection

Number of LH to RH (or vise versa) spirals is pair of consecutive Fibonacci numbers (ex: (8, 13), (34,55))

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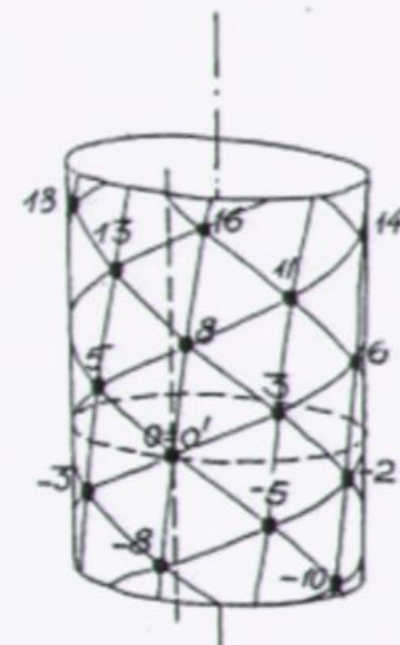
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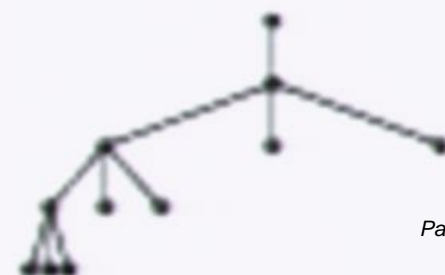
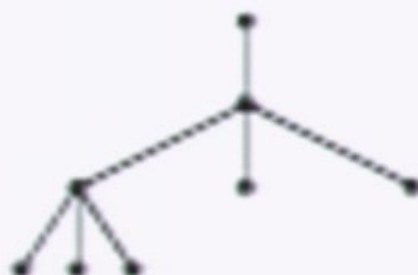
Question: Why does this happen?

# Lattice on Cylinder

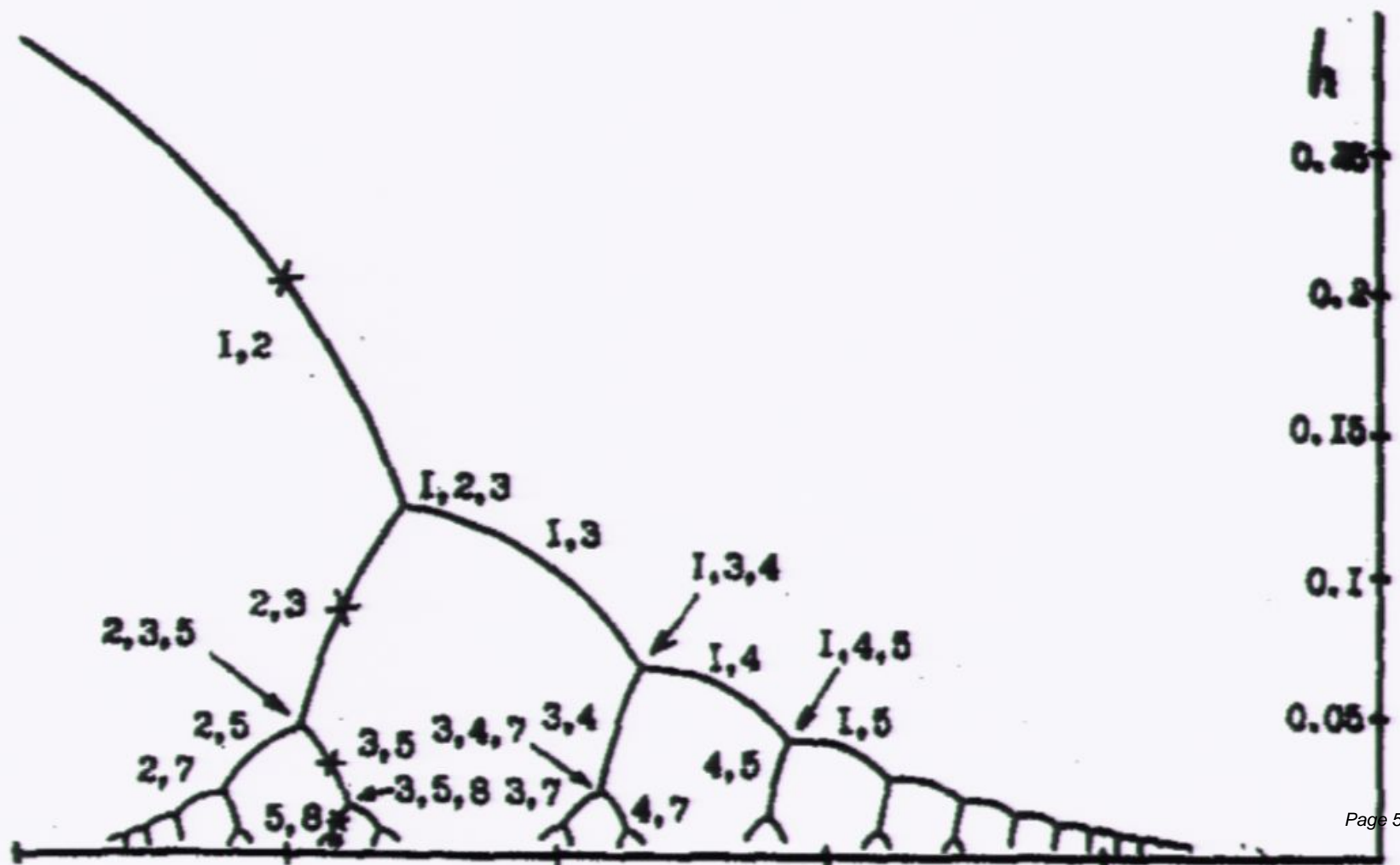
$$z_n = hn, \quad \theta_n = \alpha n \pmod{2\pi}$$



Cayley Tree



# Cayley tree for lattices



## Change lattice

$$\vec{r}_{mn} = ((m + nx)/\sqrt{y}, n\sqrt{y}), \quad m, n \in \mathbb{Z}.$$

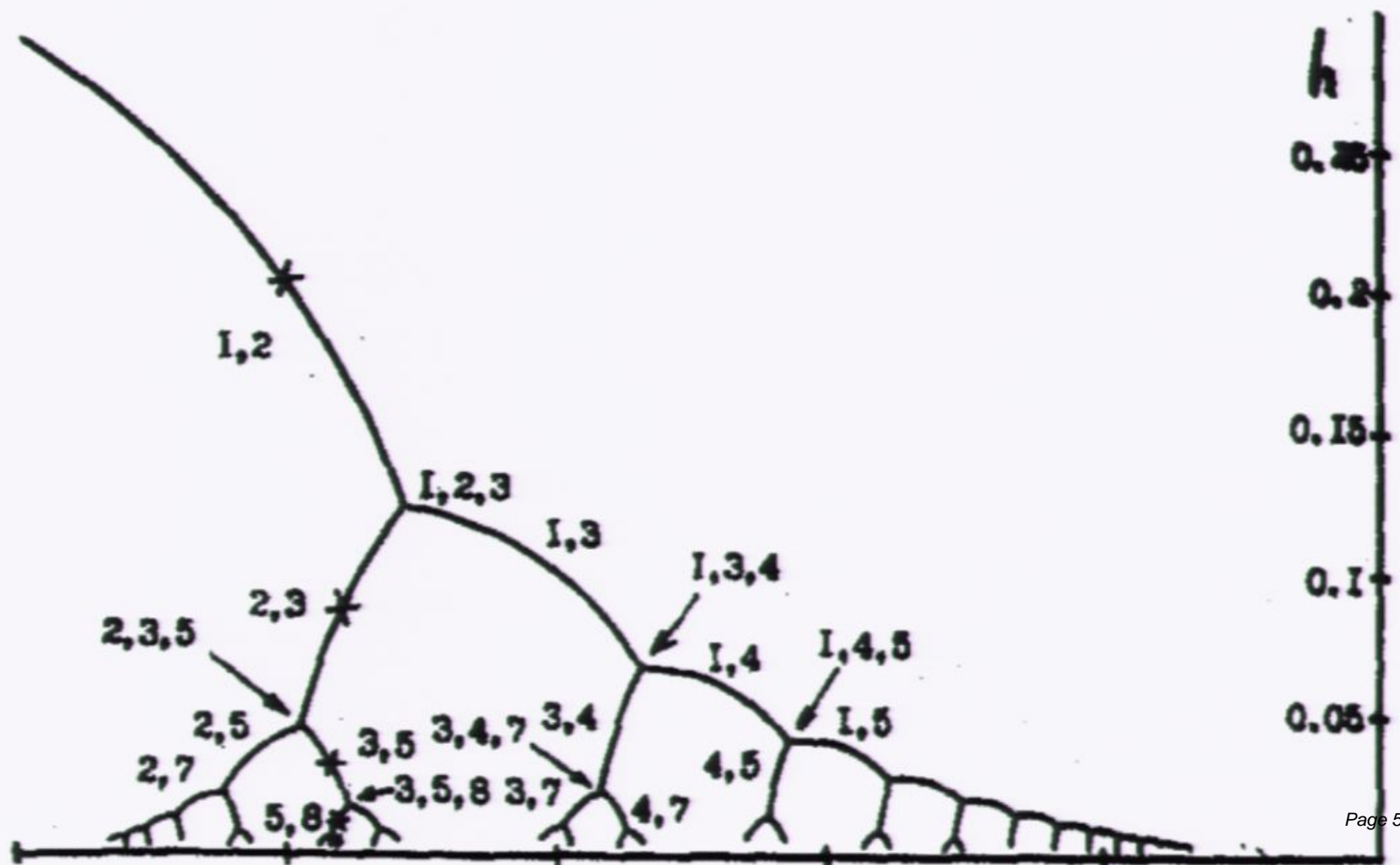
Define energy function:

$$E(x, y) = \sum_{mn} U(|r_{mn}|).$$

For calculations:  $U(\lambda) = \exp(-\lambda^2)$



# Cayley tree for lattices



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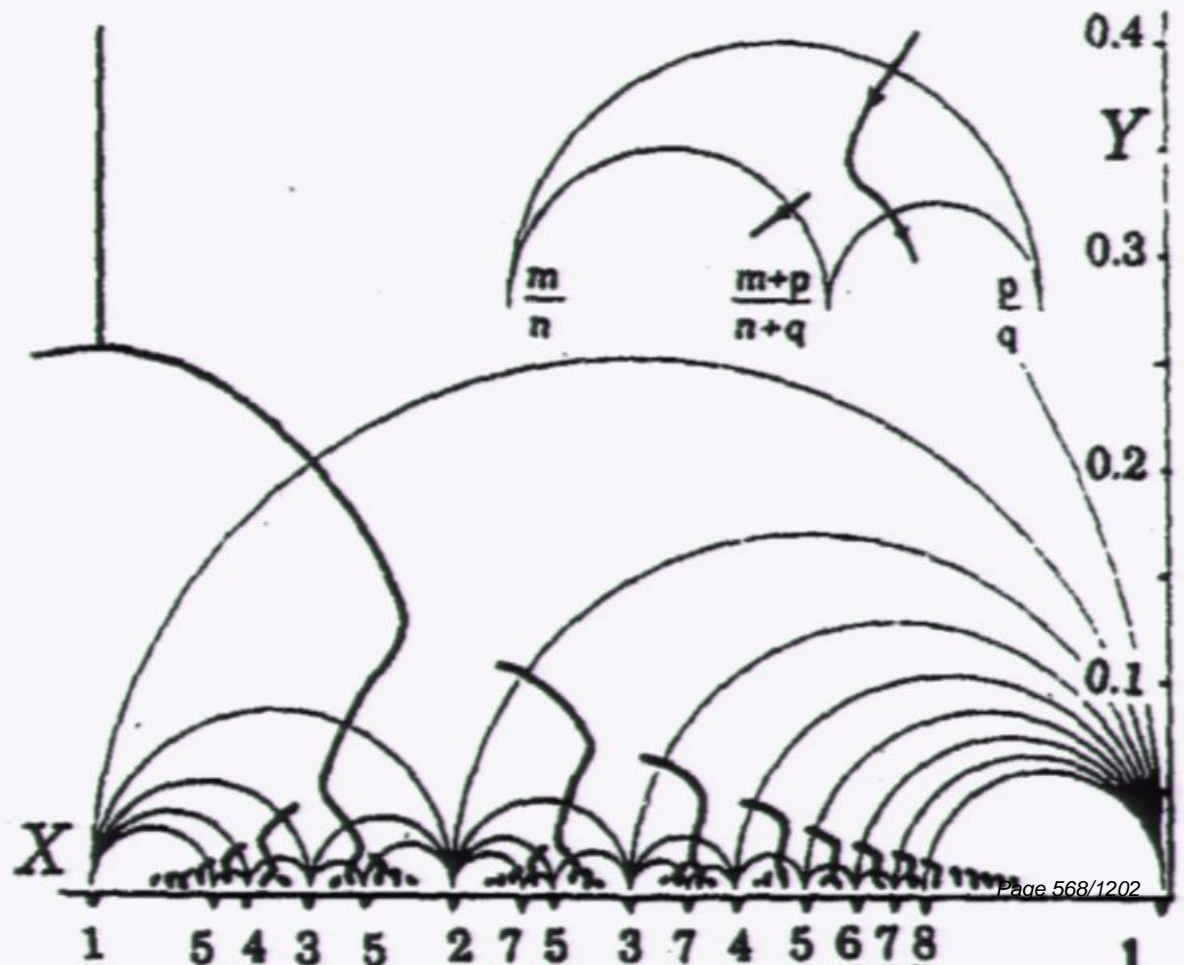
$$E(x, y) = \sum_{mn} U(|r_{mn}|).$$

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# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path



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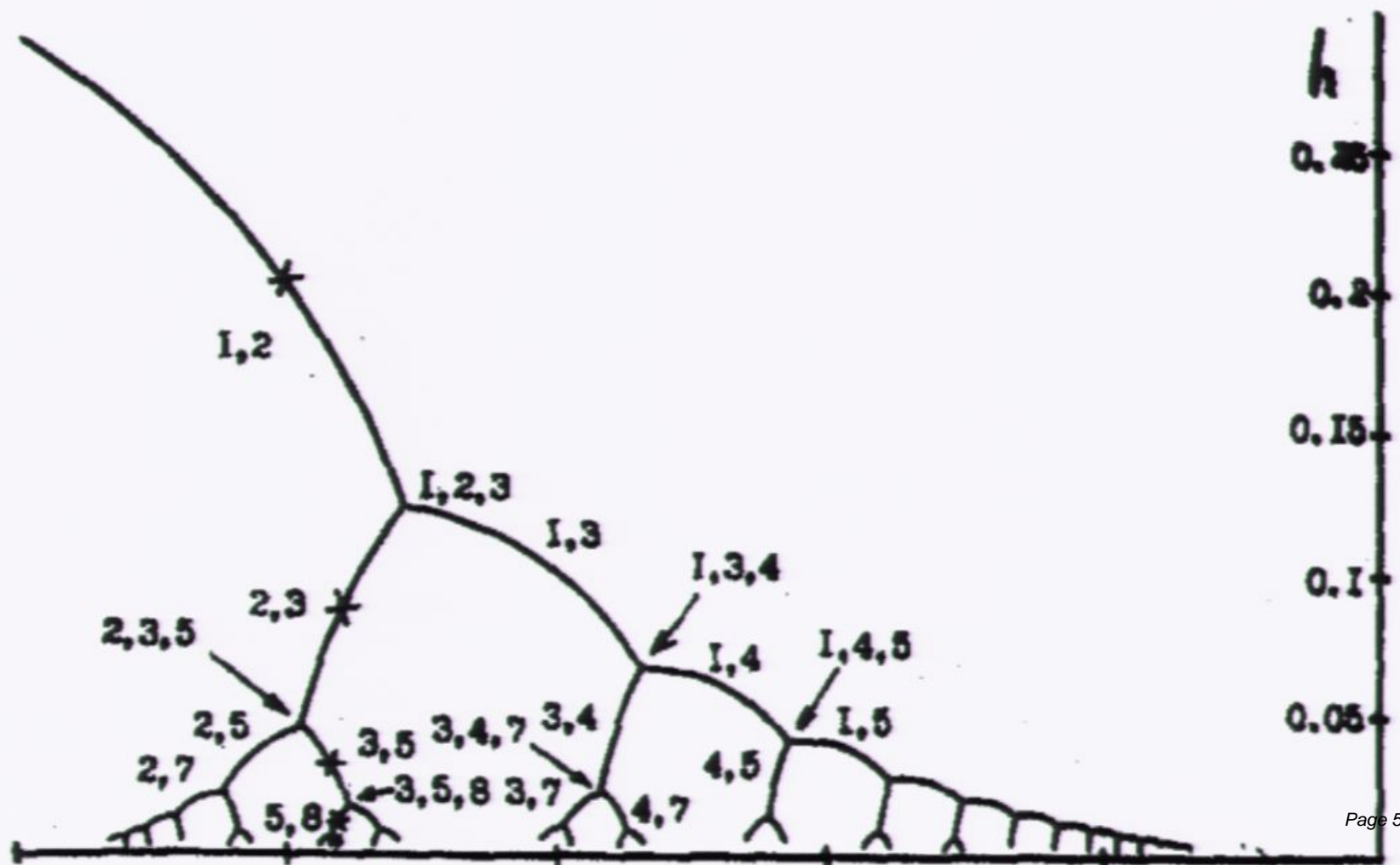
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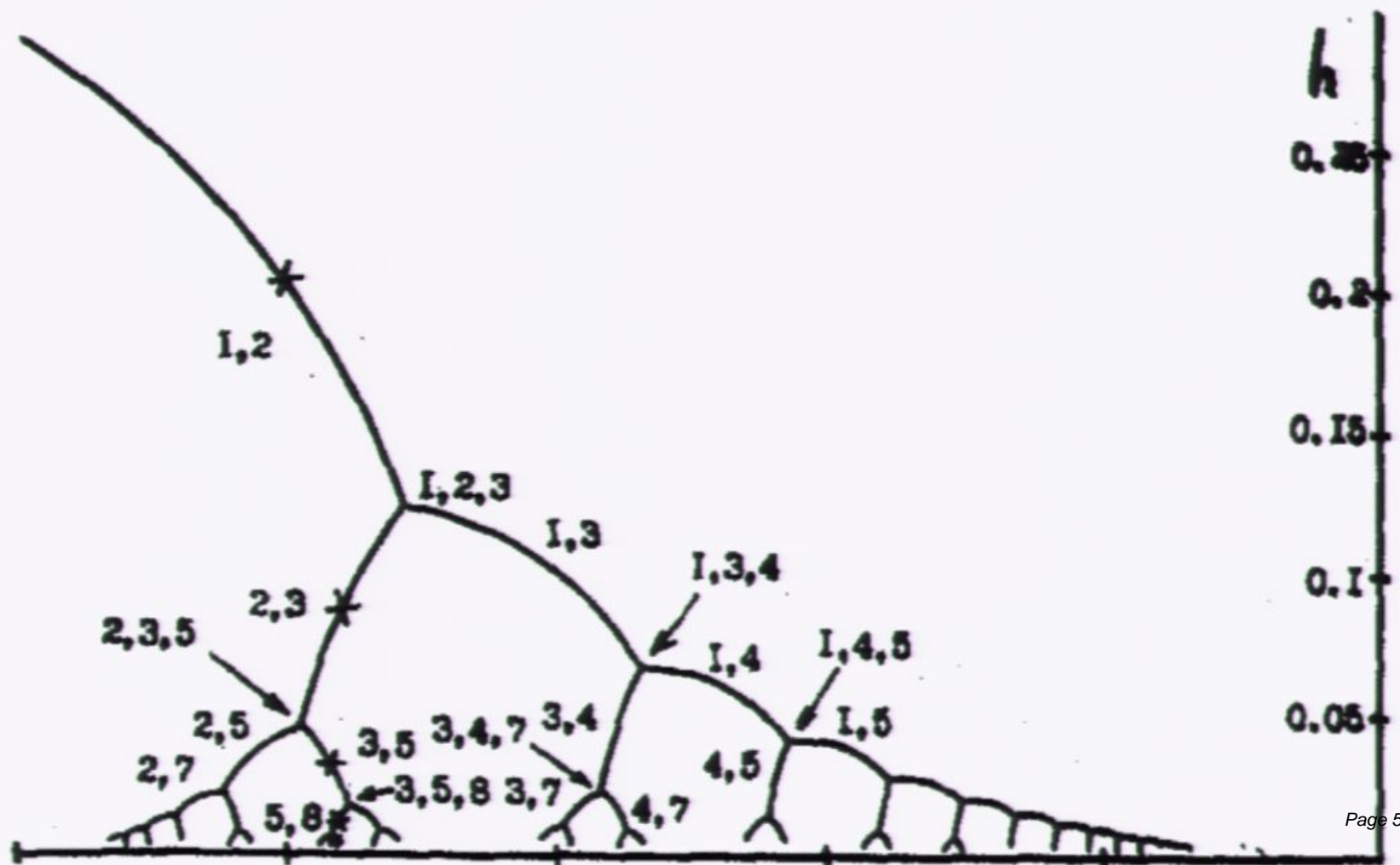
For calculations:  $U(\lambda) = \exp(-\lambda^2)$



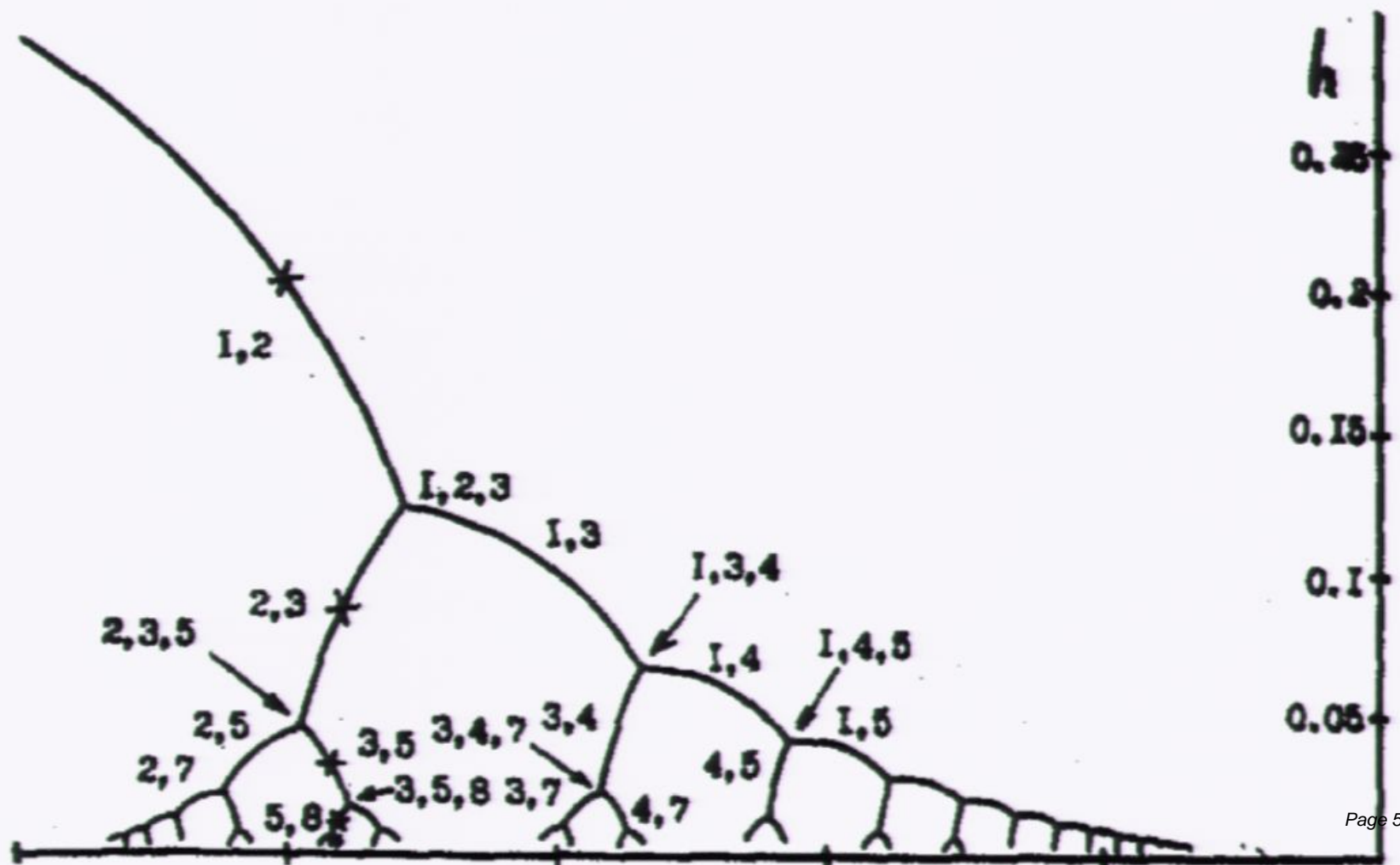
# Cayley tree for lattices



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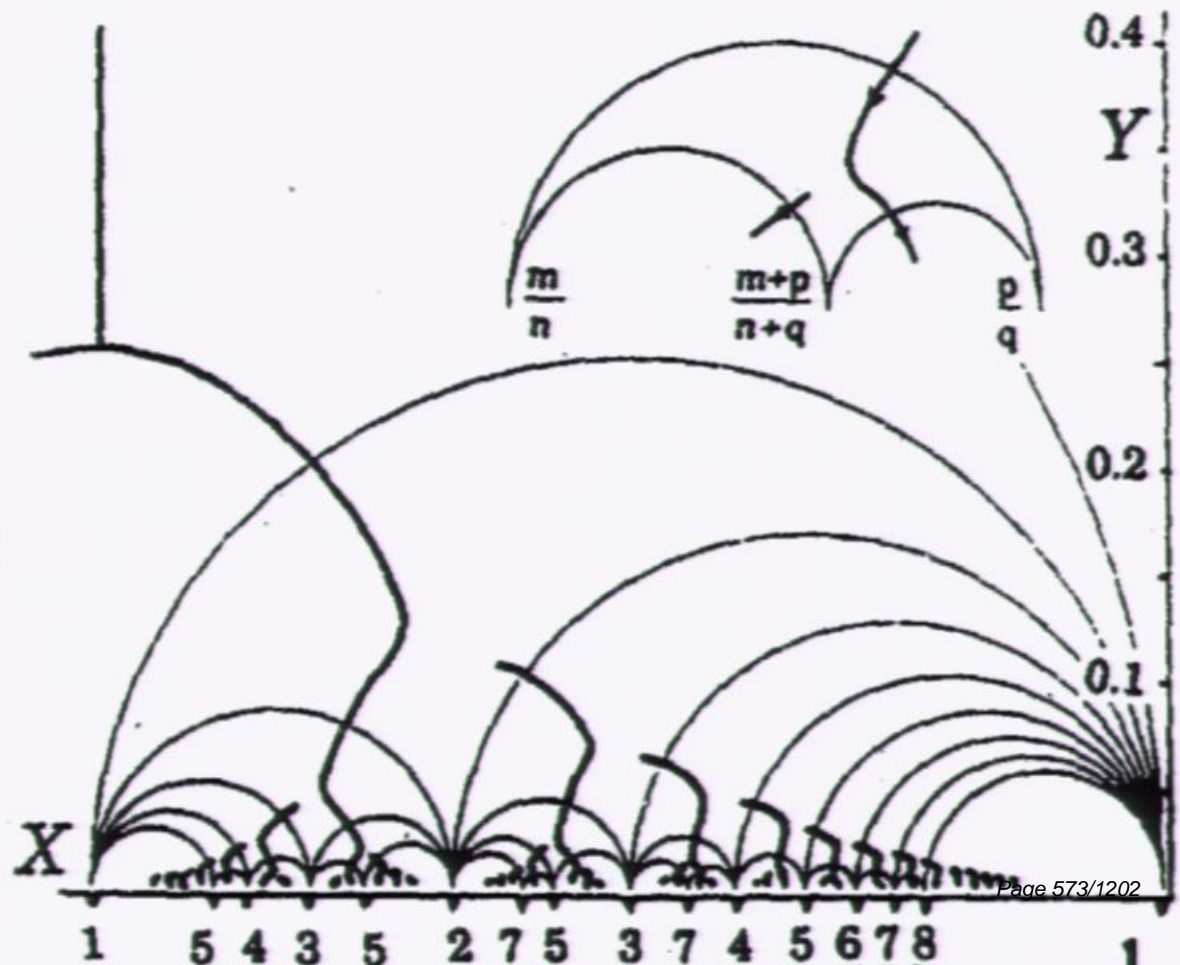
# Cayley tree for lattices



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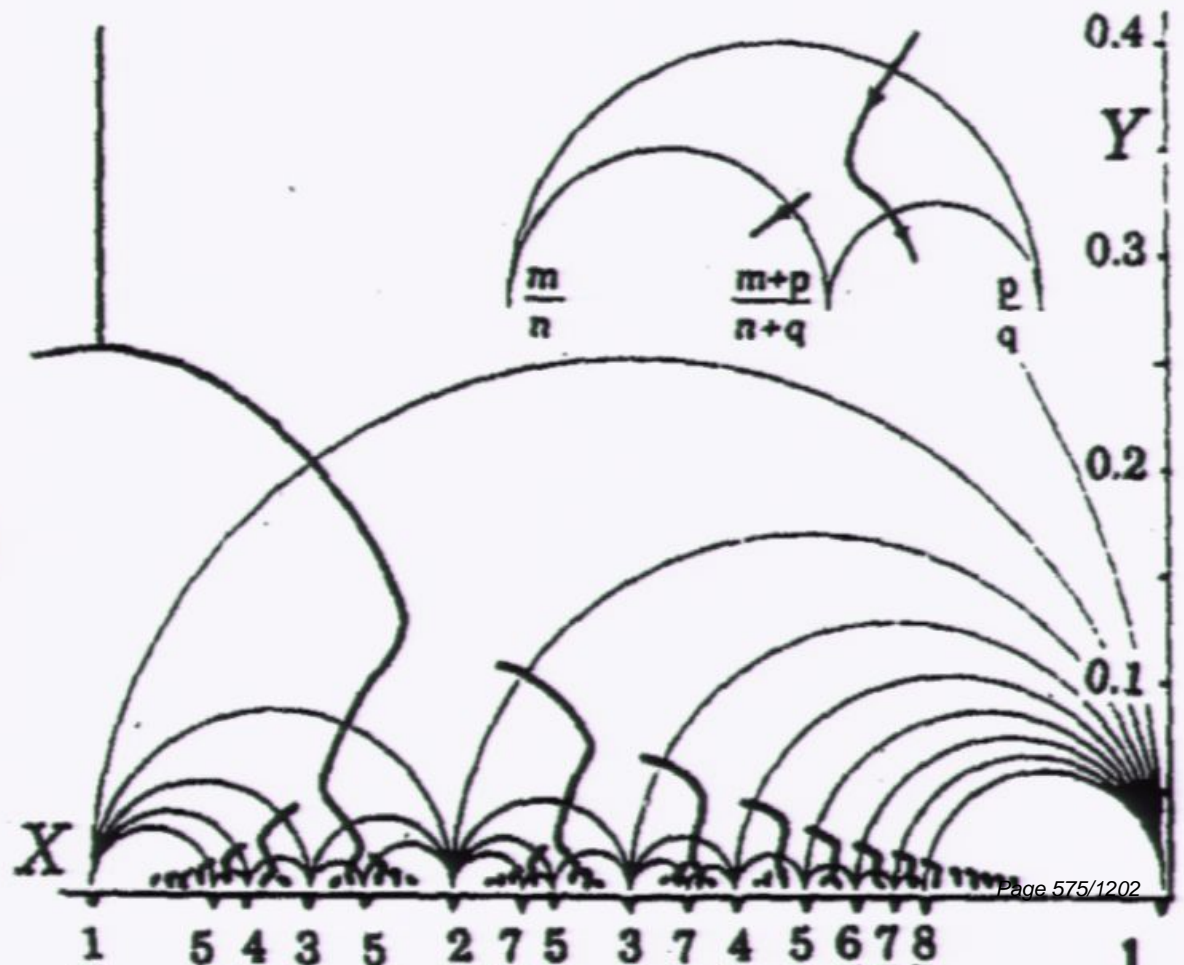
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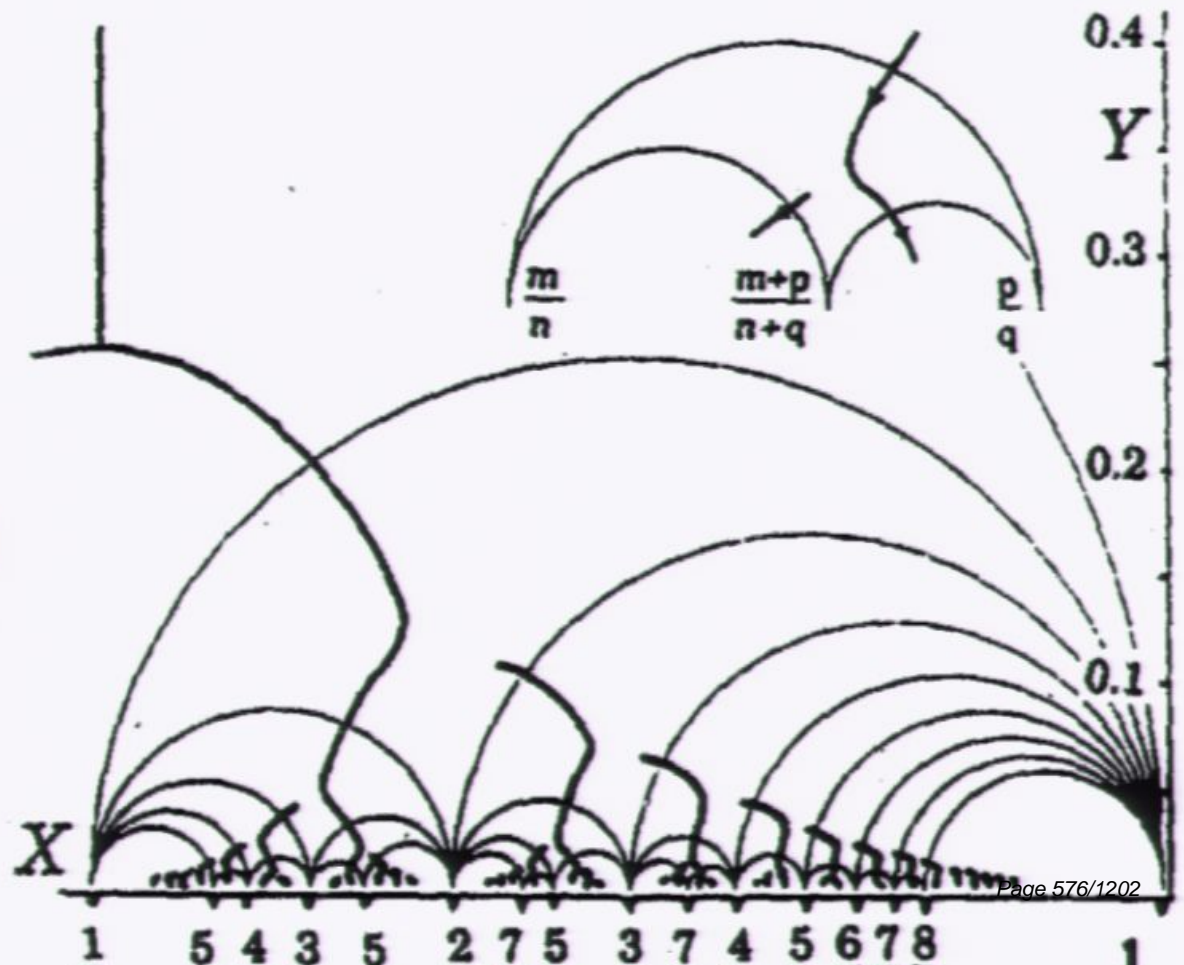
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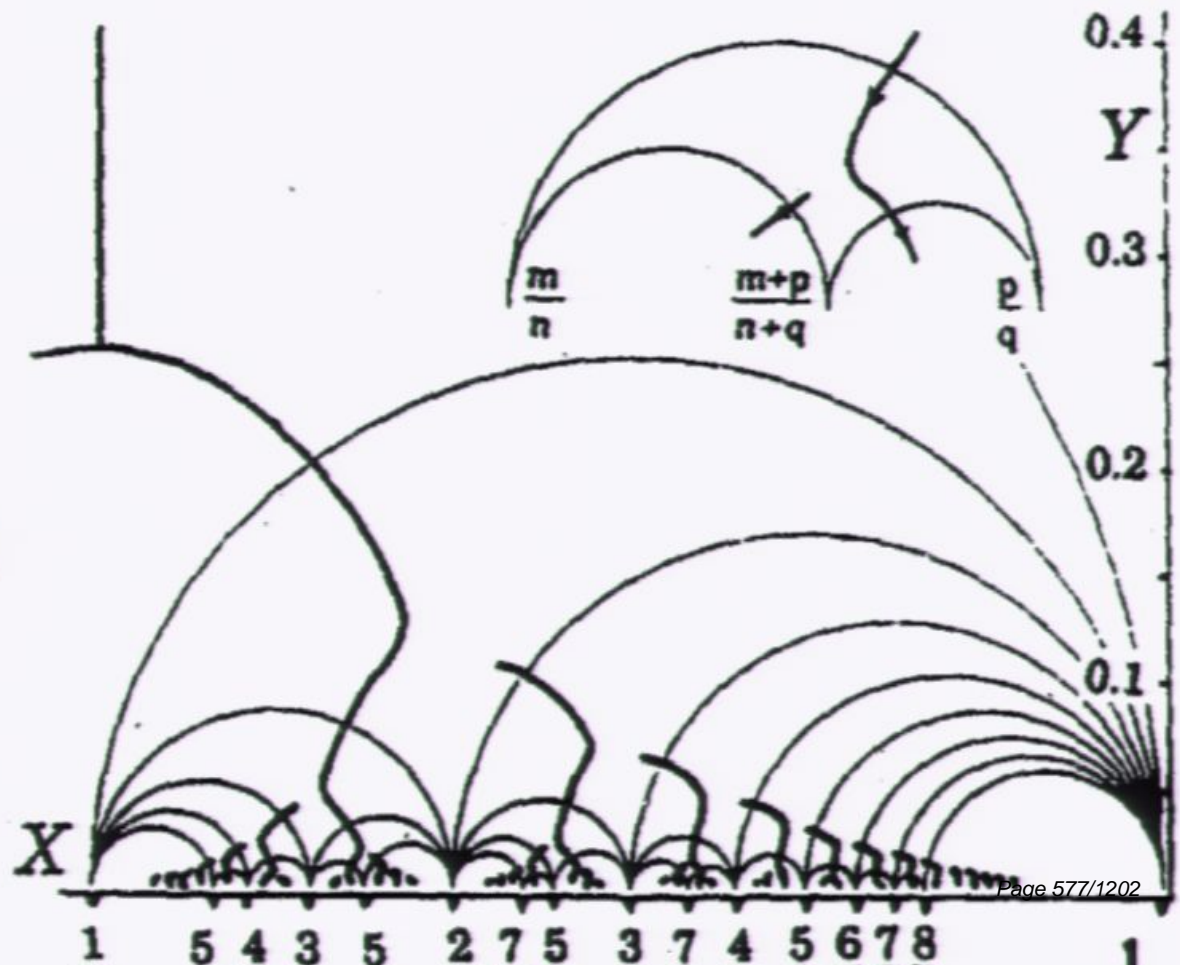




# Energy minima

Vary  $y$  from  
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Quasi bifurcations lead  
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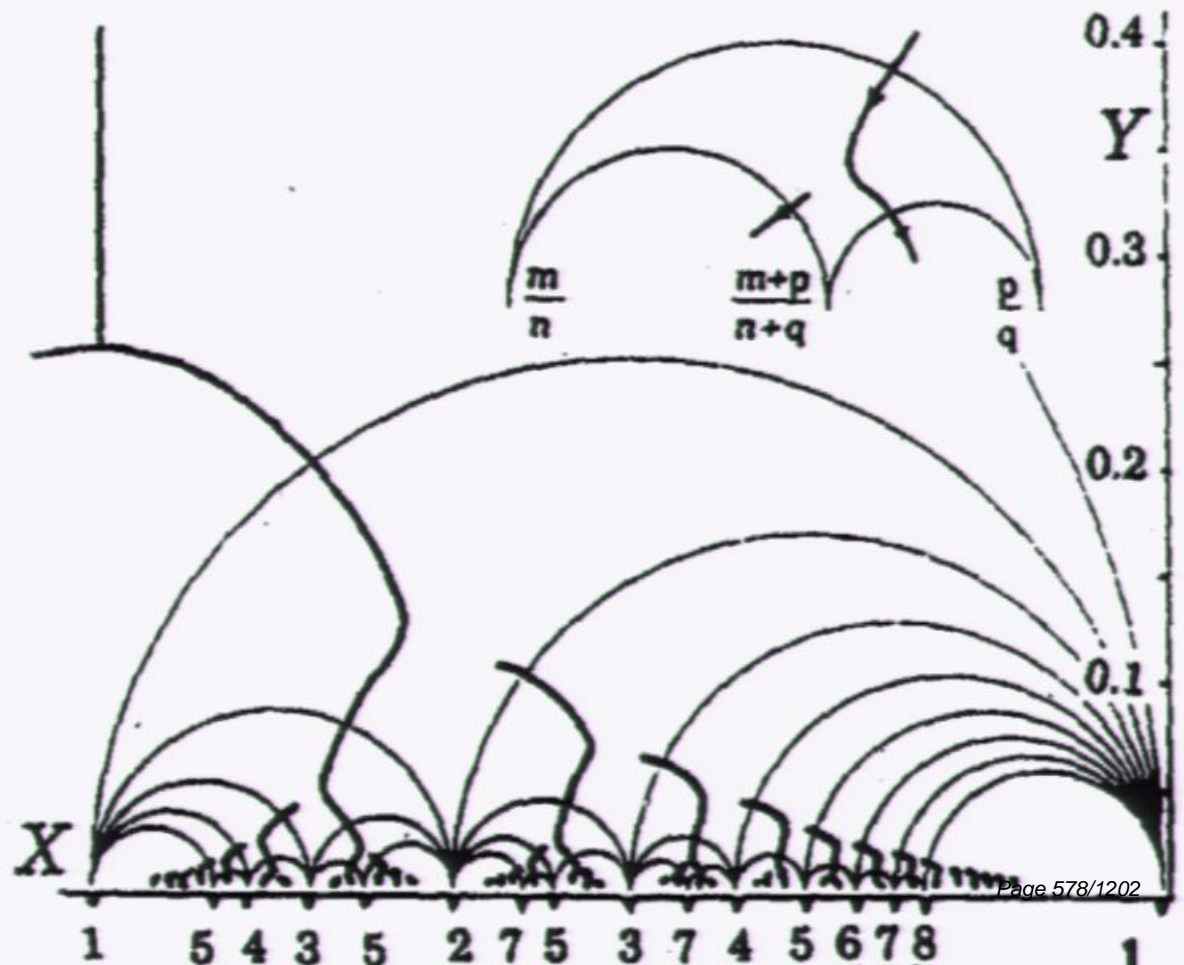




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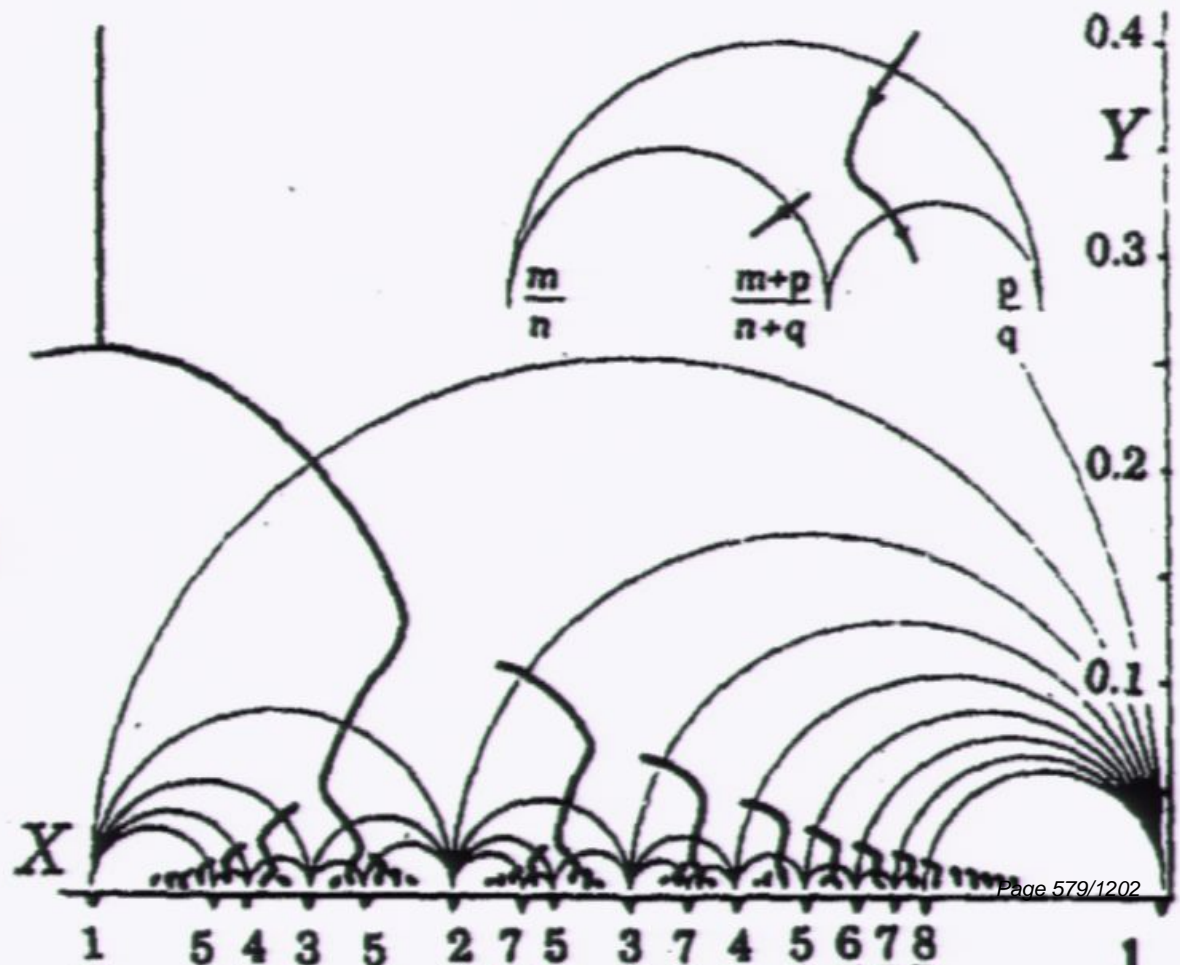
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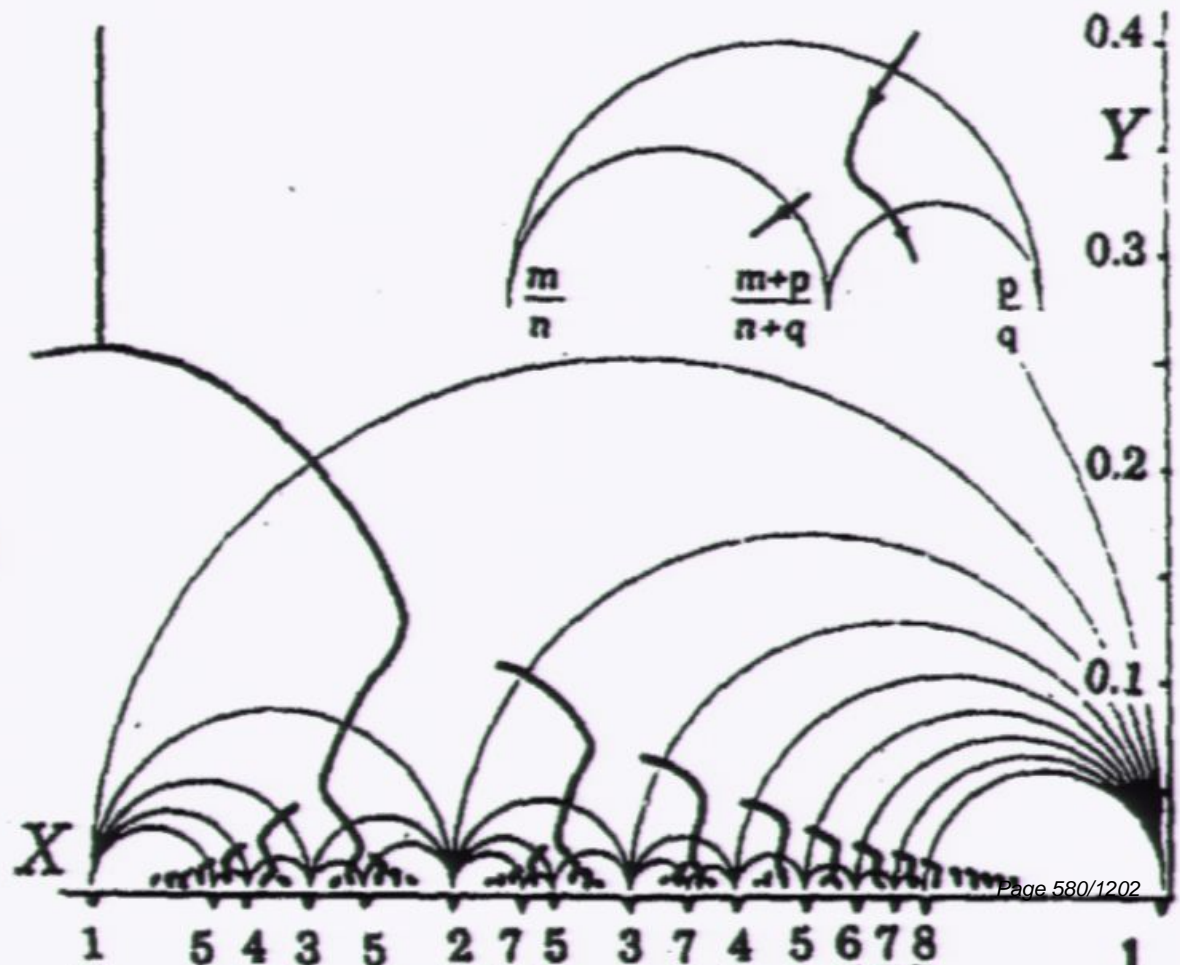
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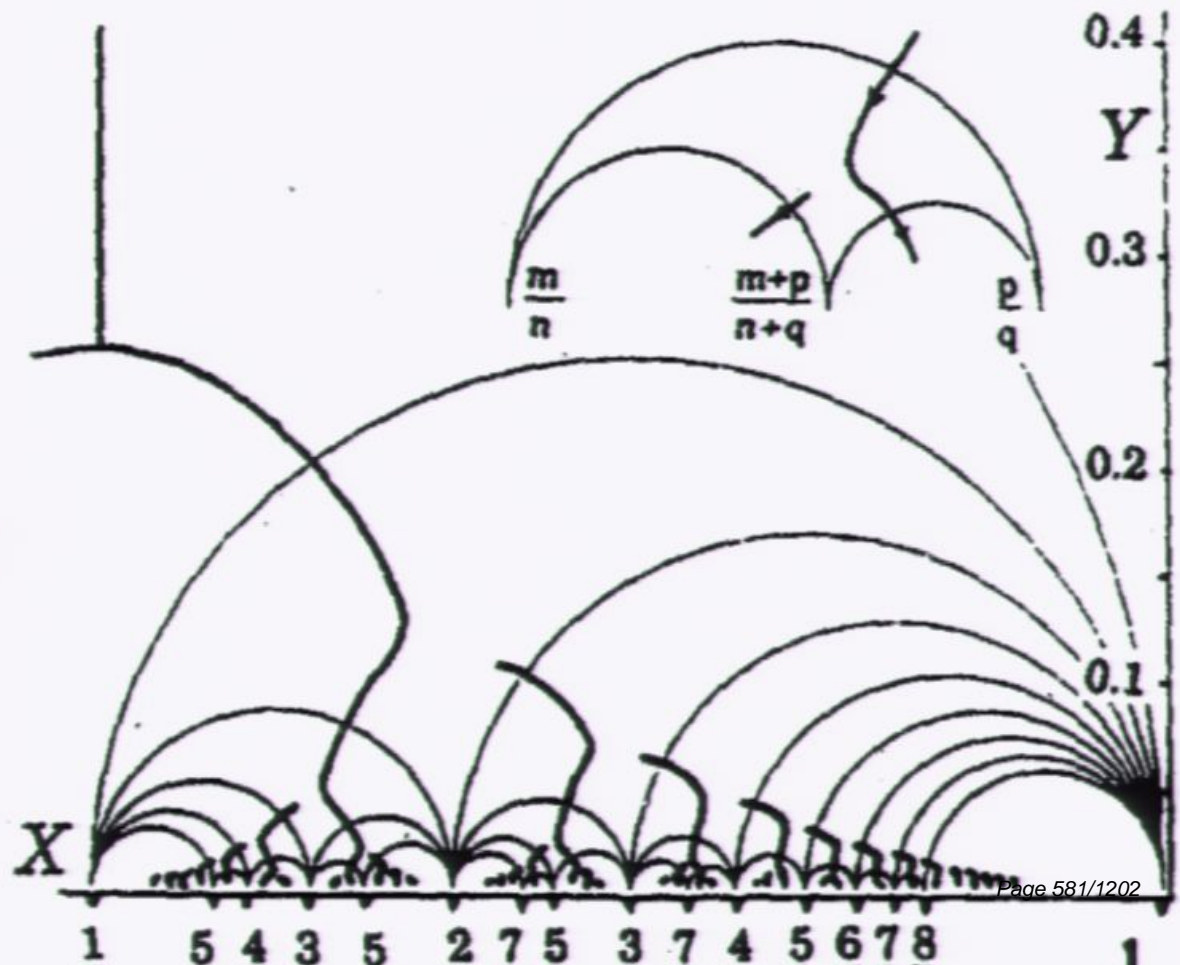




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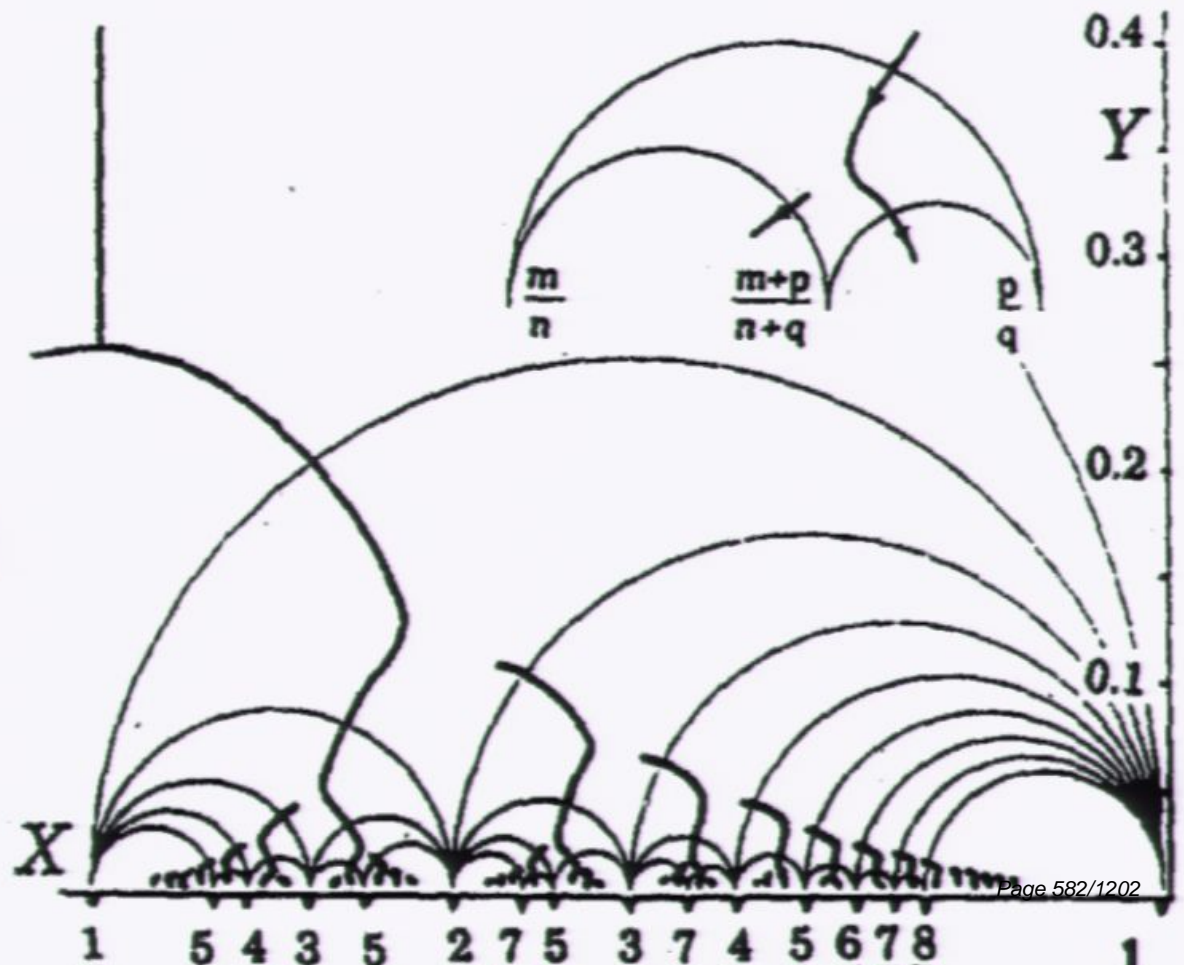




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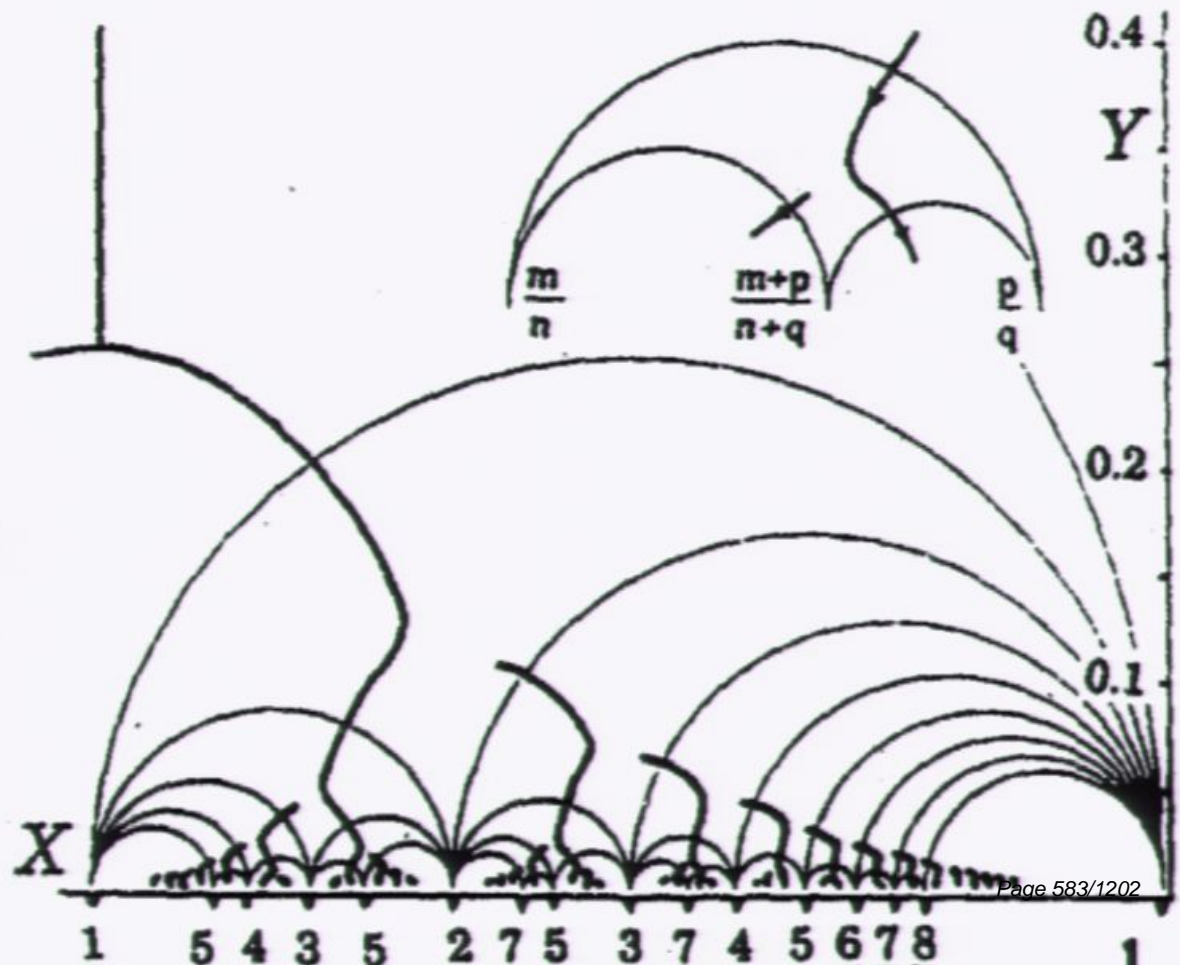
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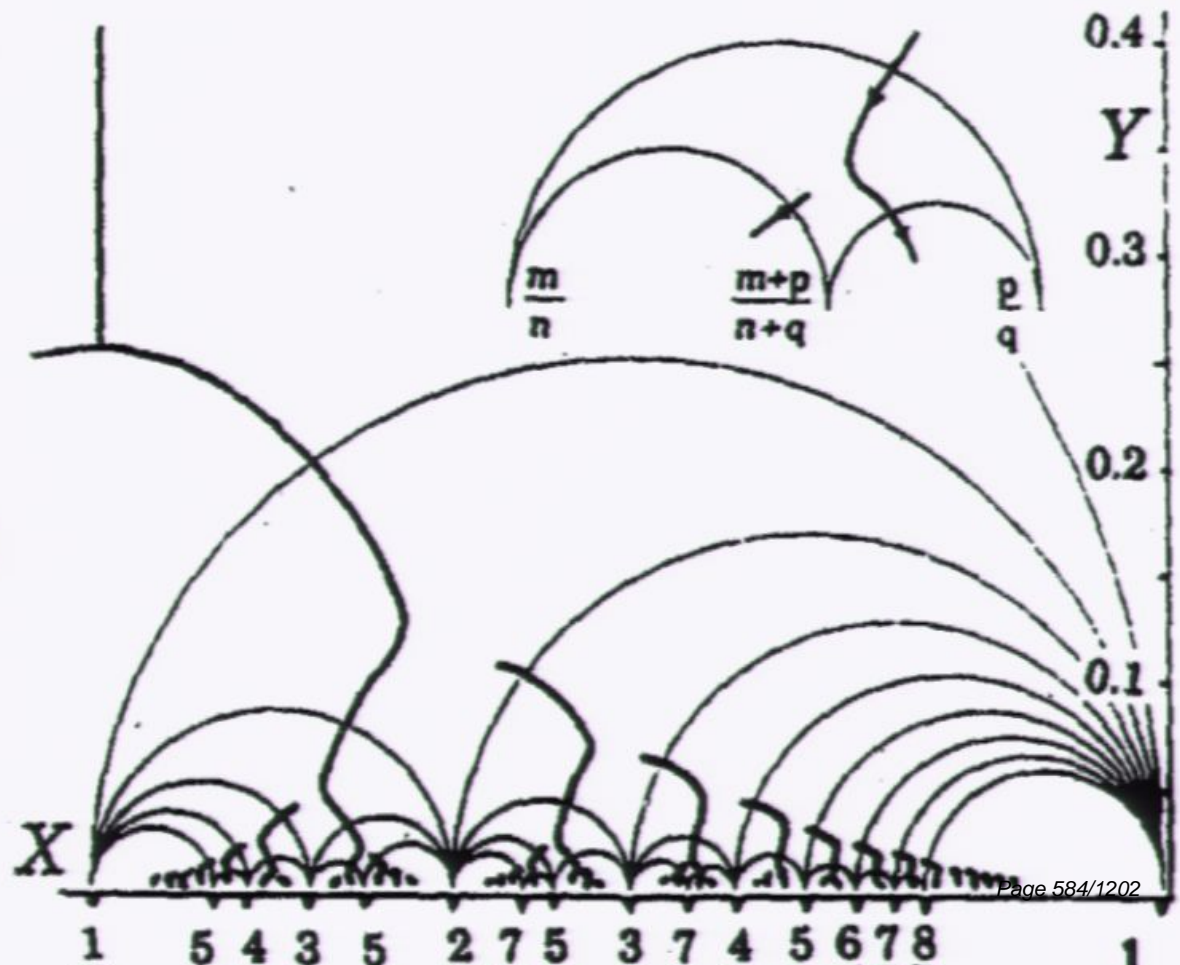
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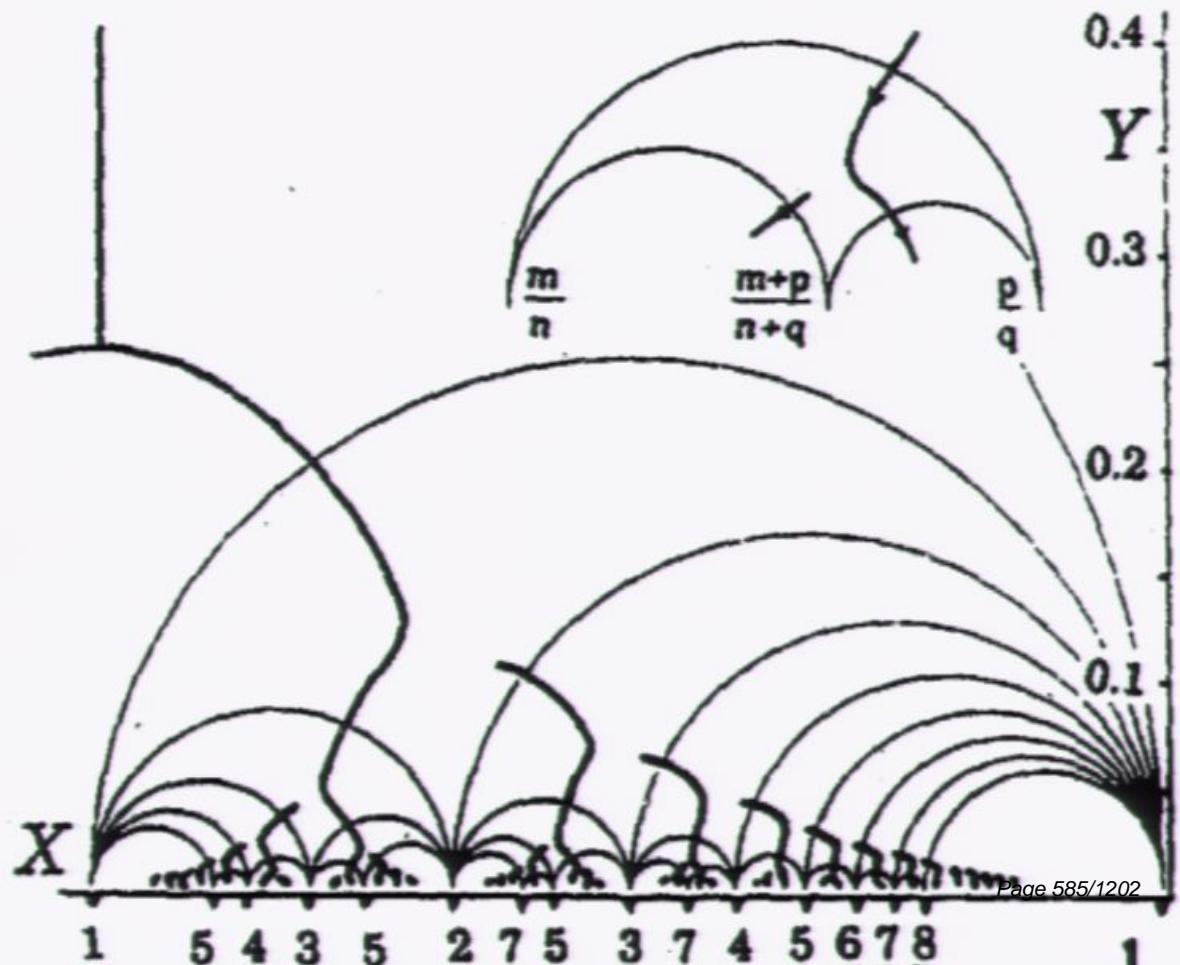




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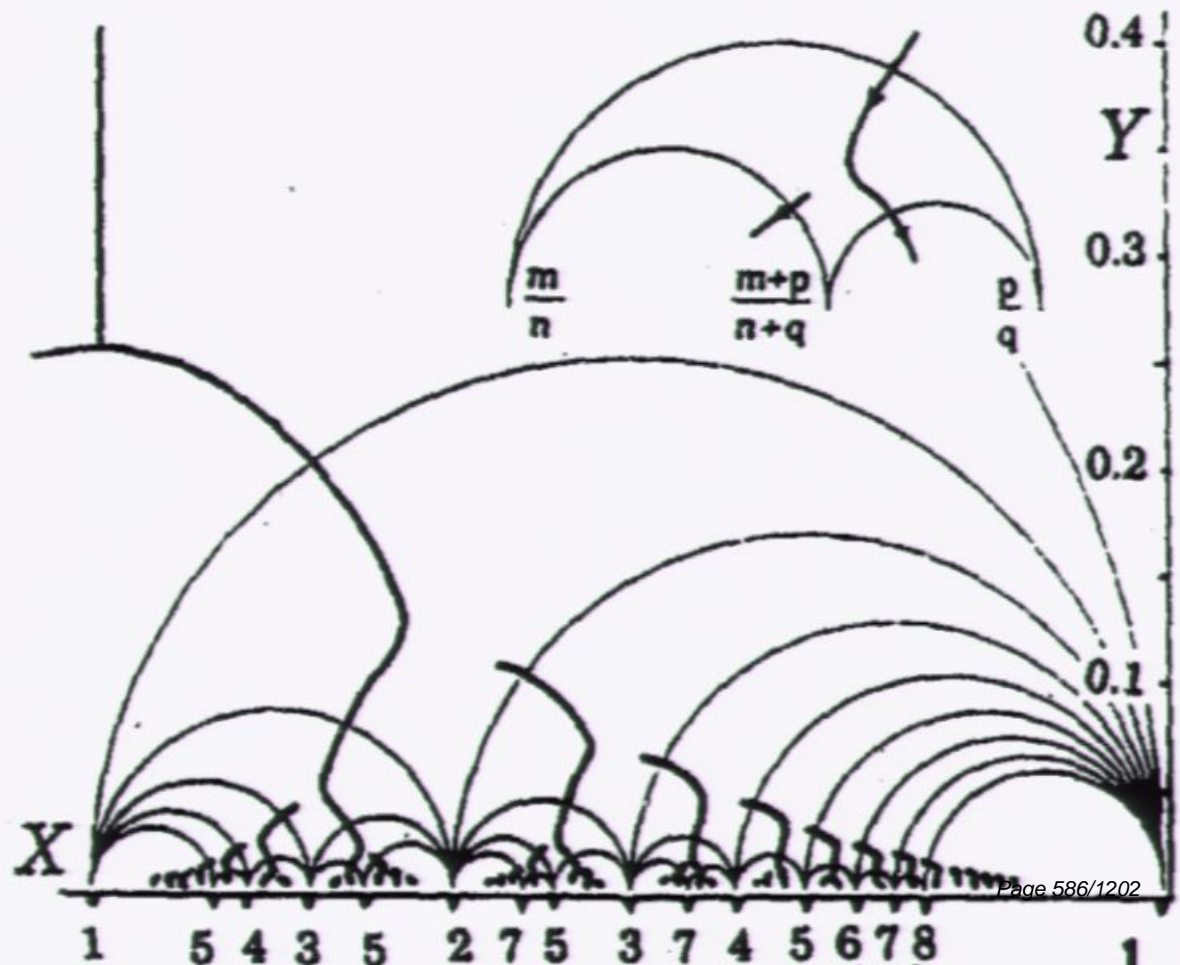




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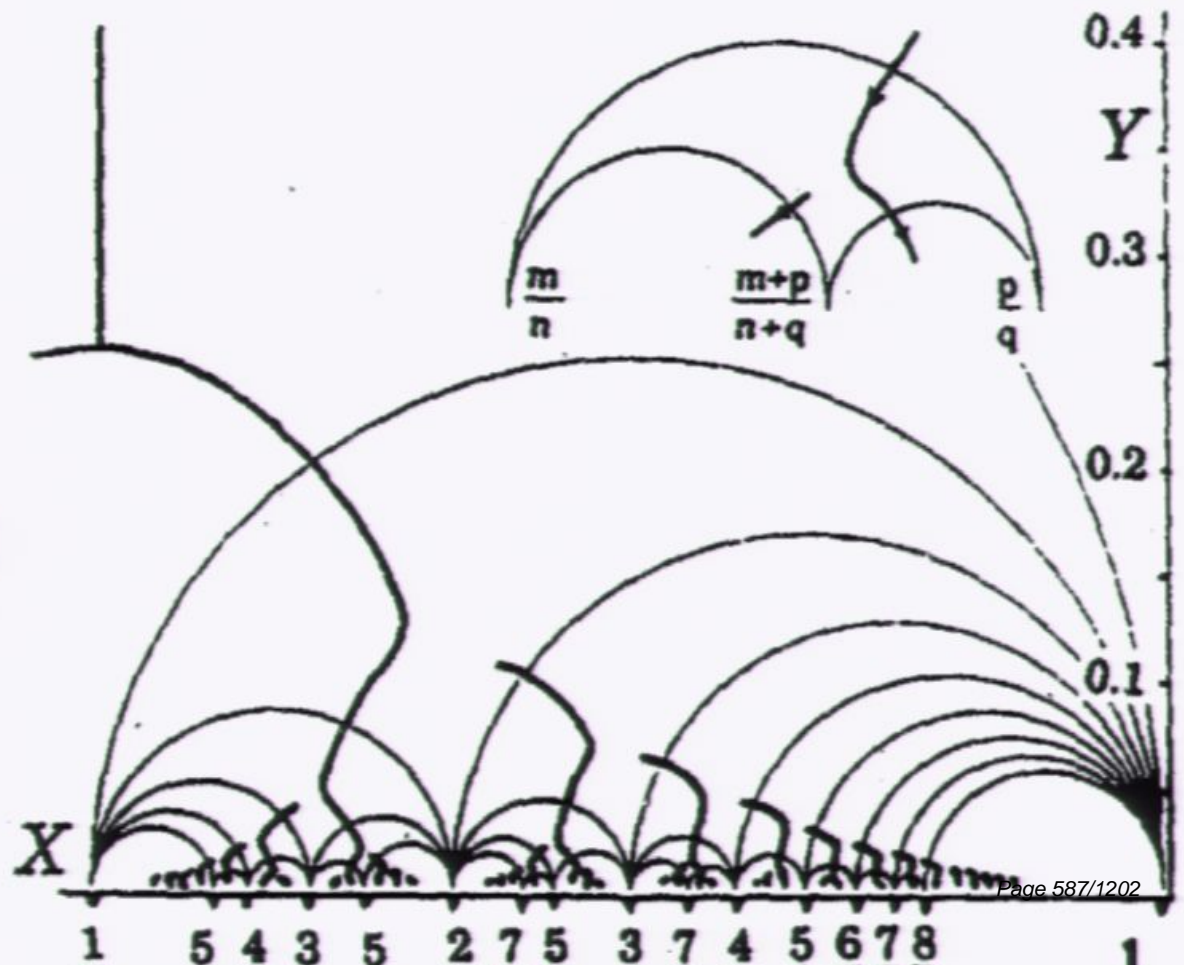
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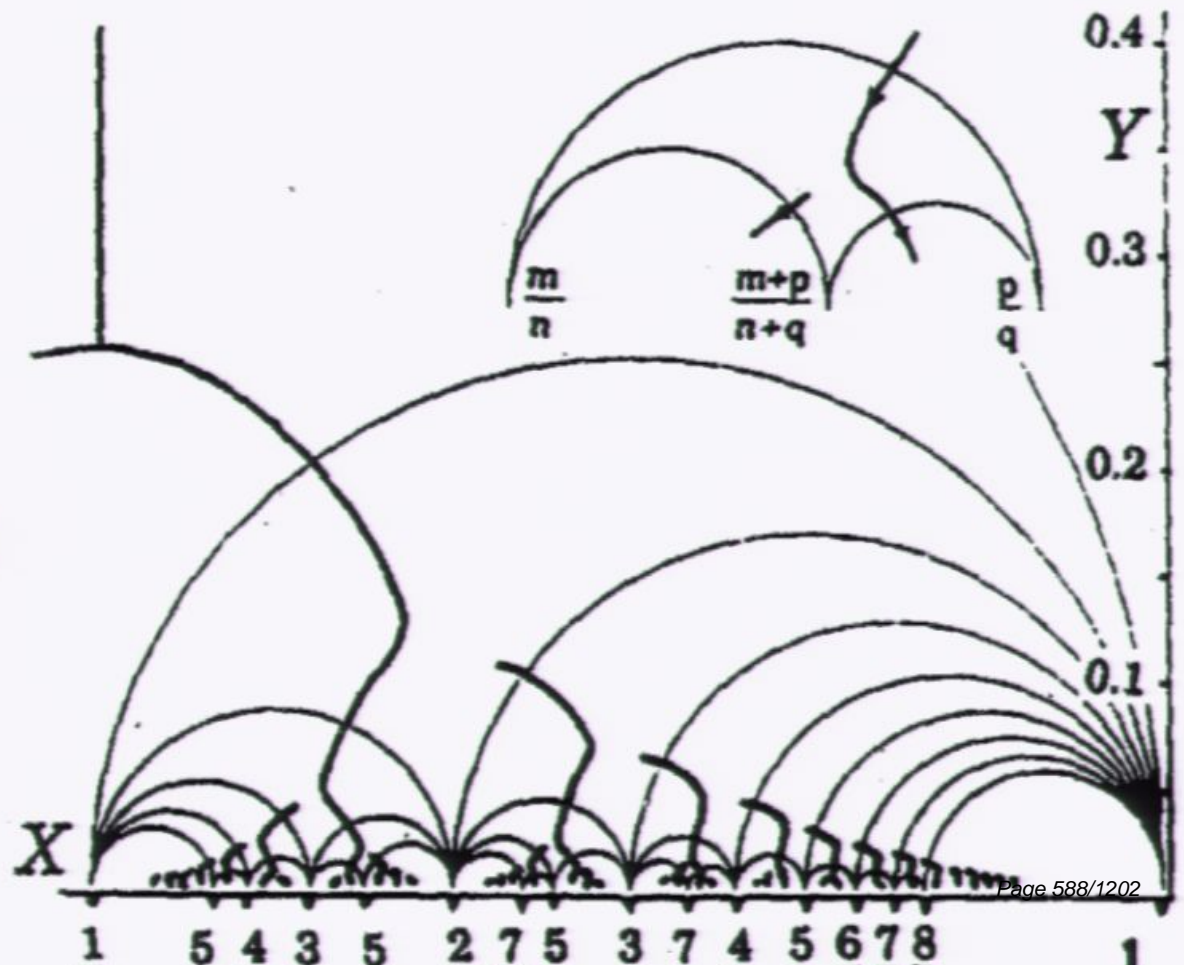
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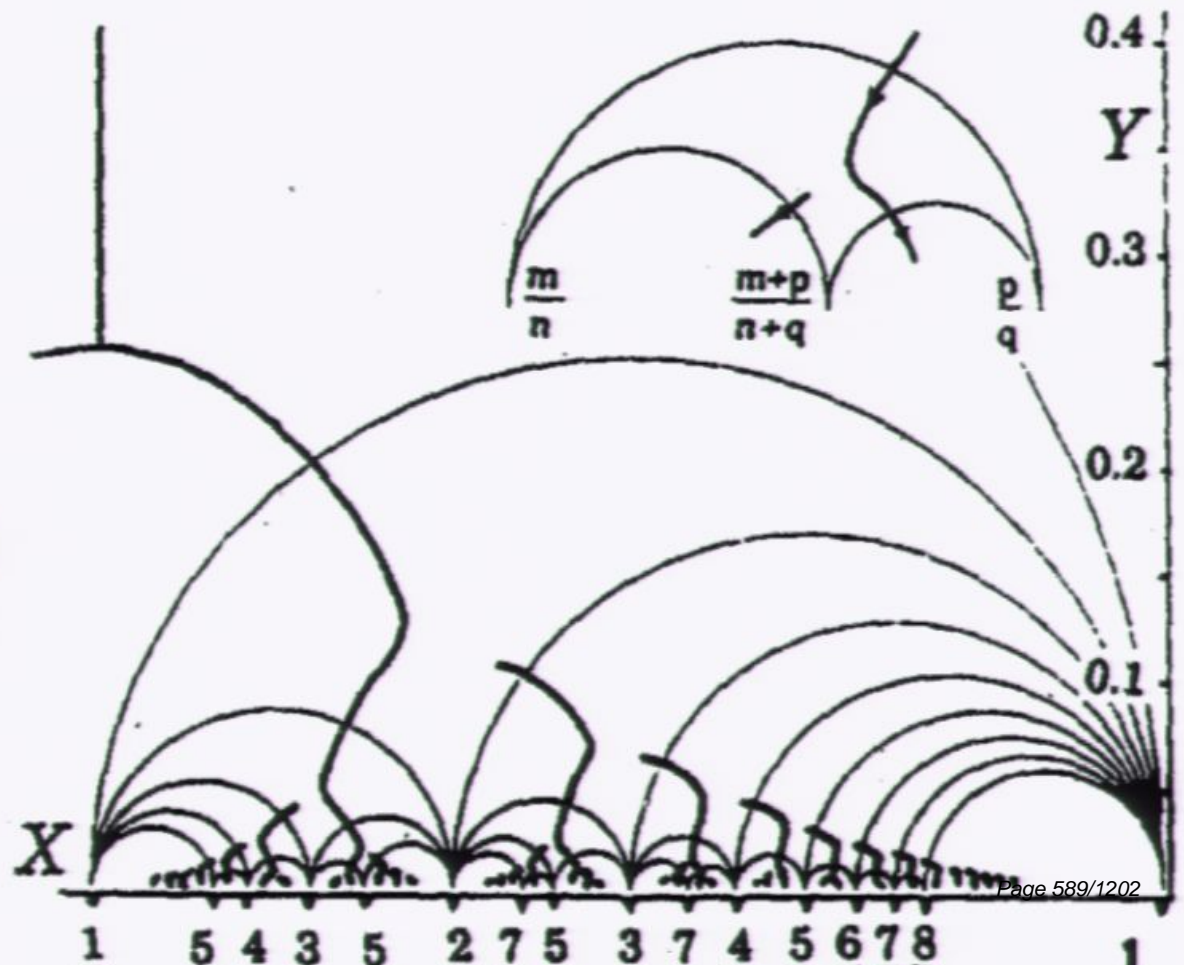




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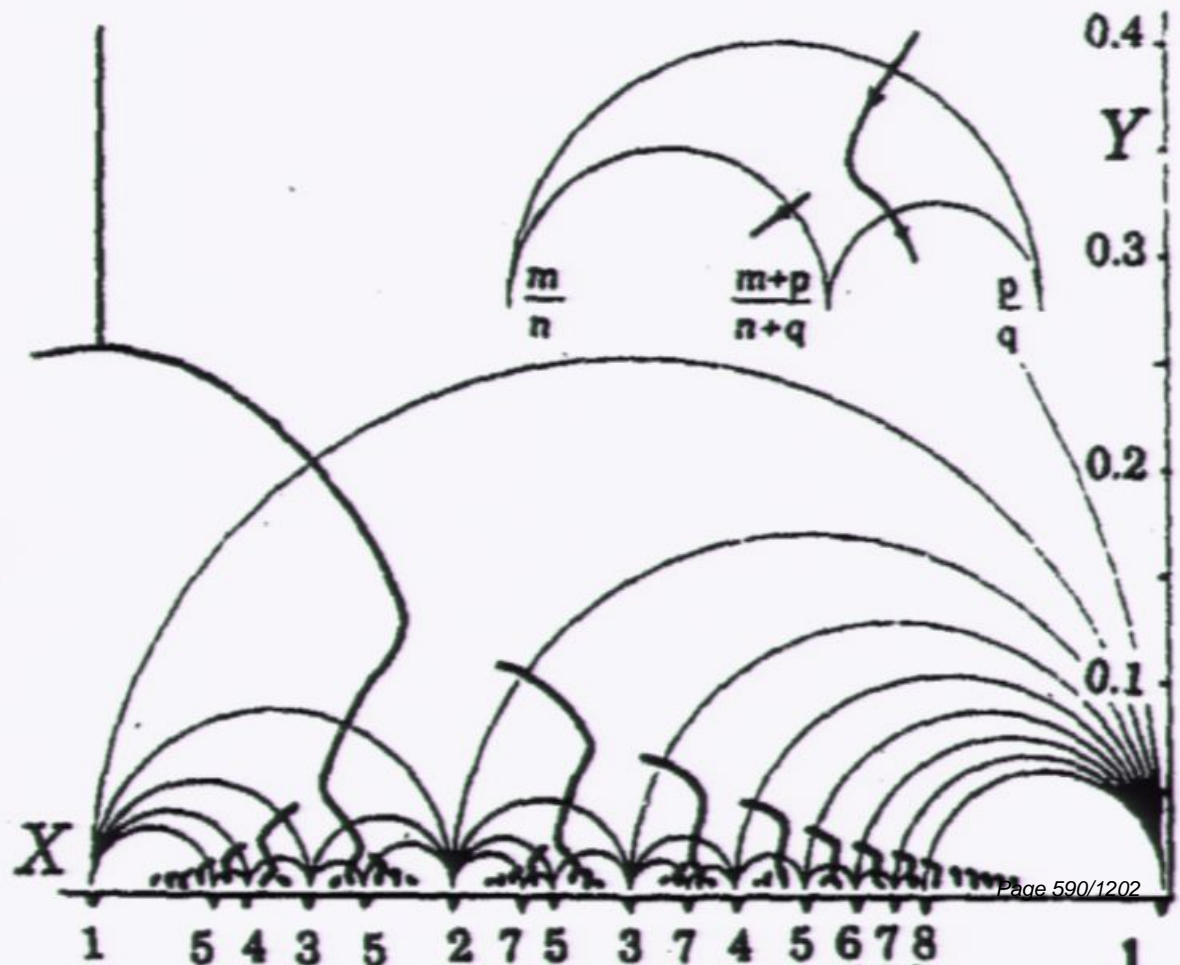




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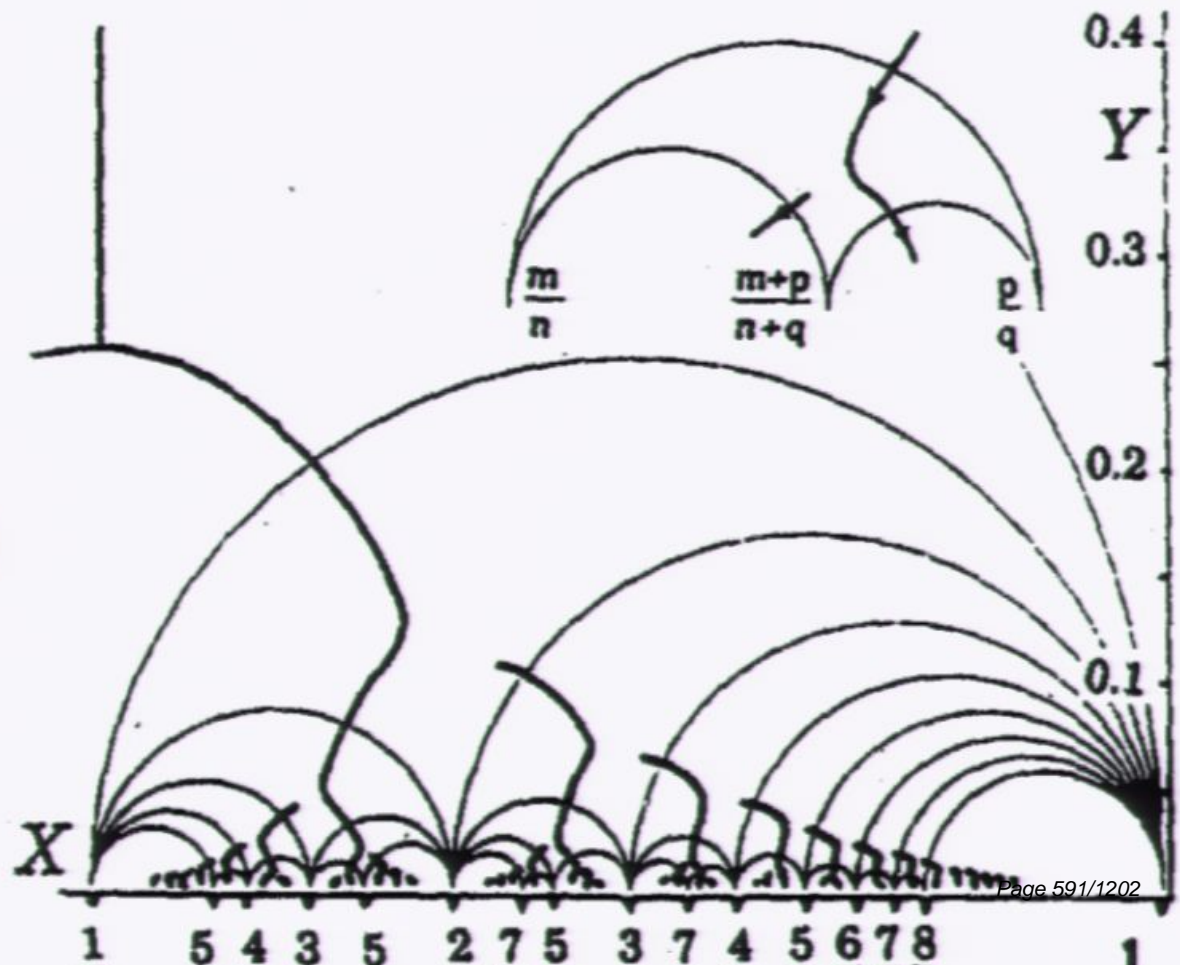
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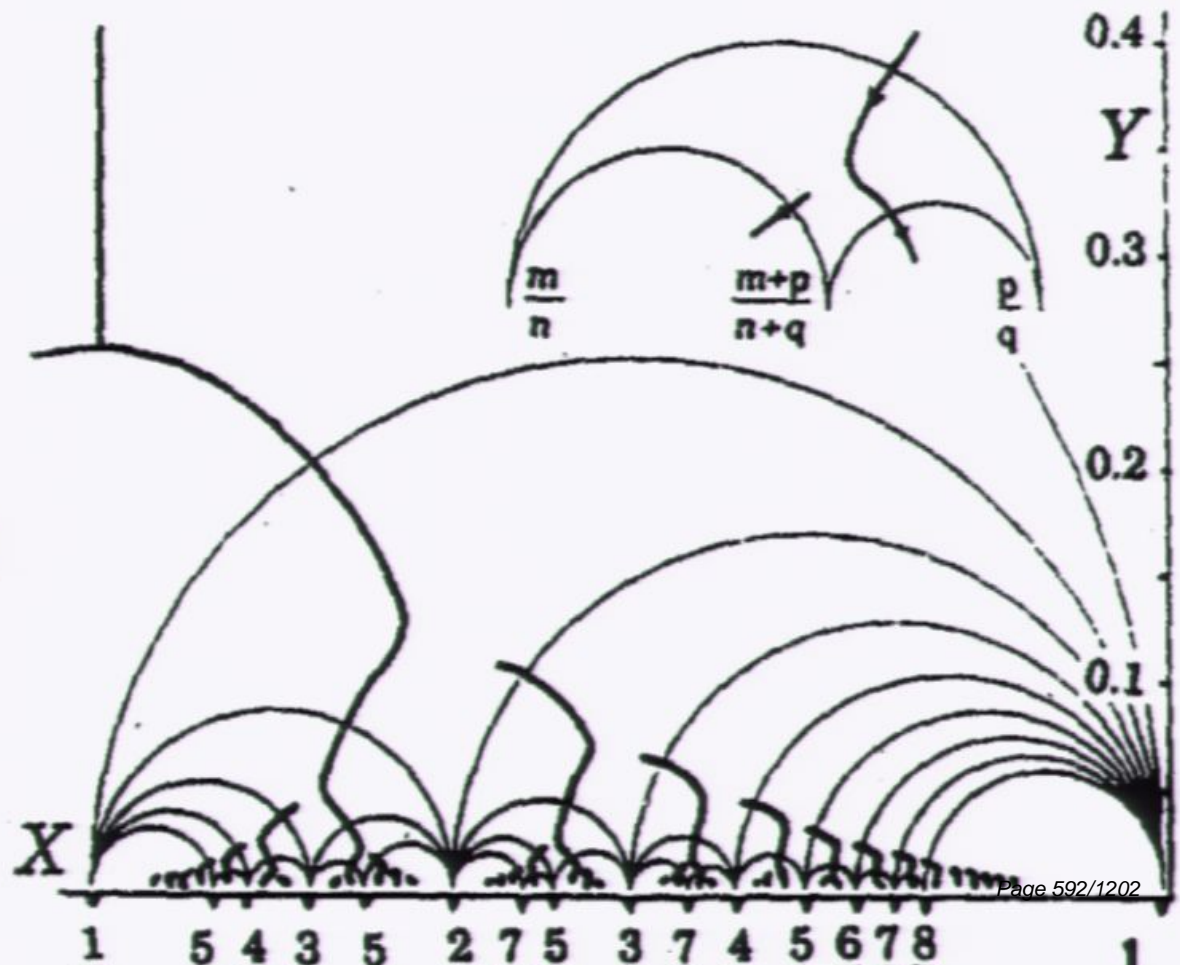
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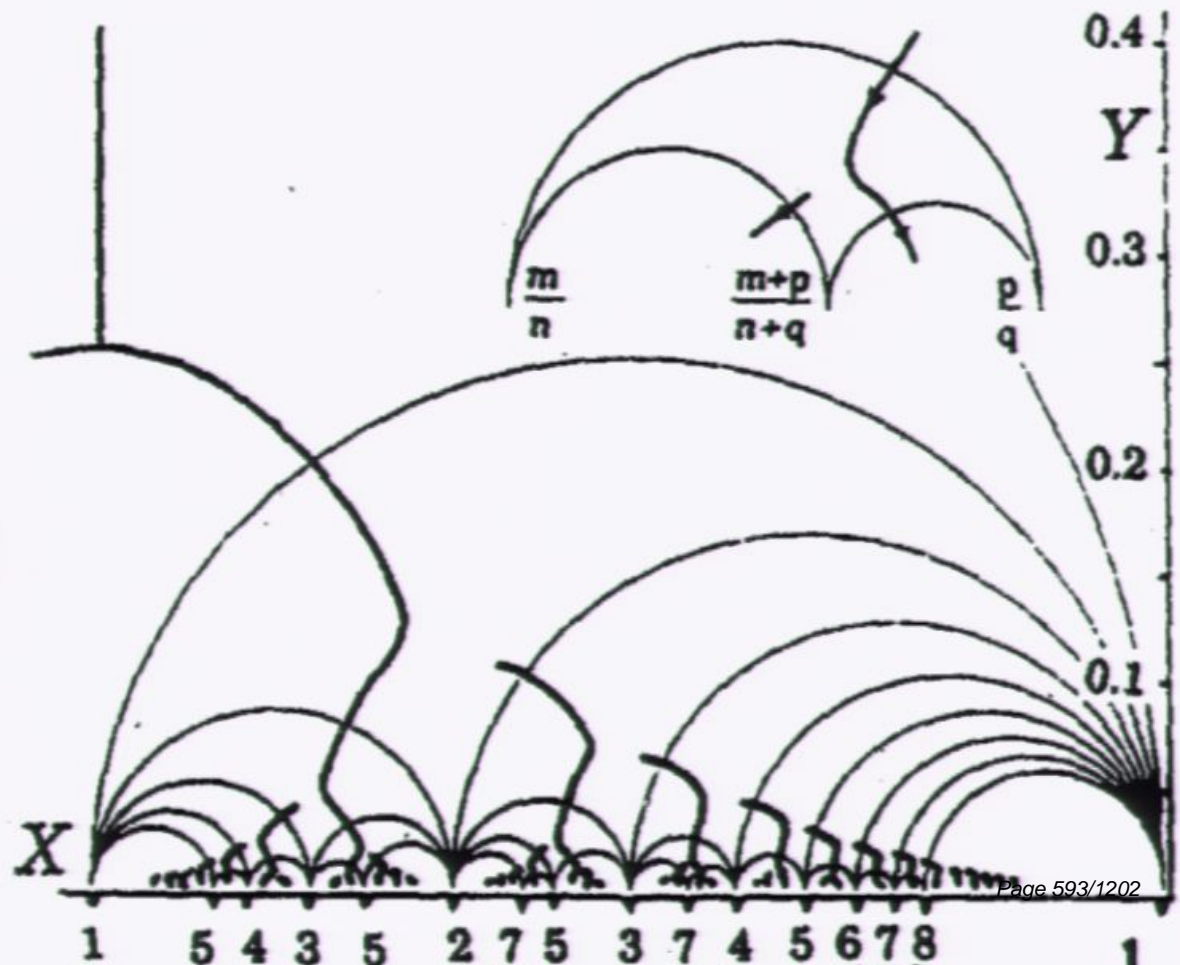




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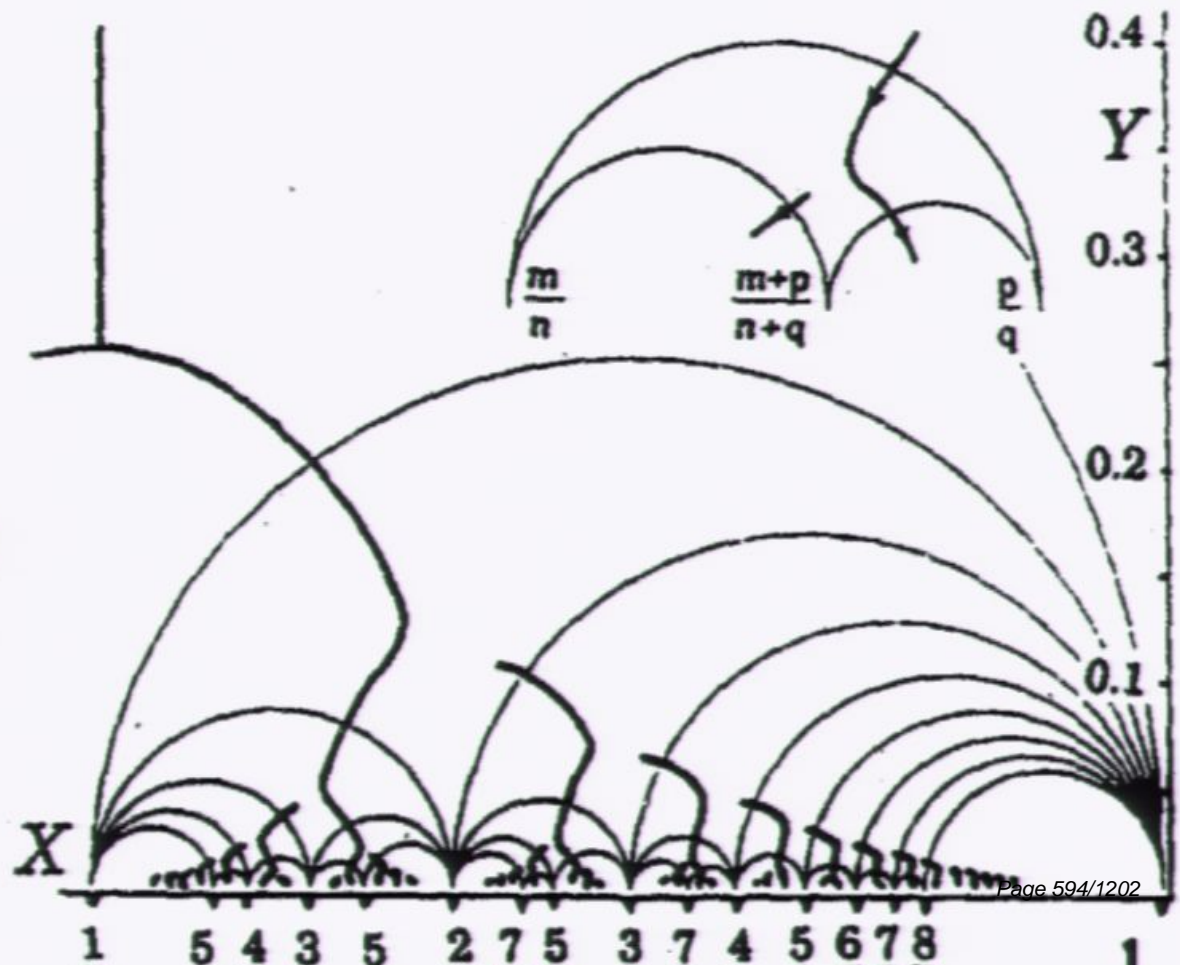




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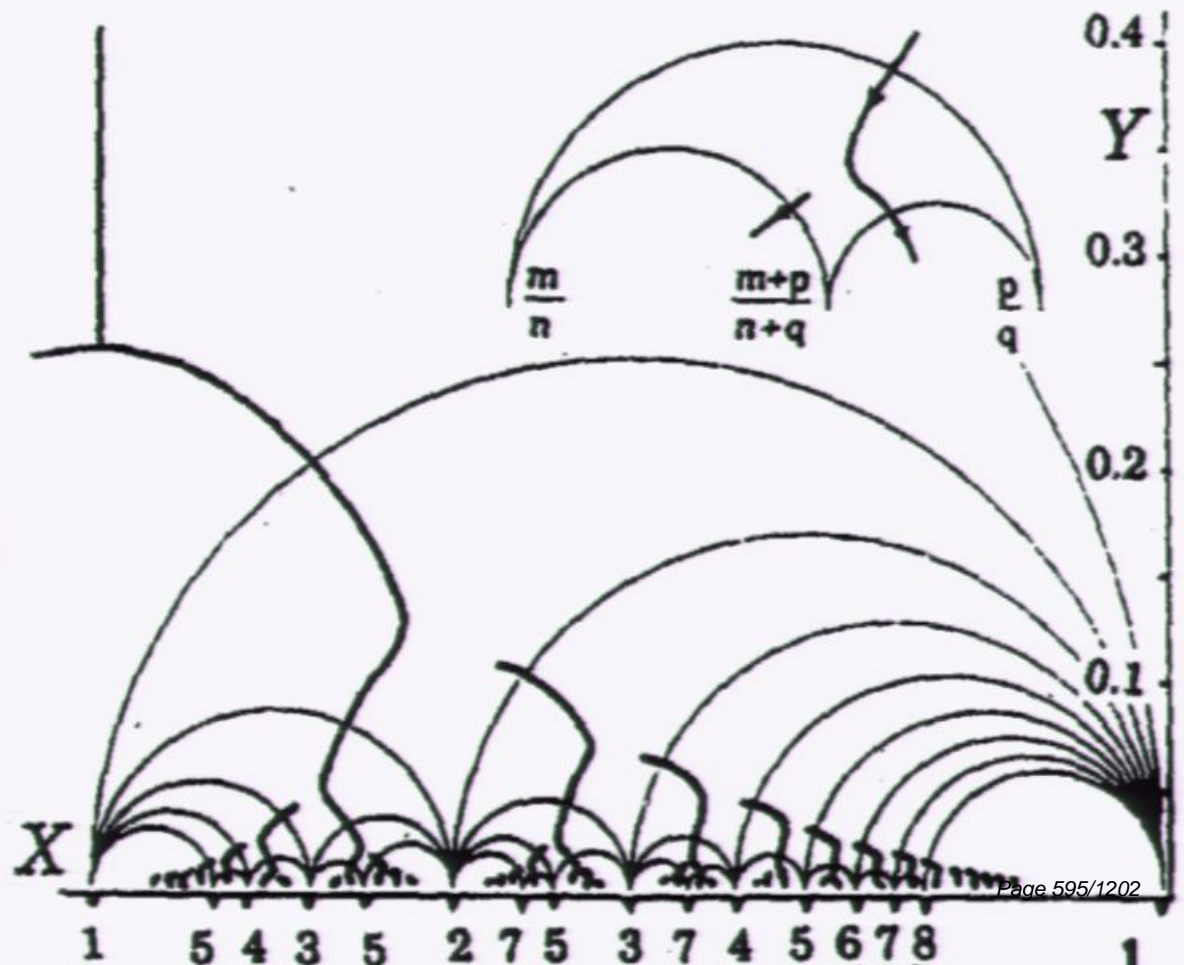
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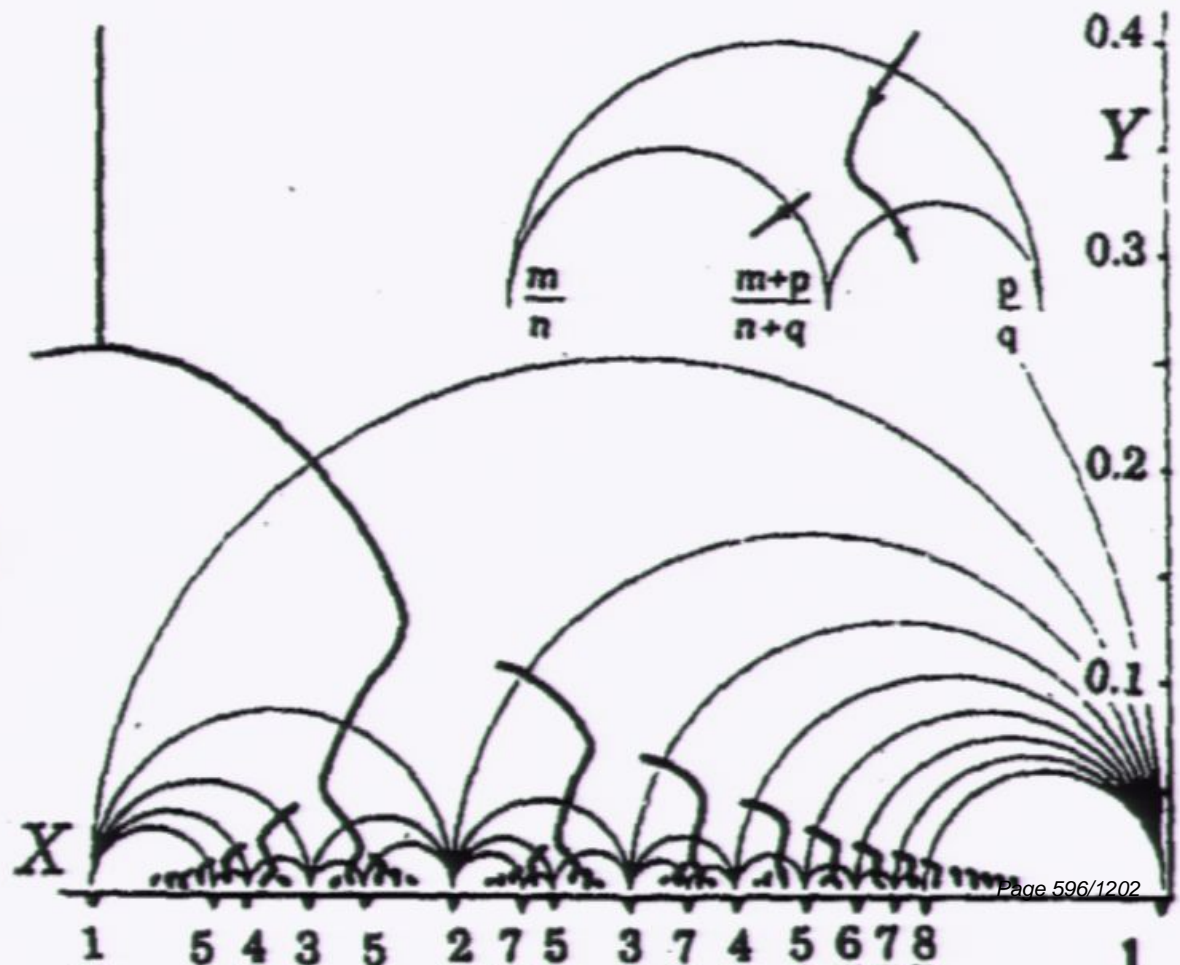
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Quasi bifurcations lead  
to single visible path

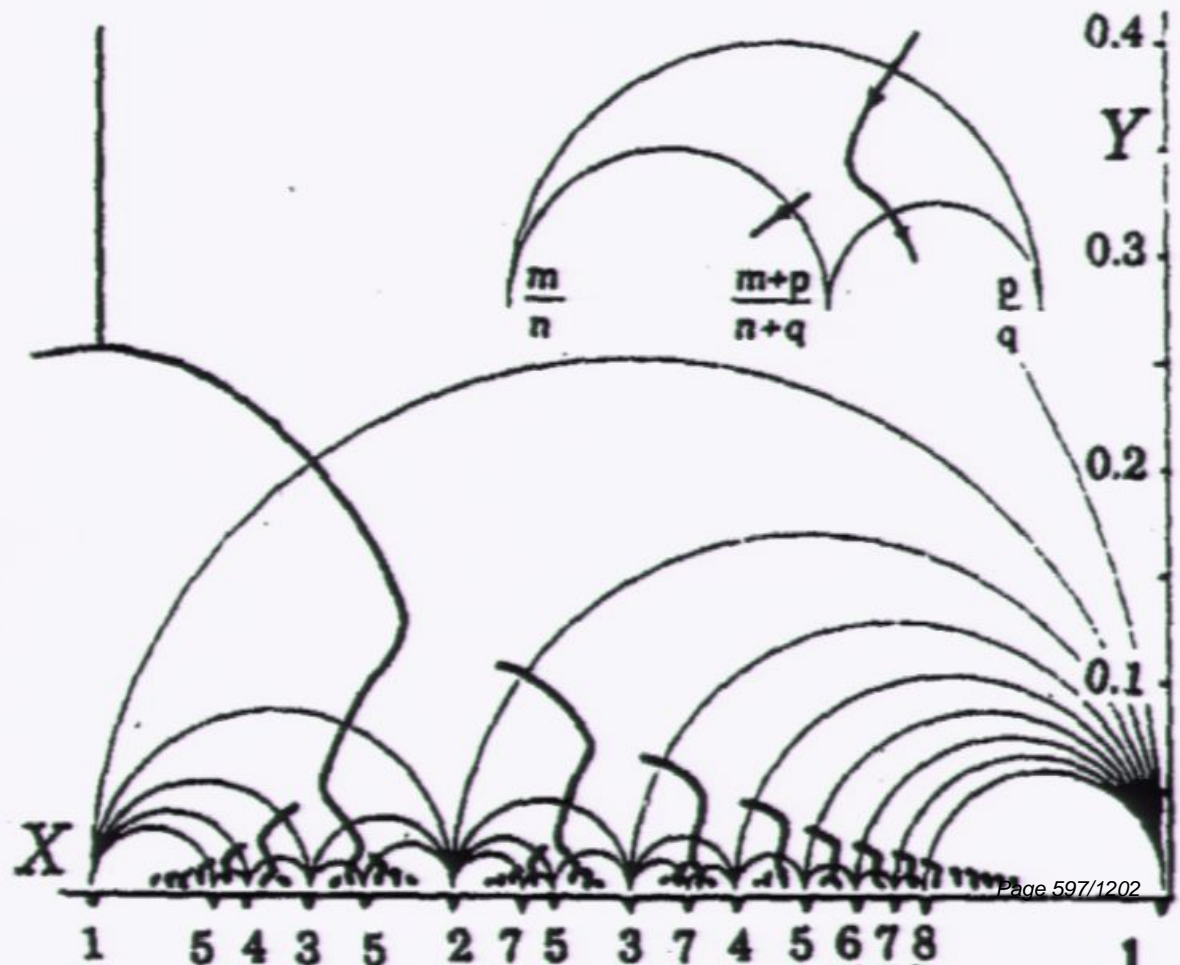




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path

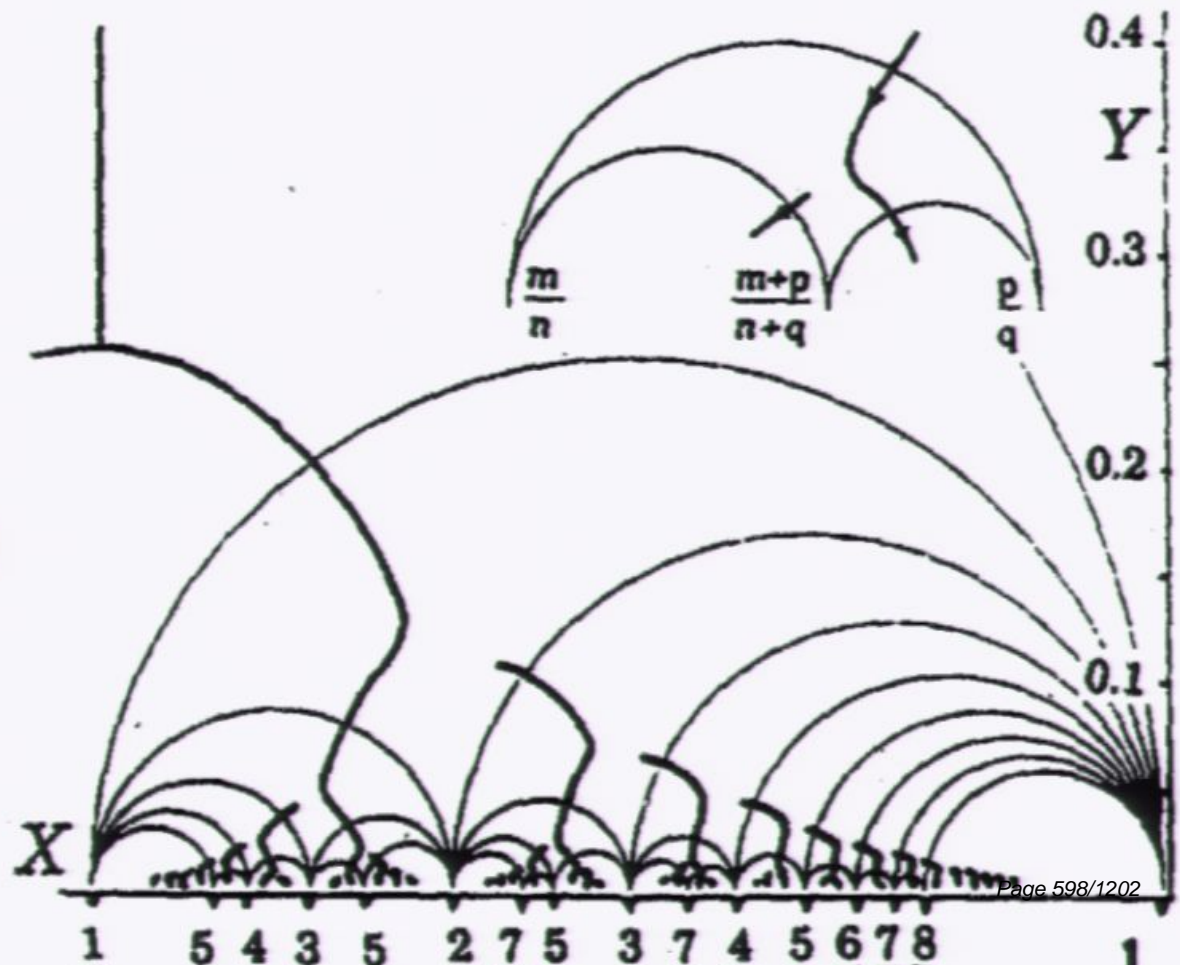




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

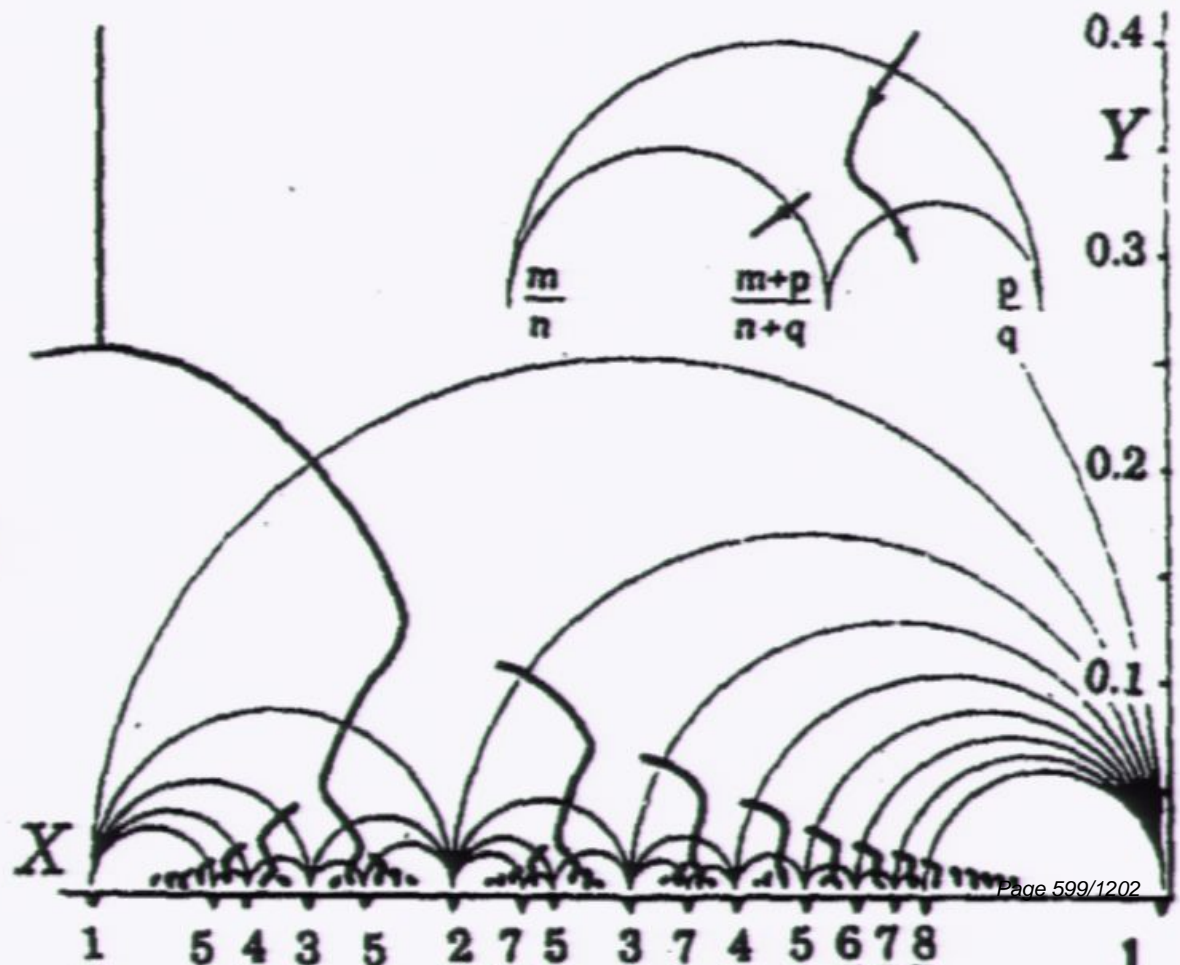
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

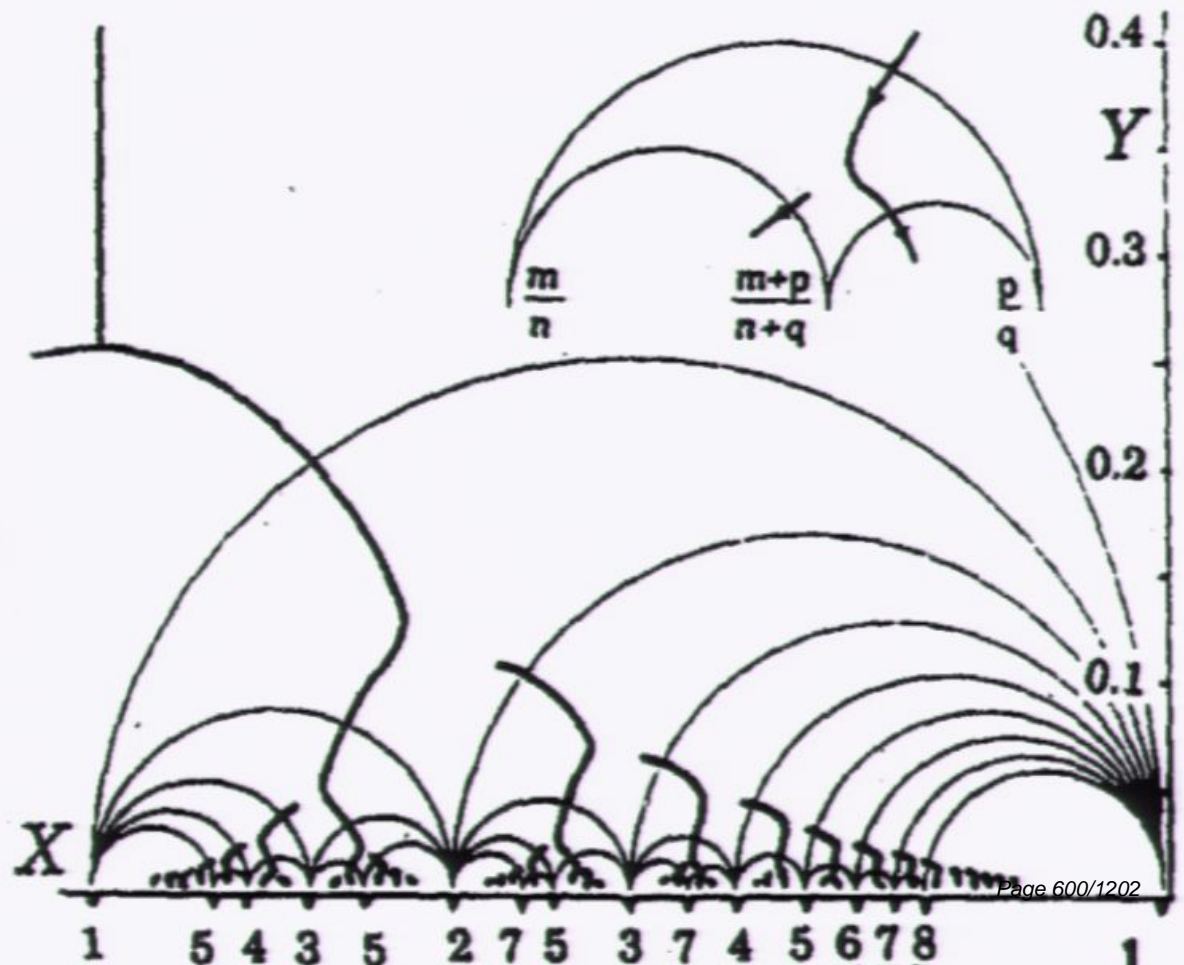
Quasi bifurcations lead  
to single visible path



# Energy minima

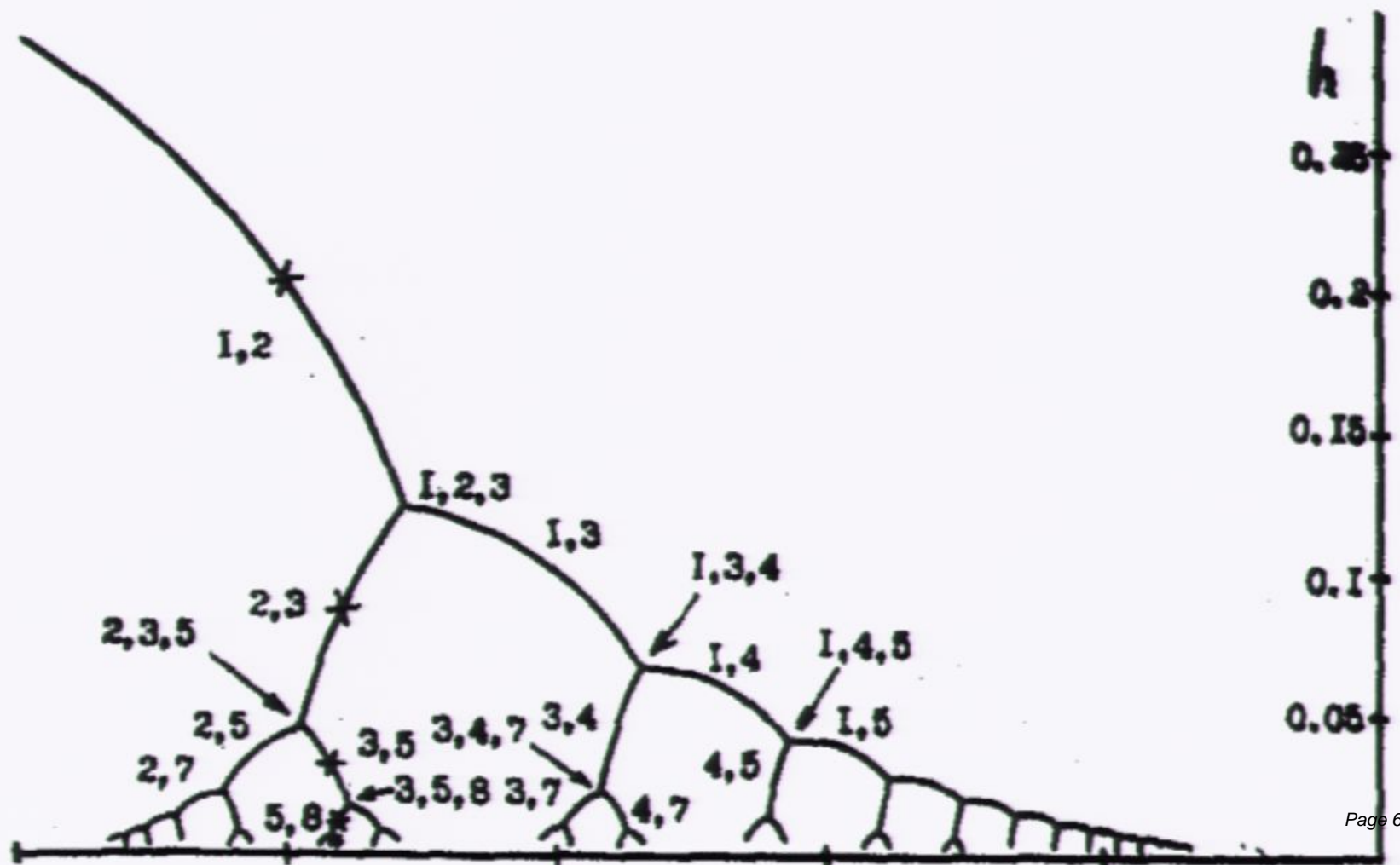
Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path



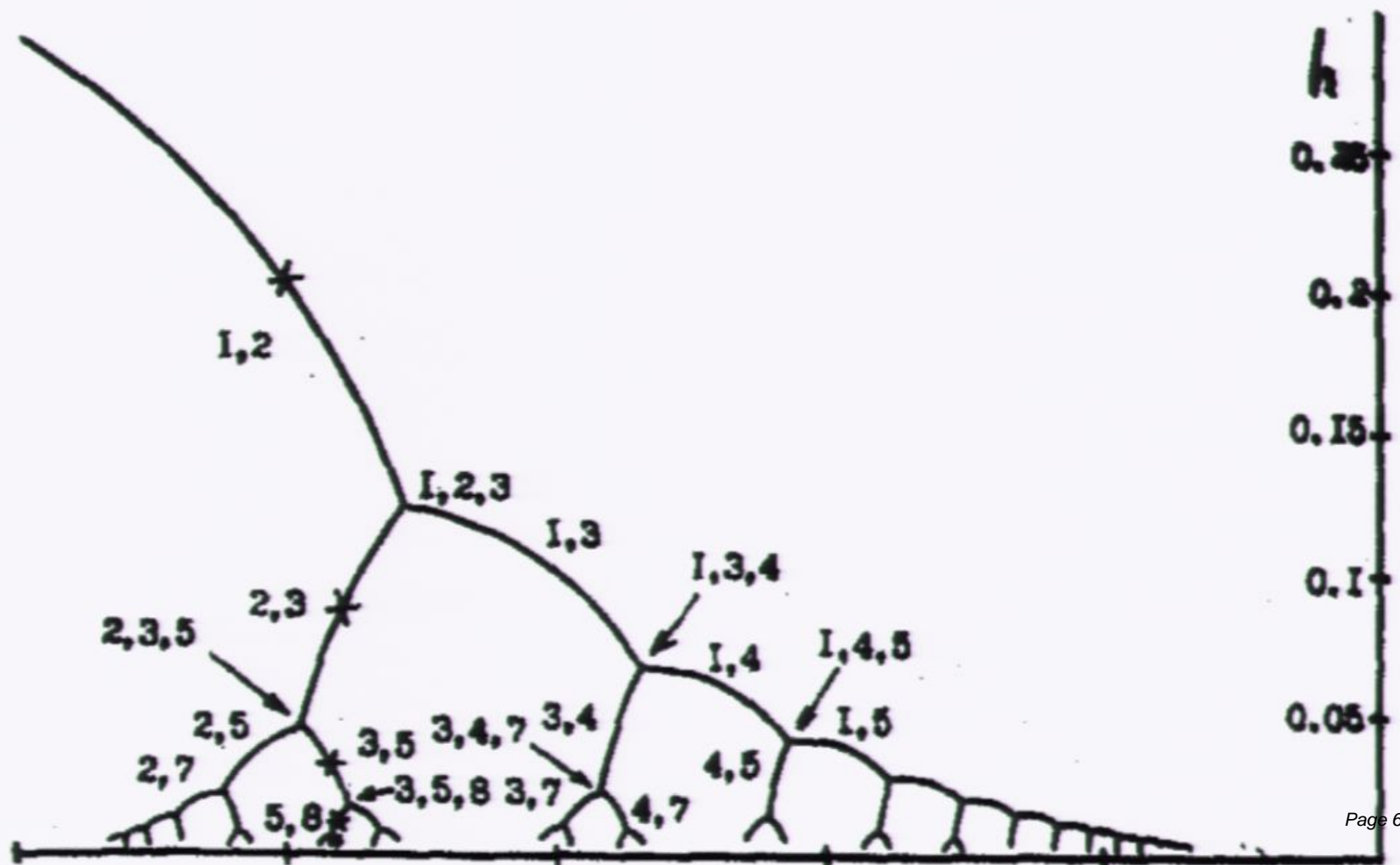


# Cayley tree for lattices

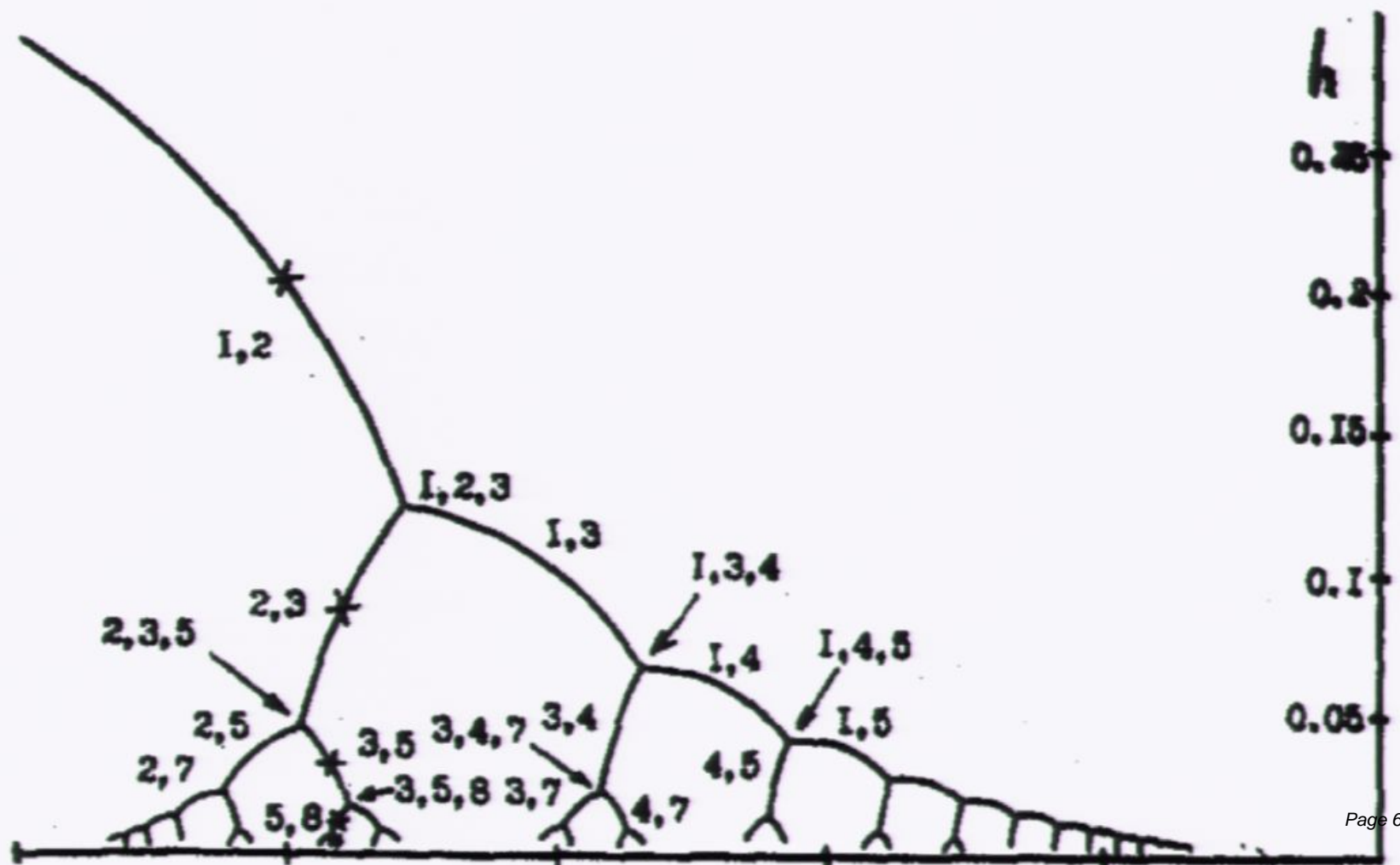




# Cayley tree for lattices



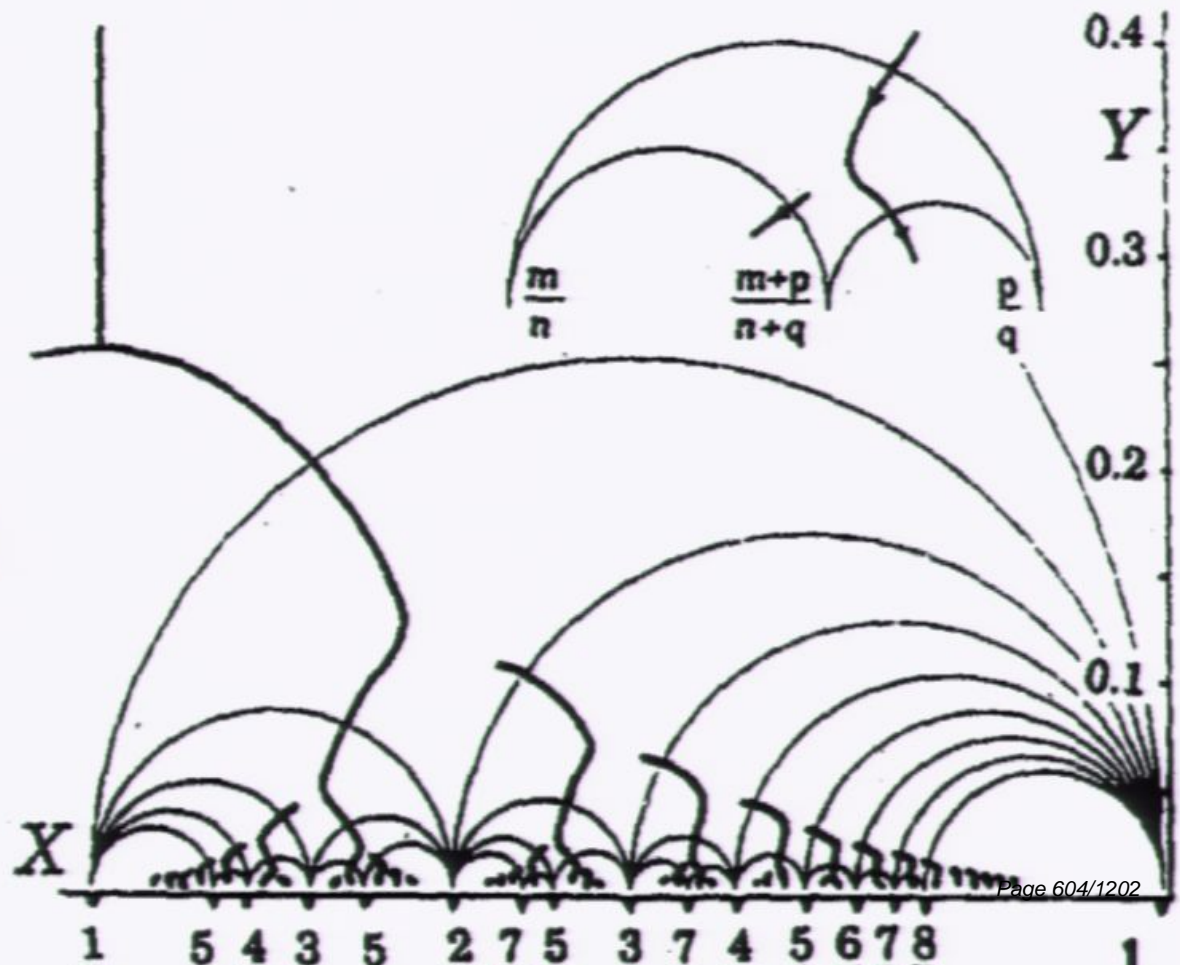
# Cayley tree for lattices



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

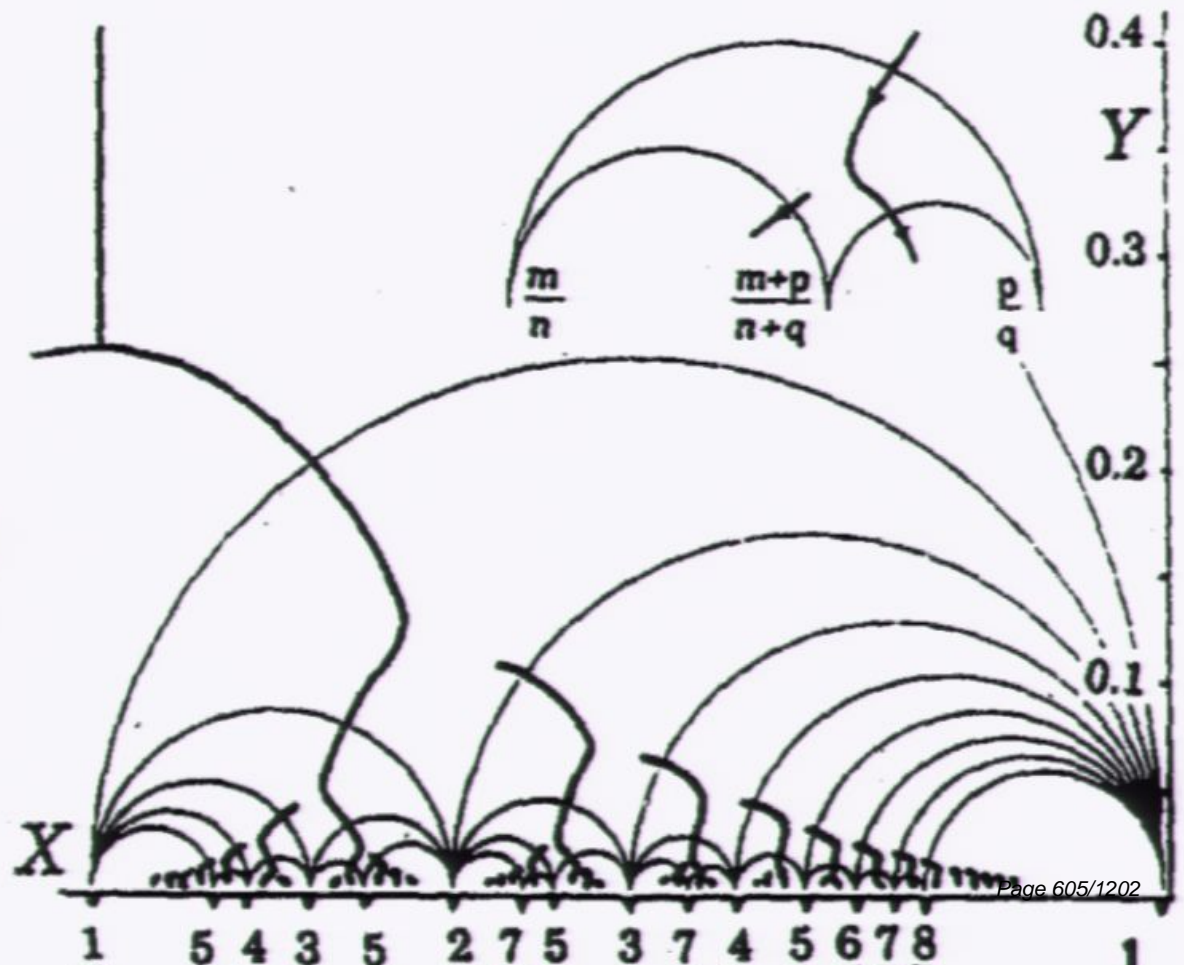
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path

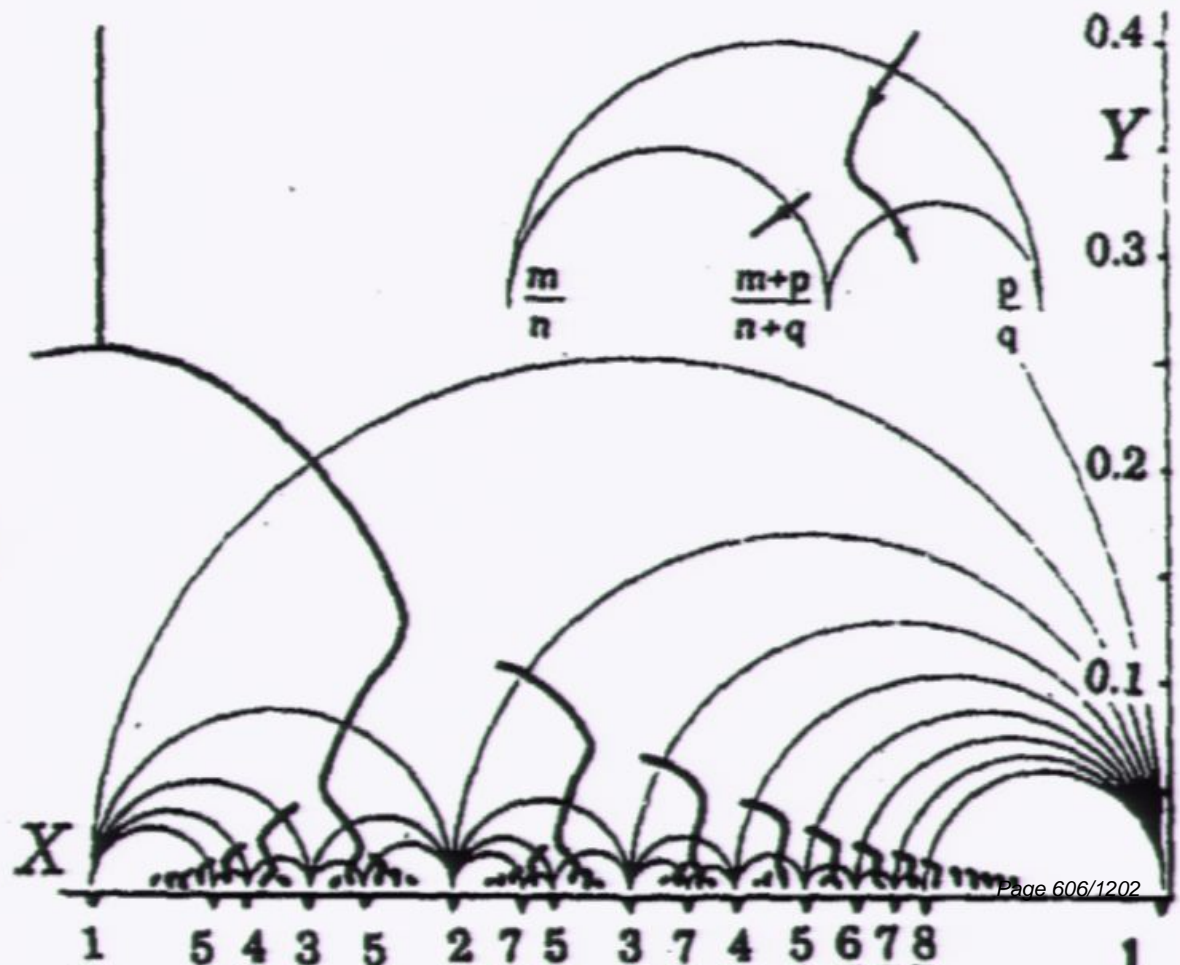




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

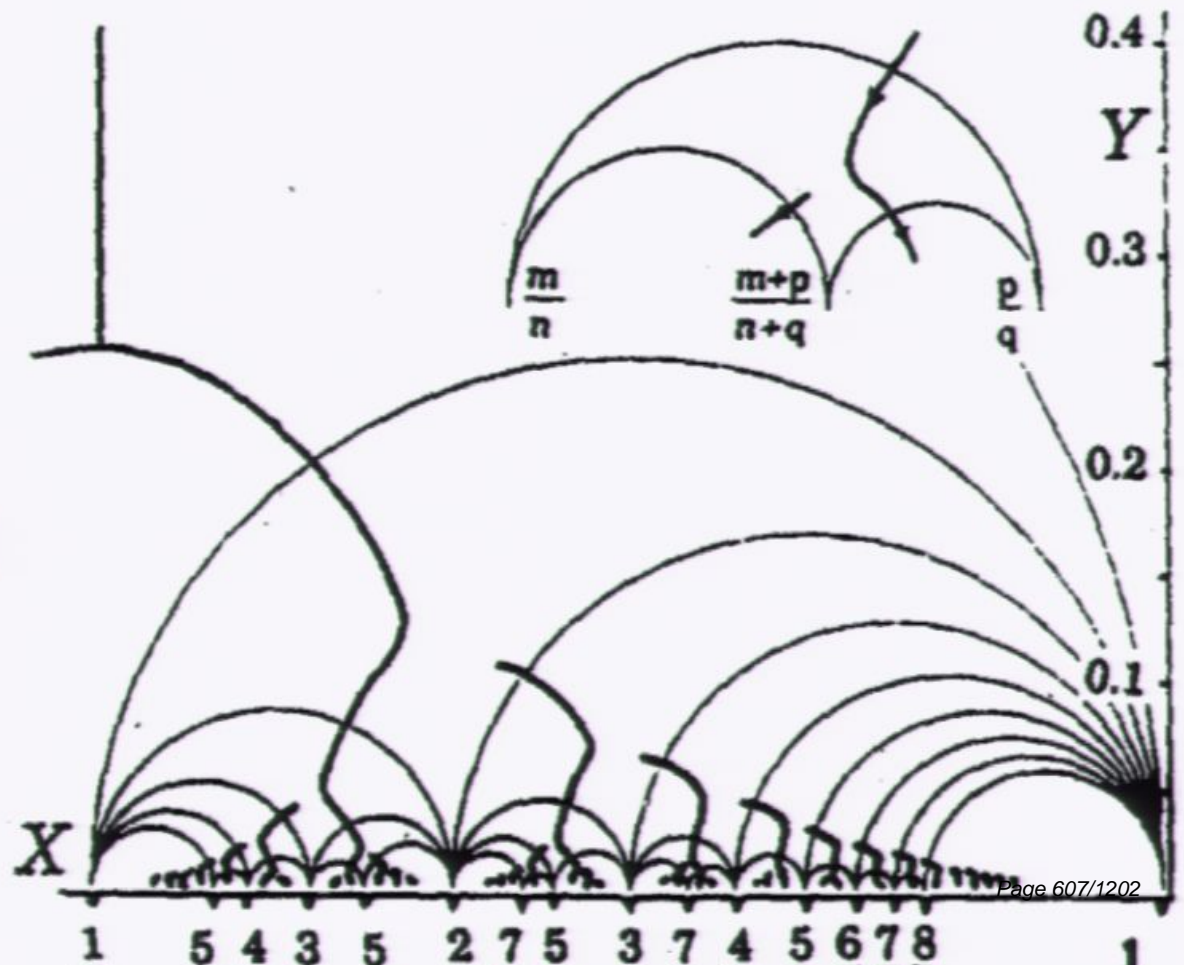
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

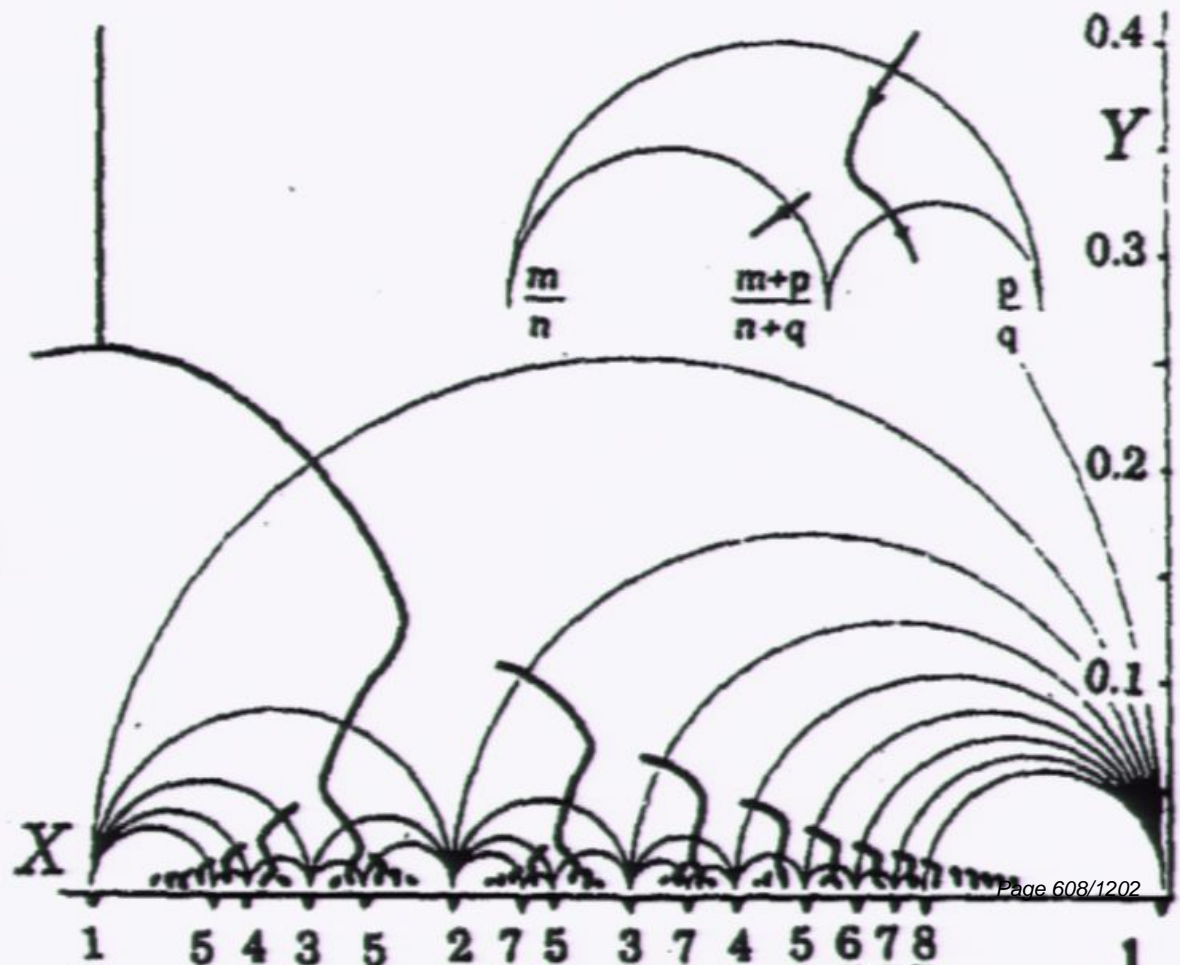
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path

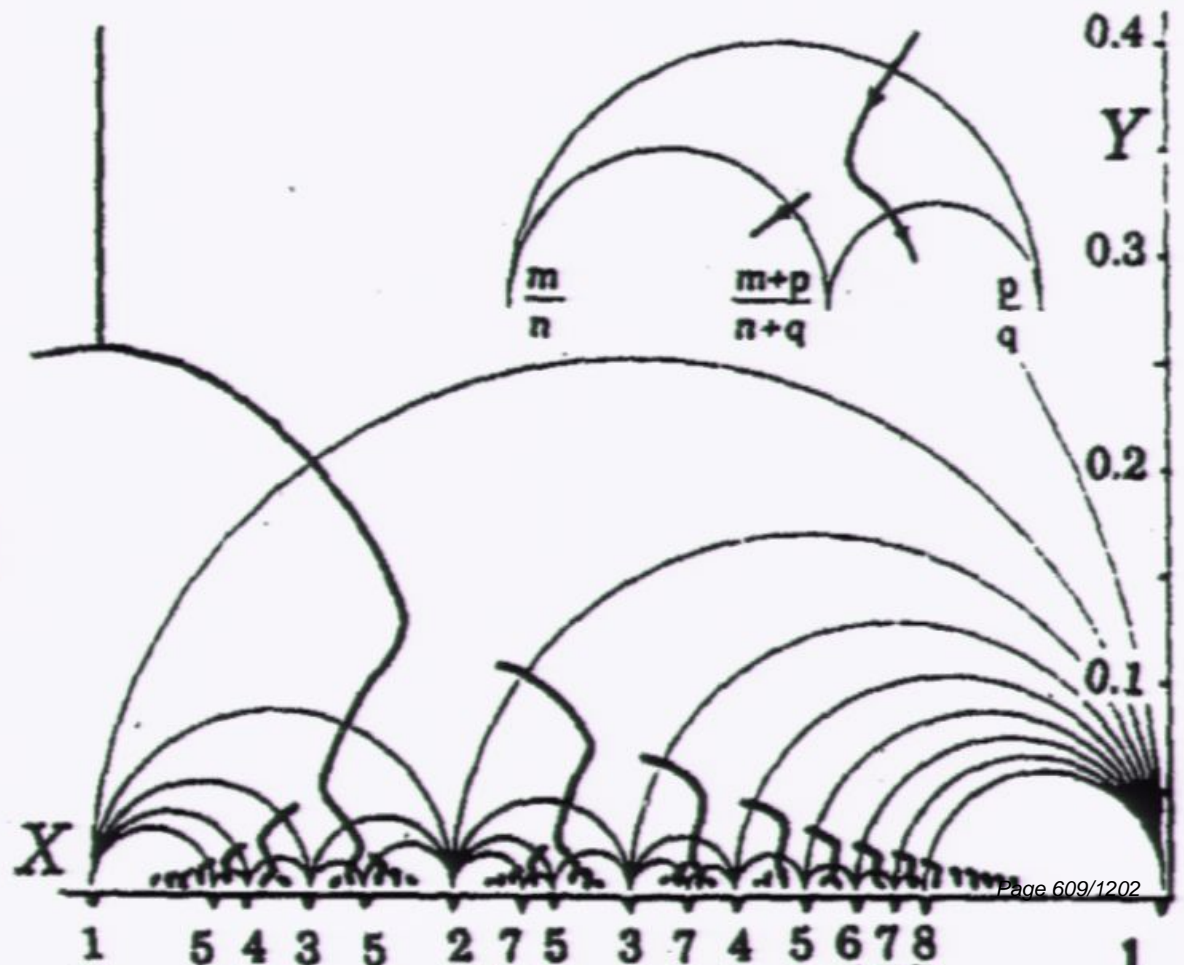




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path





# Equivalence of graphs

Both graphs are equivalent to Farey graph

Farey construction:  $m/n \oplus p/q = (m+p)/(n+q)$

$$0/1 \oplus 1/1 = 1/2$$

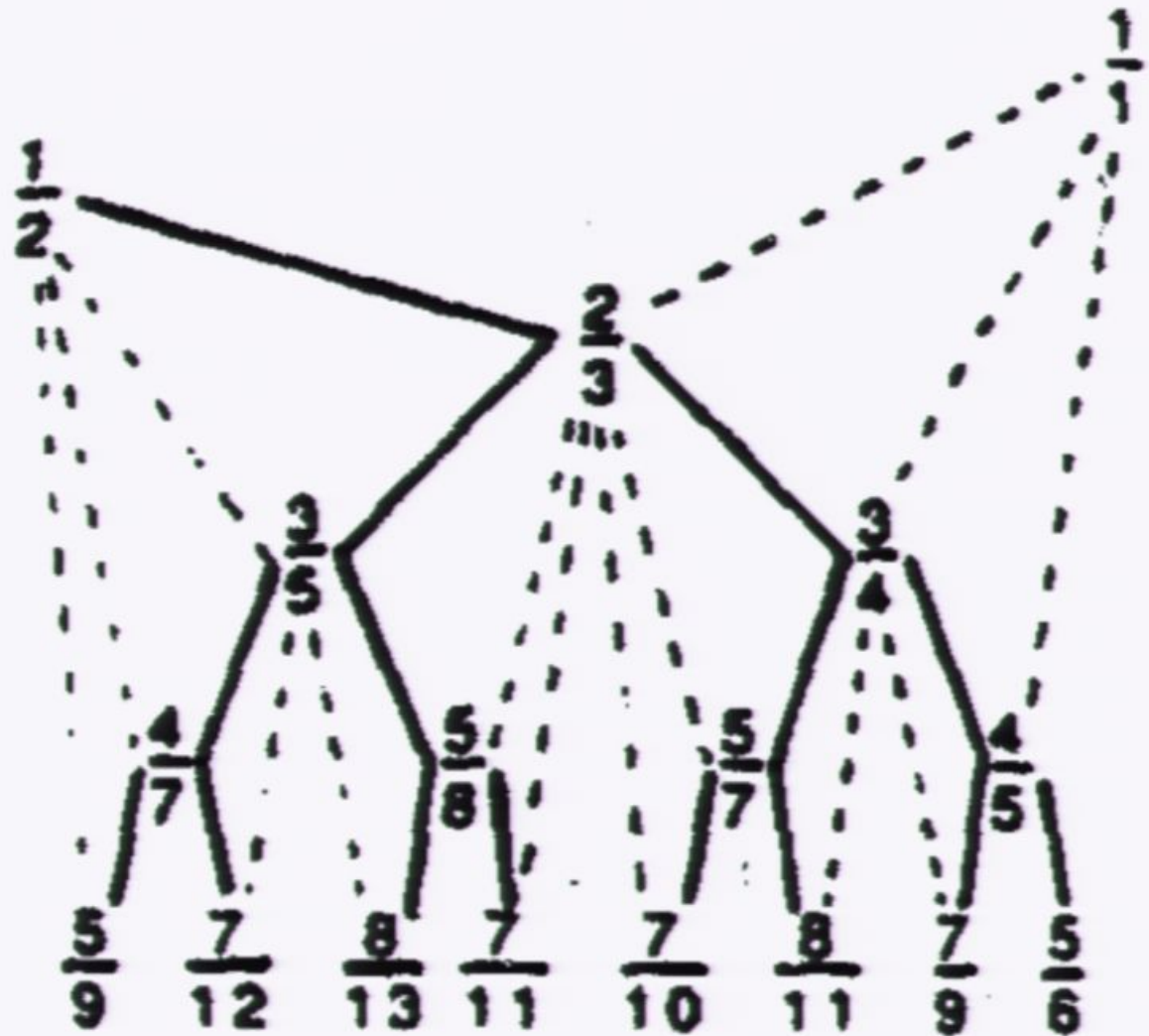
$$0/1, 1/2, 1/1$$

$$0/1, 1/3, 1/2, 2/3, 1/1$$

Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

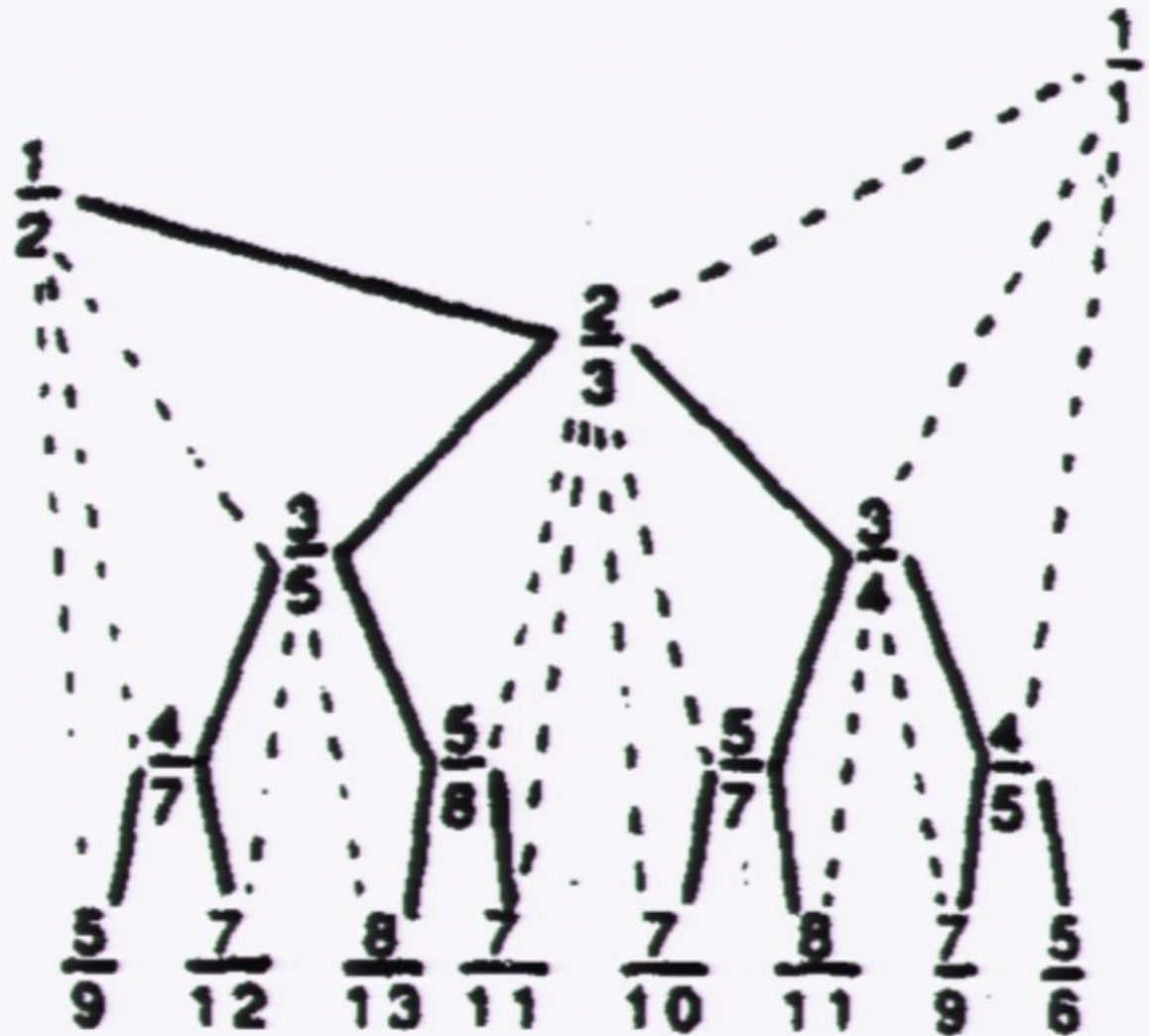
- Note that it is already  
topologically  
equivalent to first  
(would be, if not for the  
quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

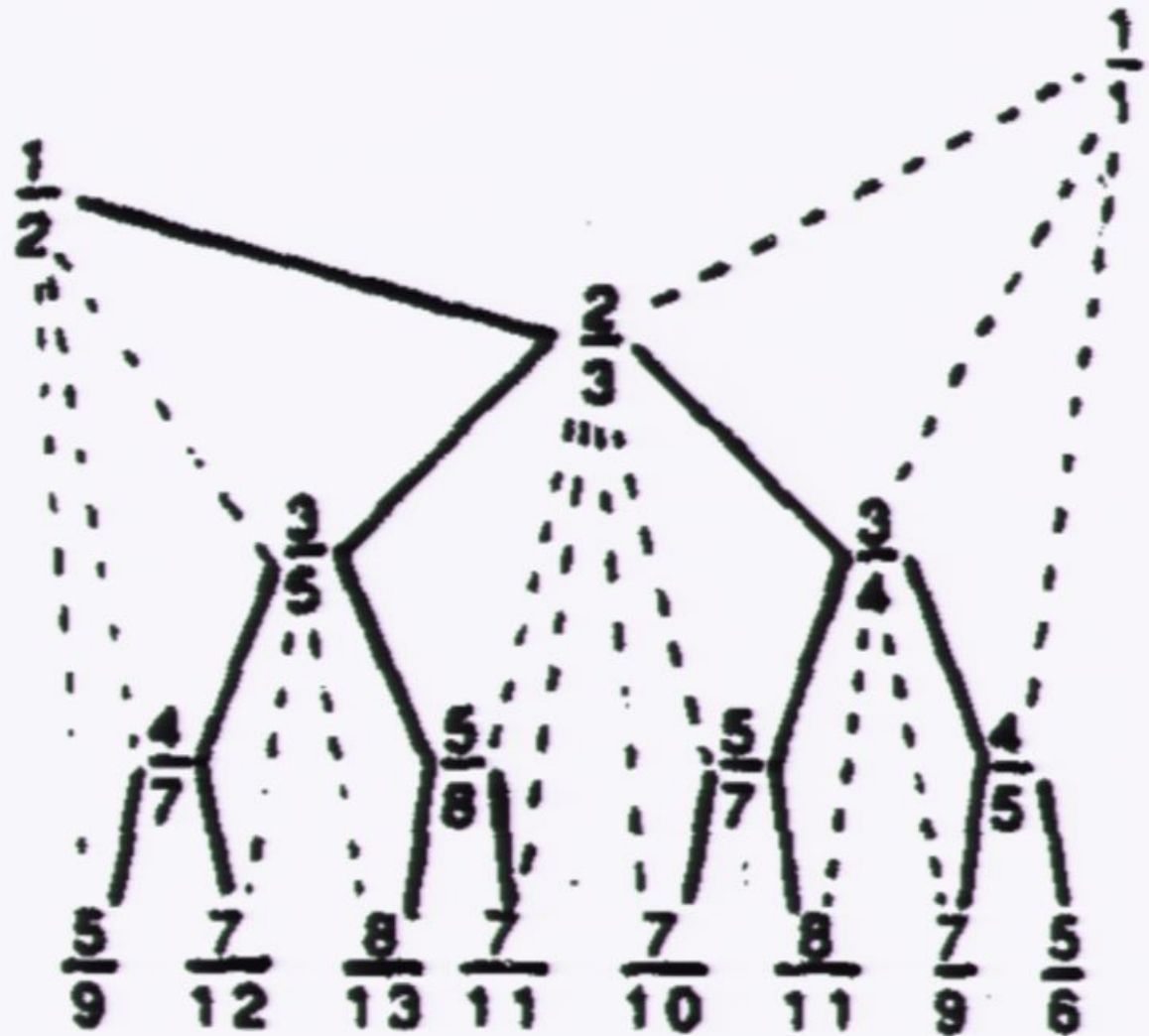




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

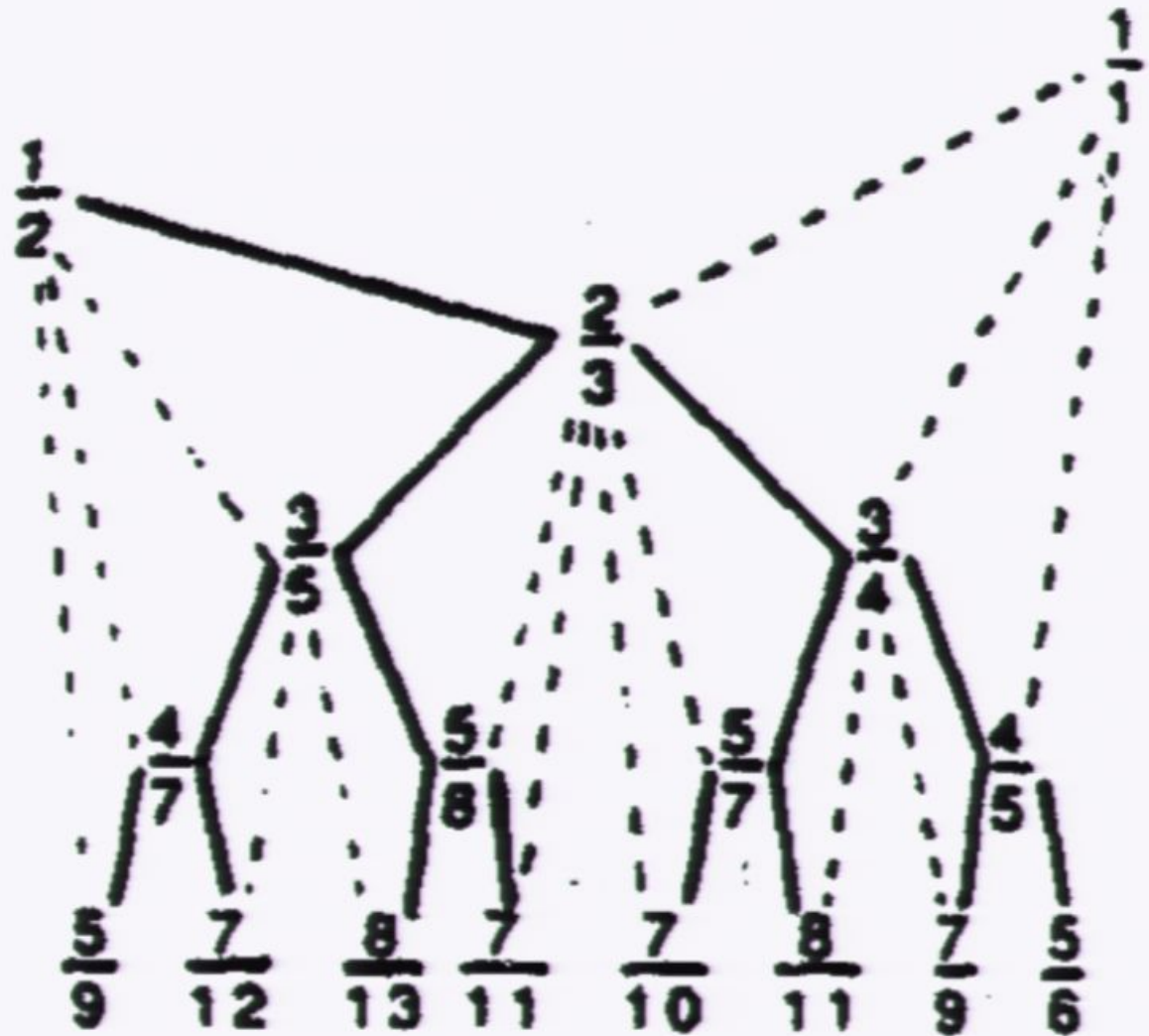




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

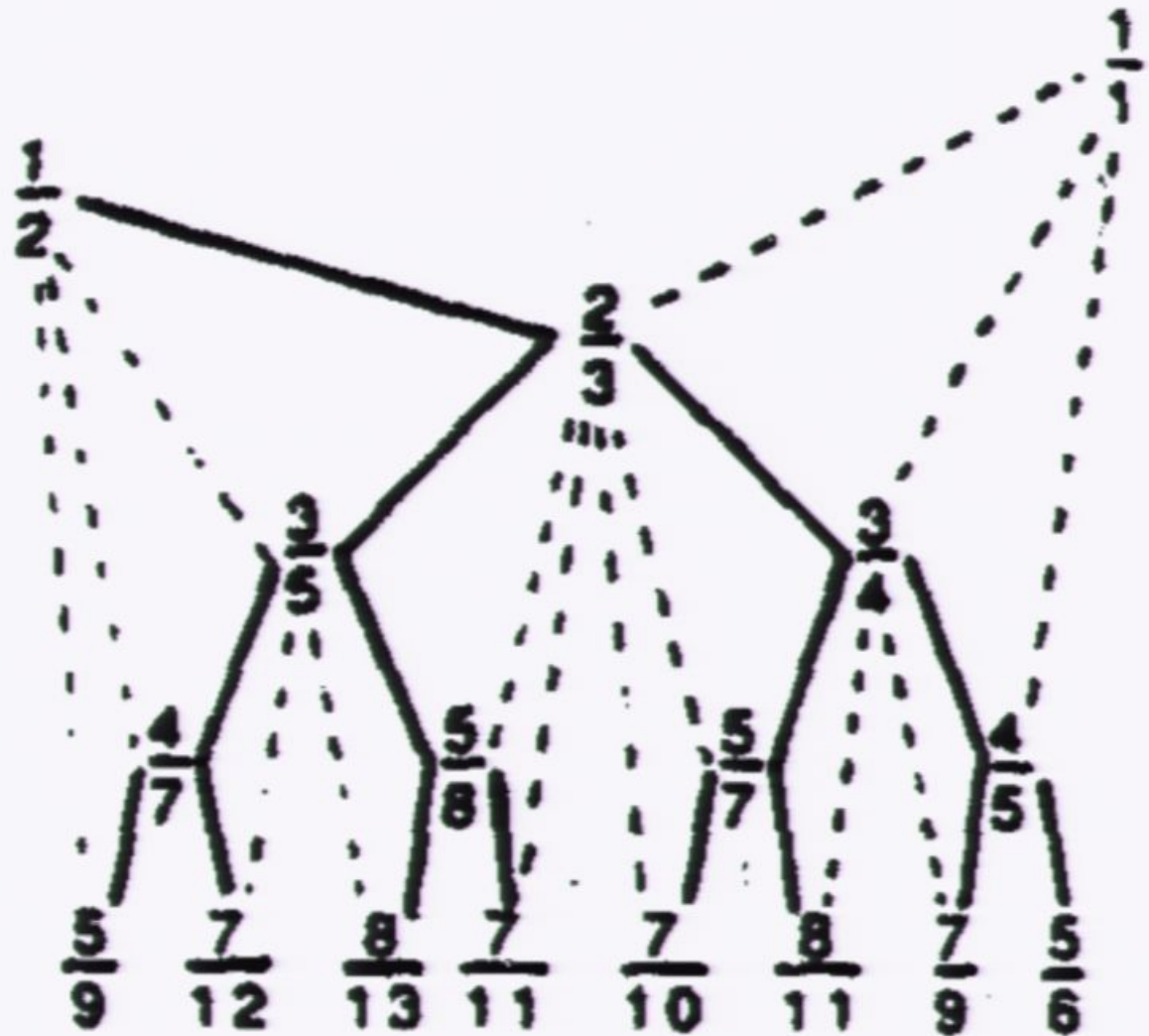
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

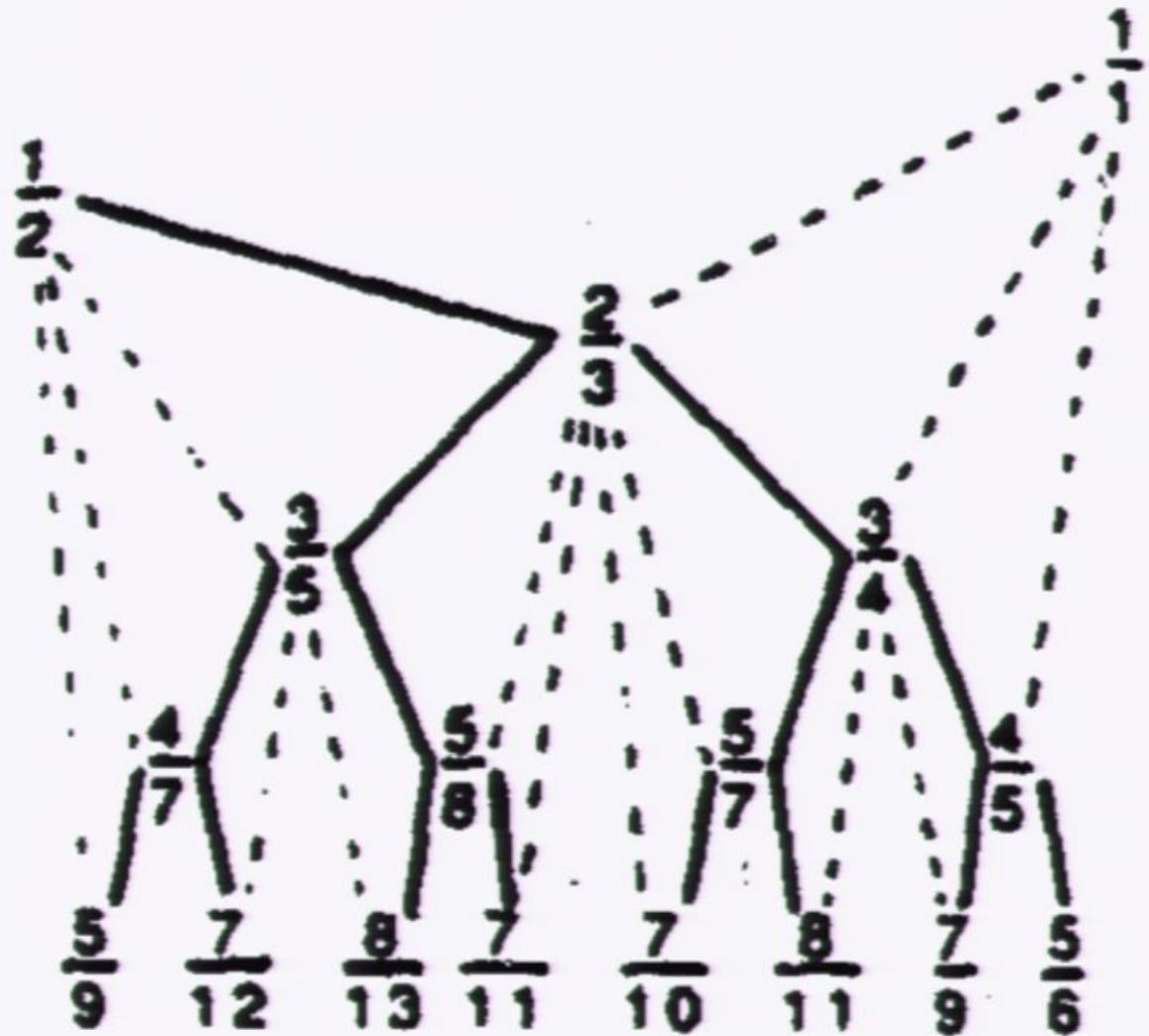
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

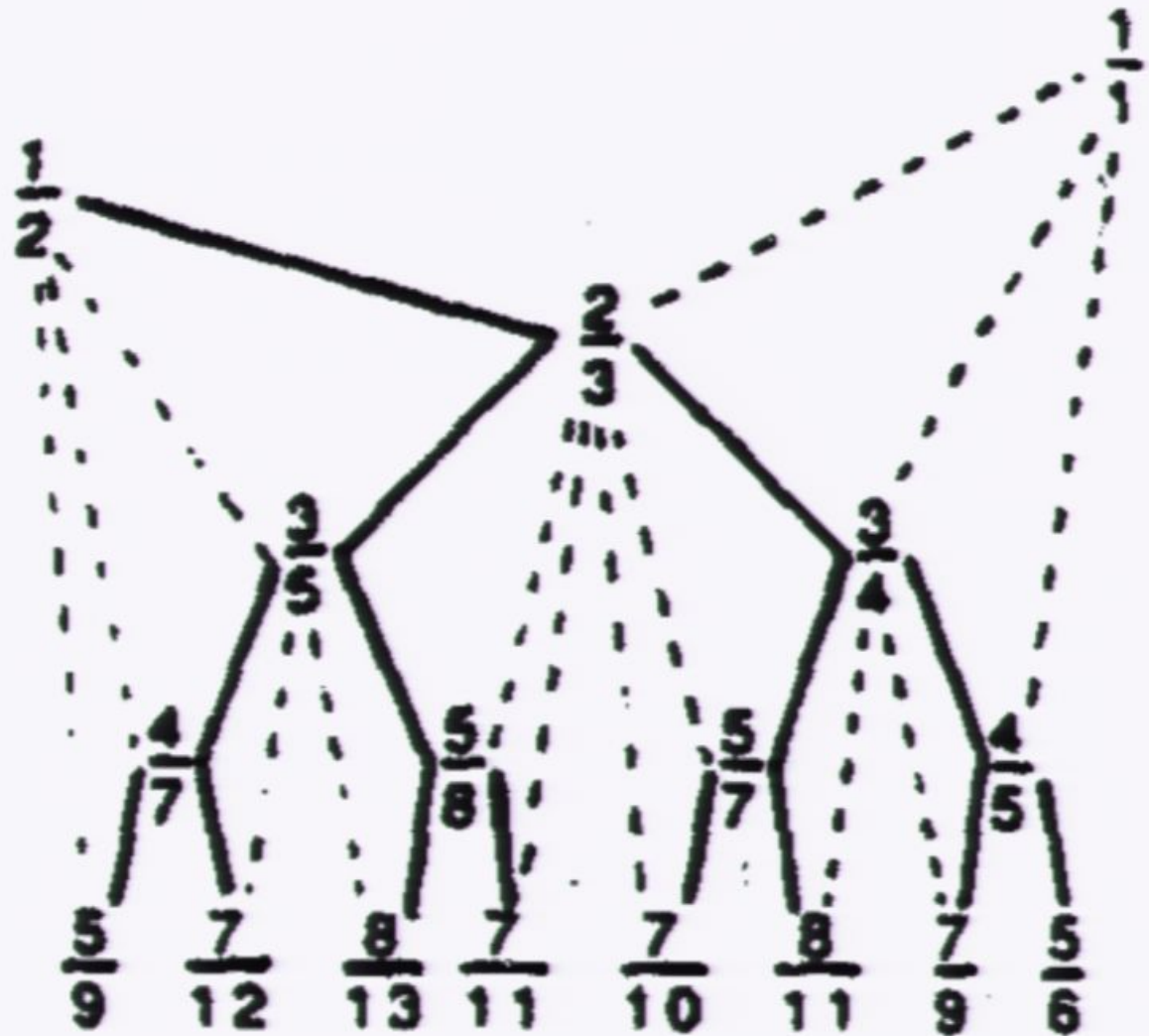




Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

- Note that it is already  
topologically  
equivalent to first  
(would be, if not for the  
quasi bifurcations)

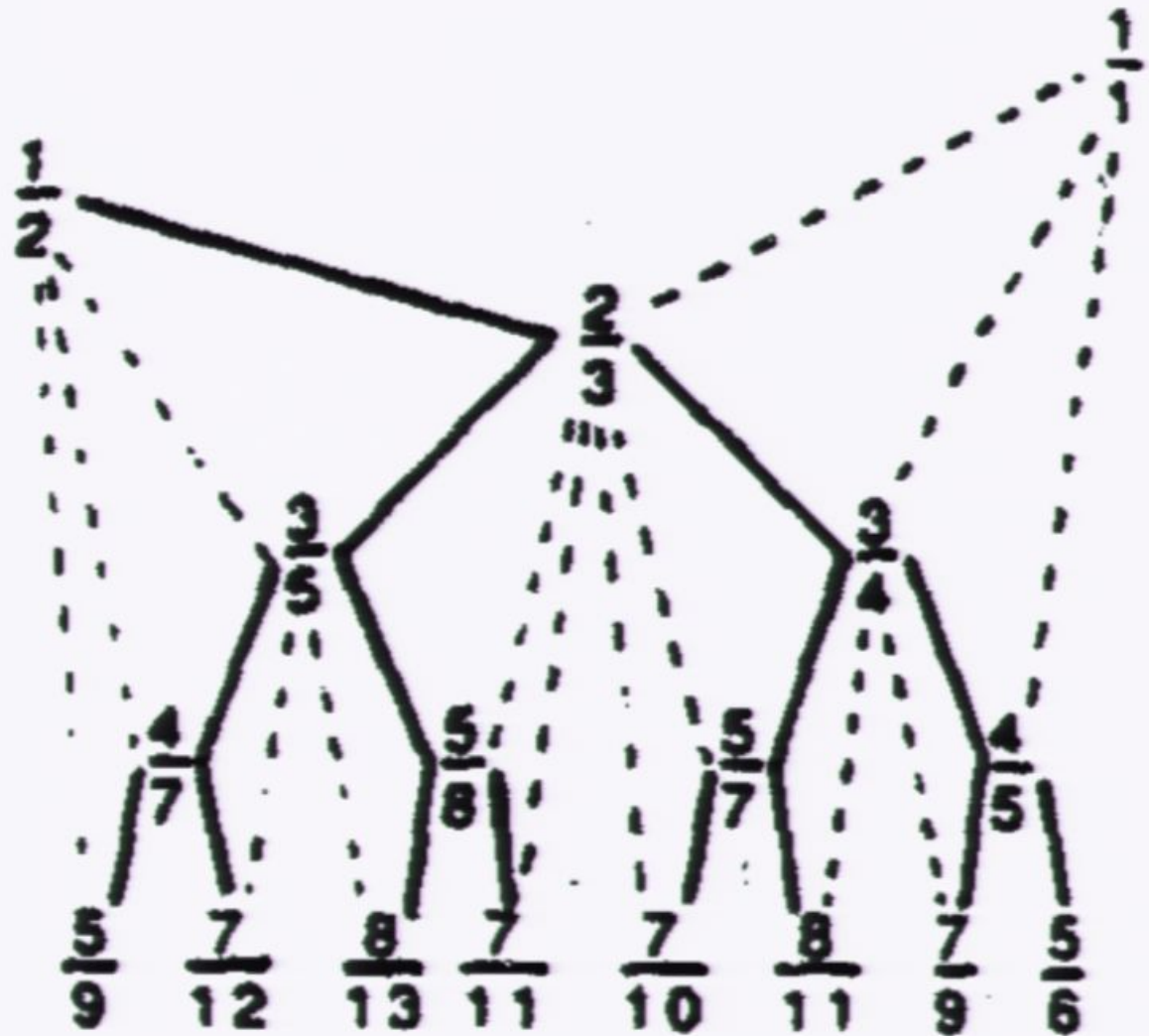




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

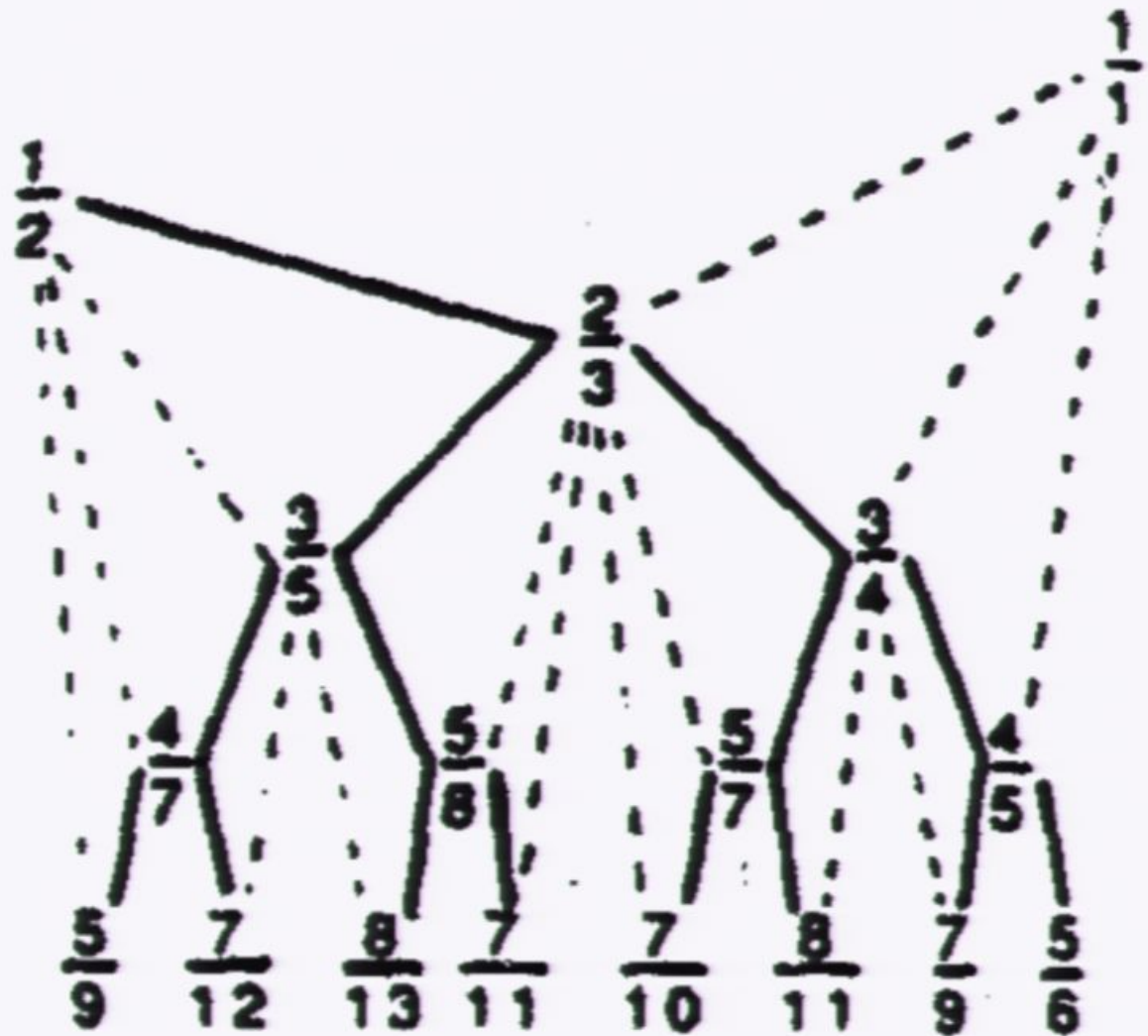
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

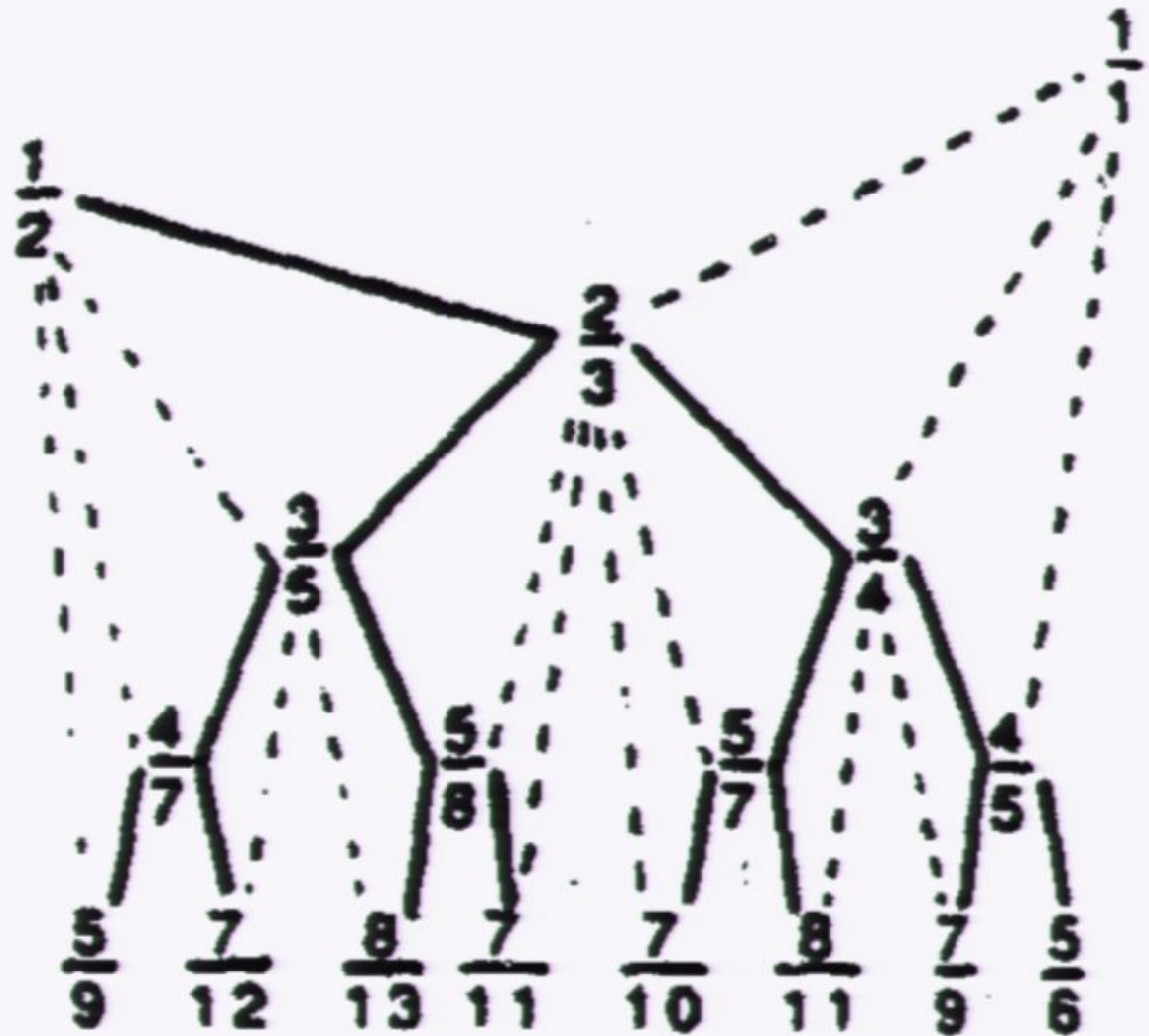
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

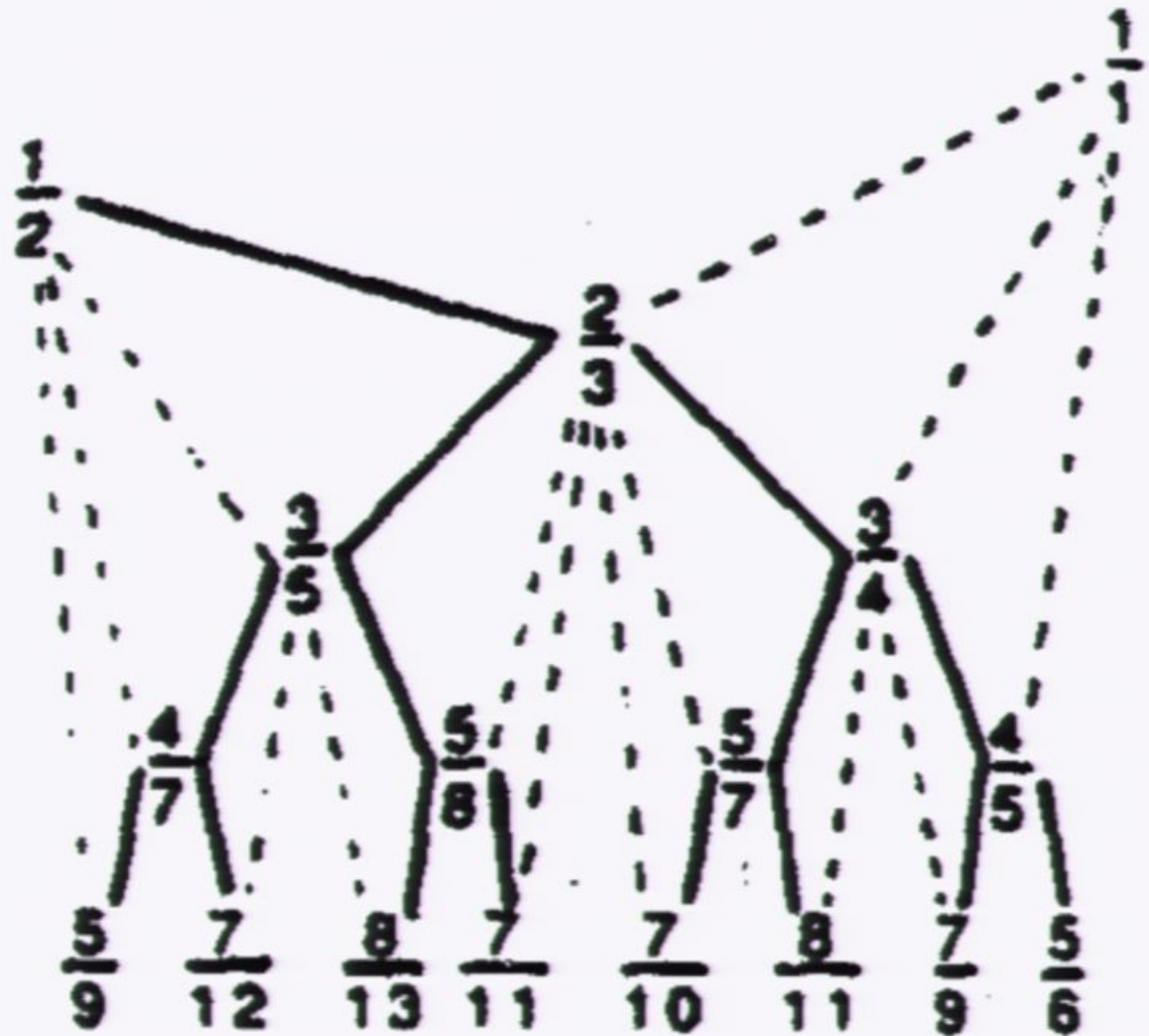




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

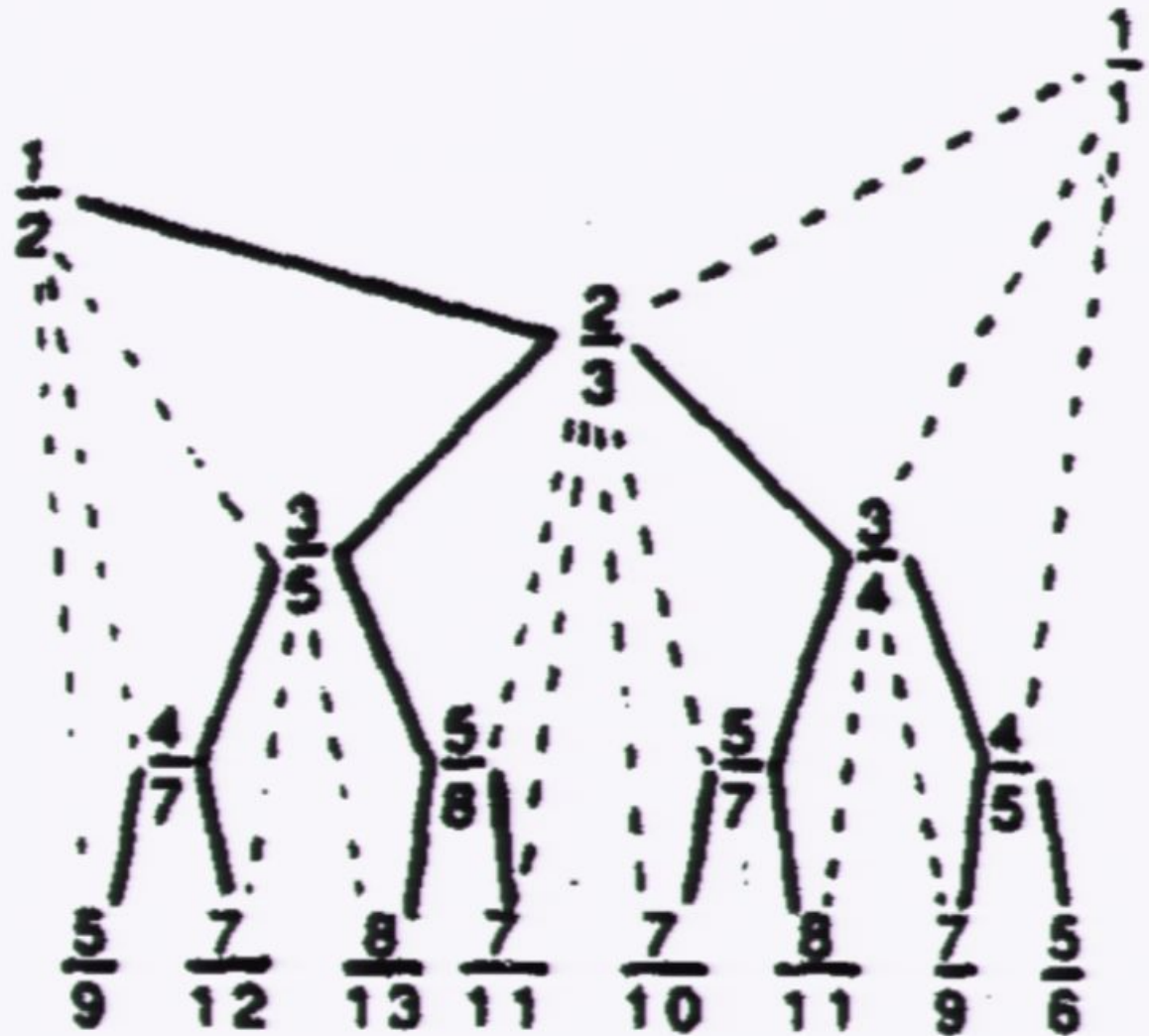




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

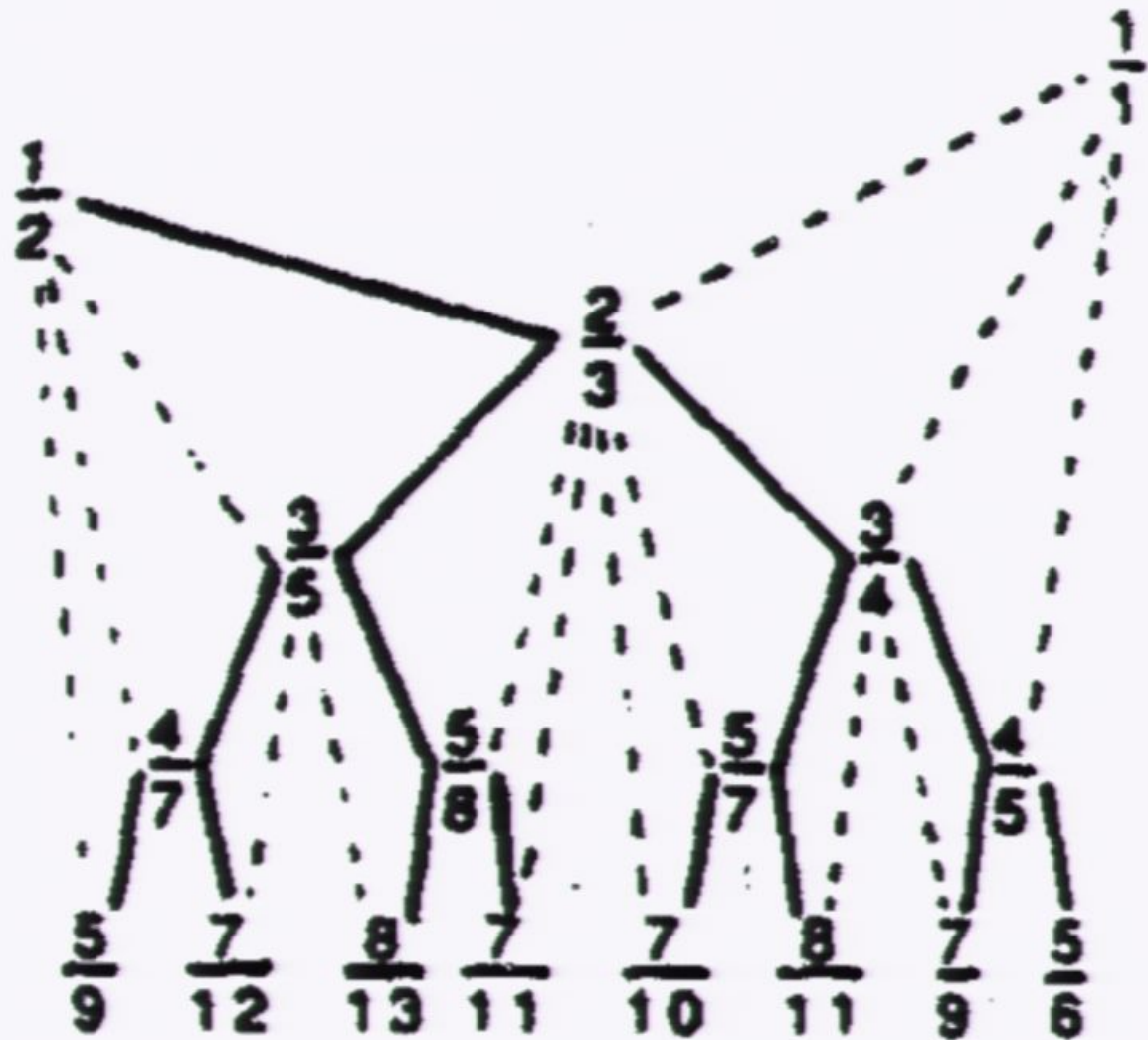
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

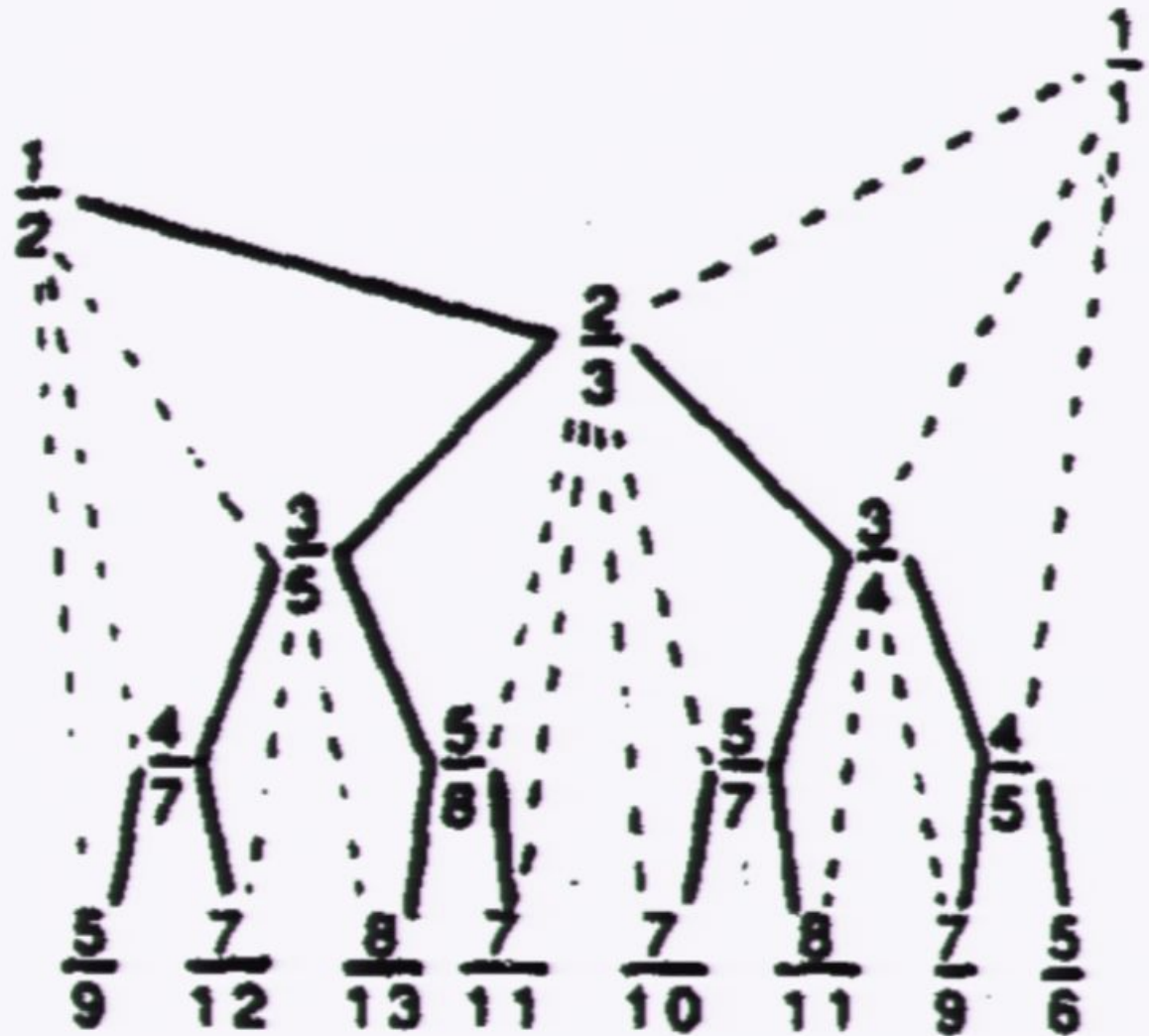
- Note that it is already  
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Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

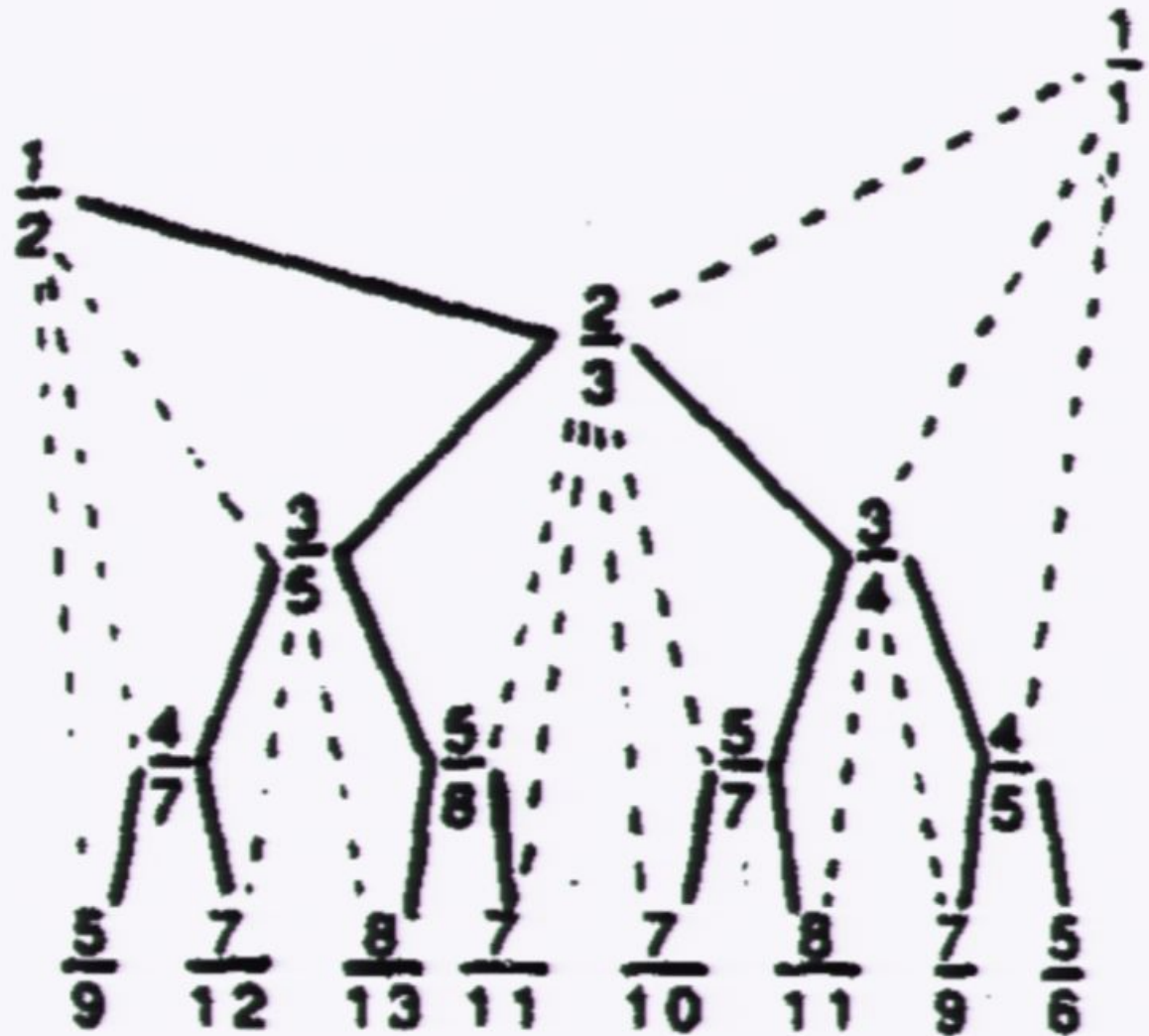




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

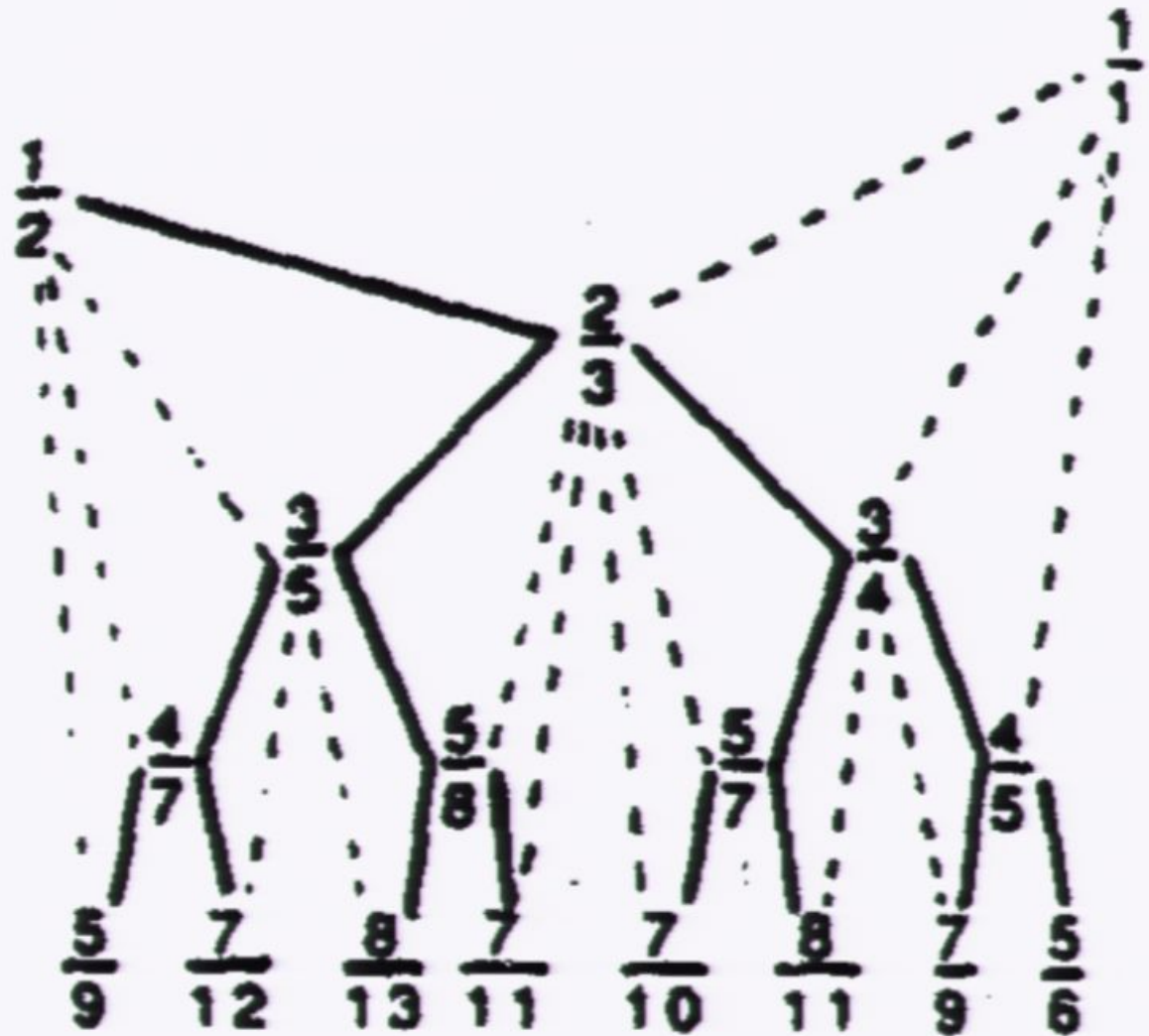




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

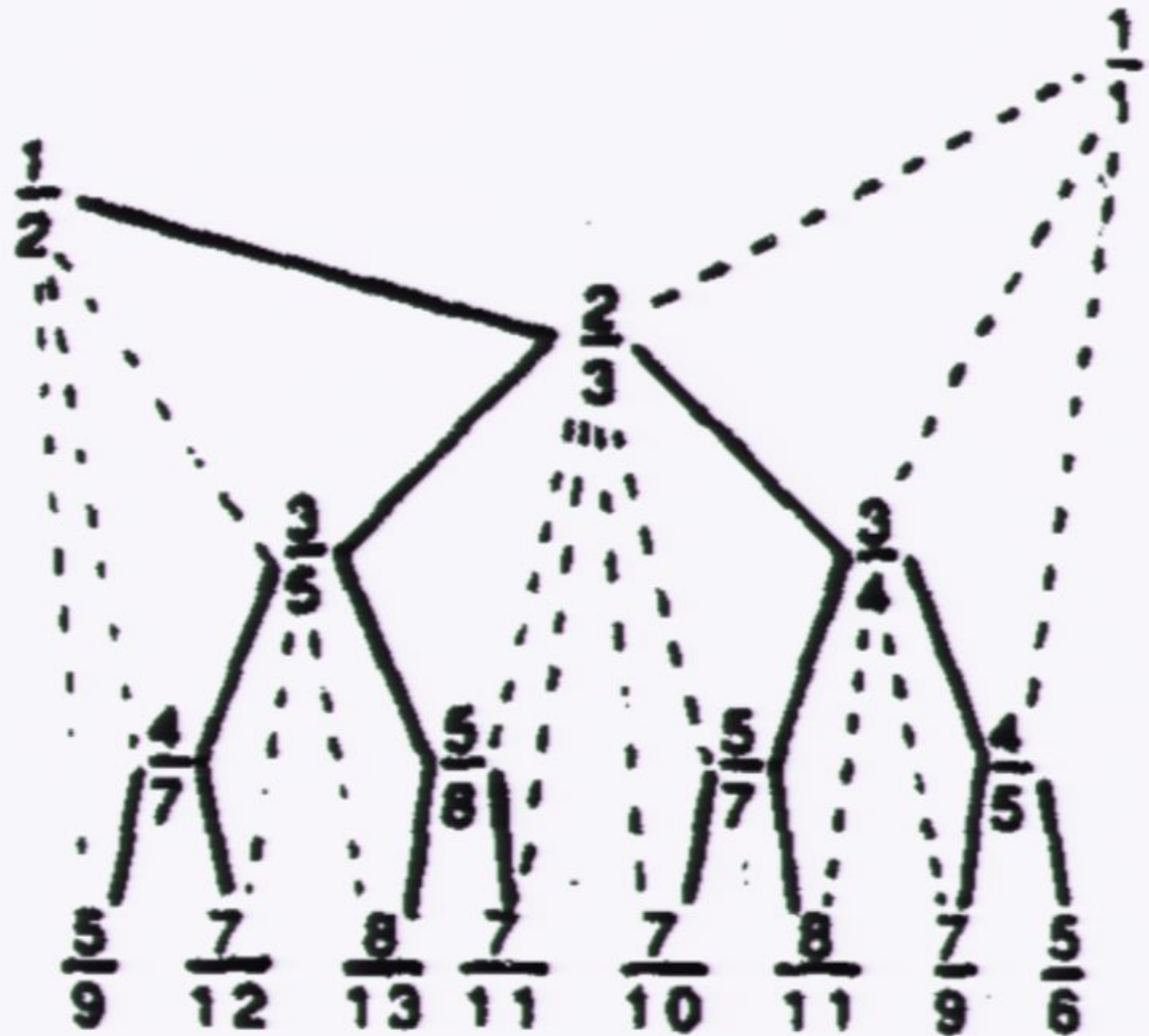
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

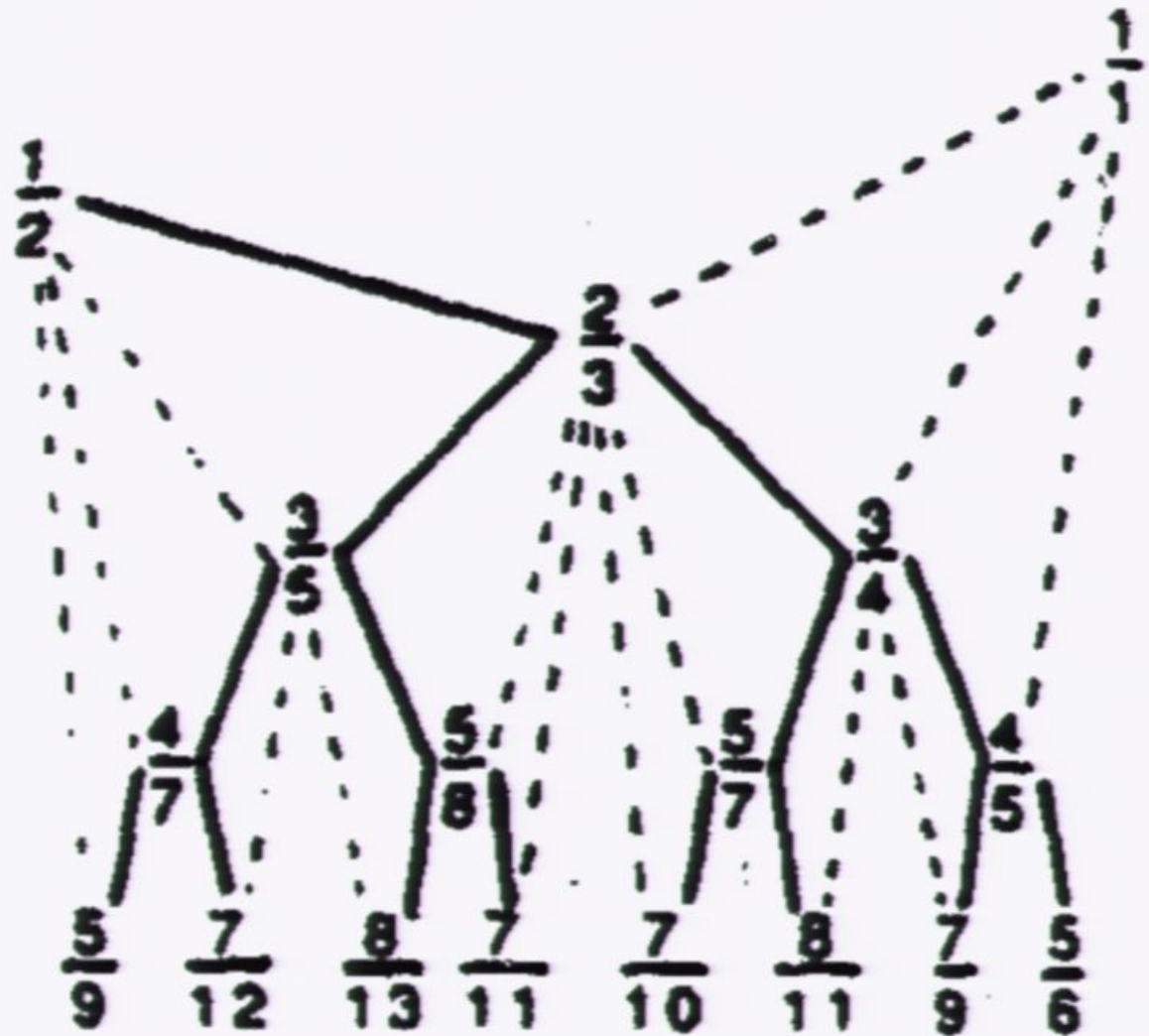
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

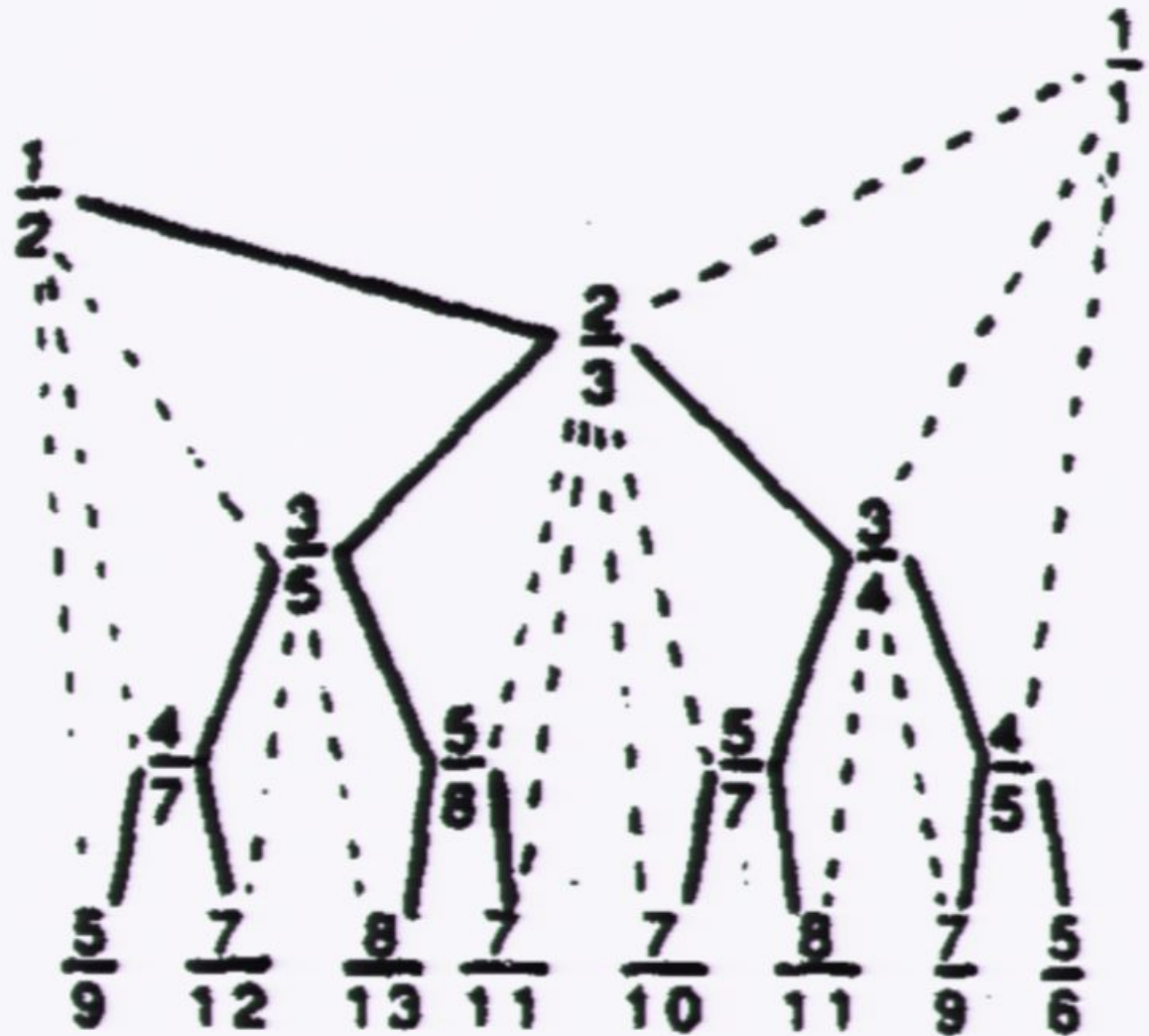




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

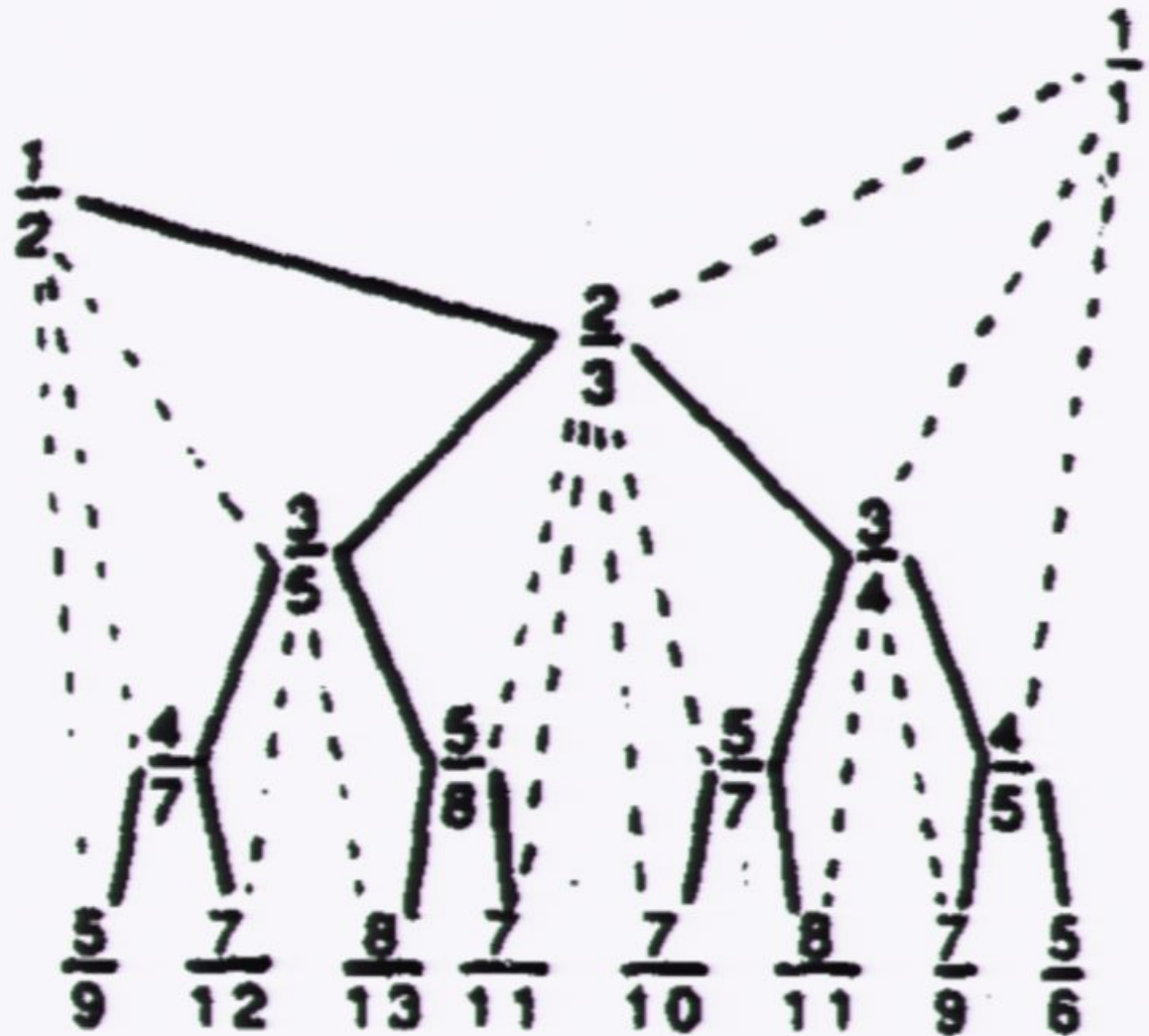
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

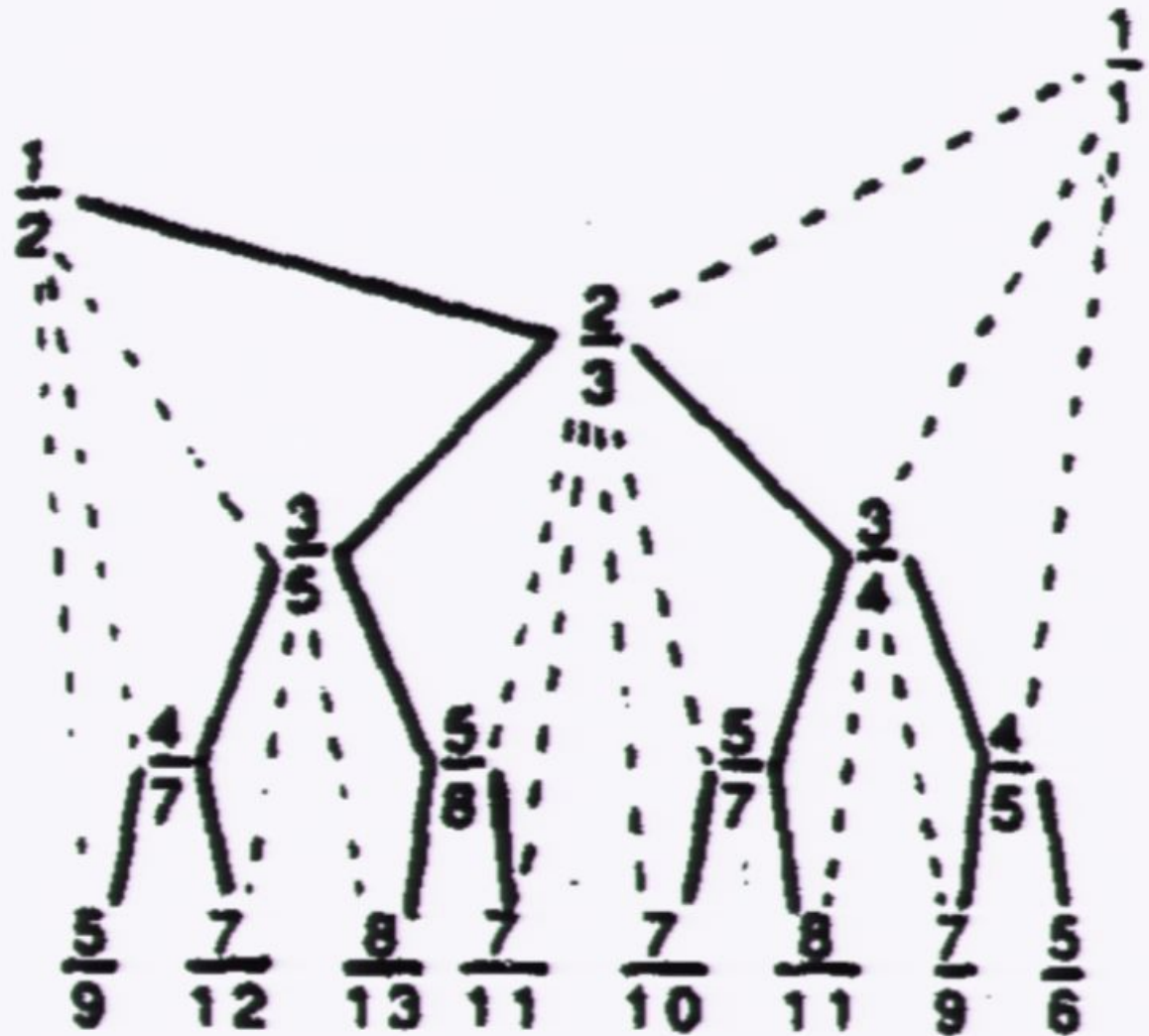
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

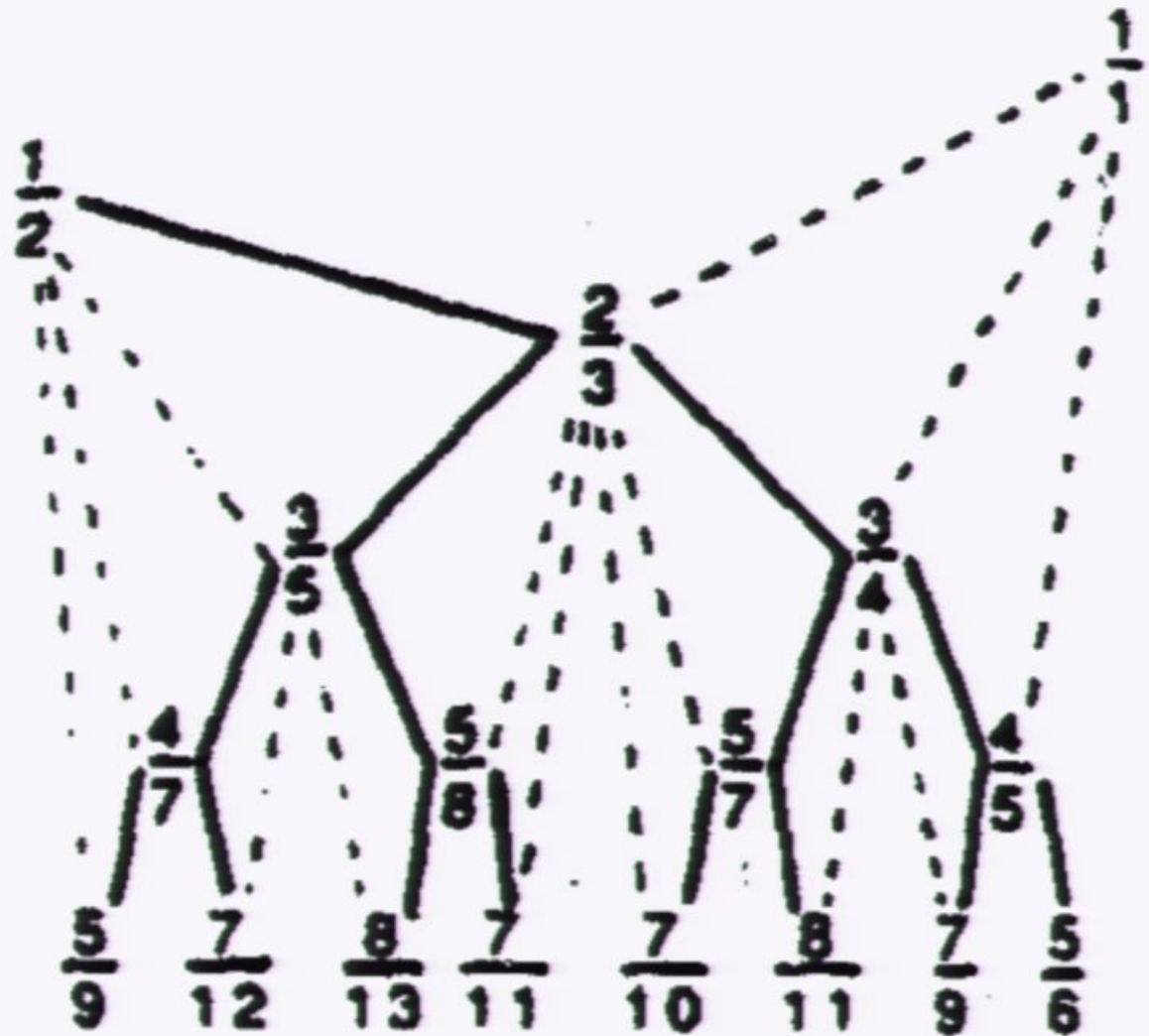




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

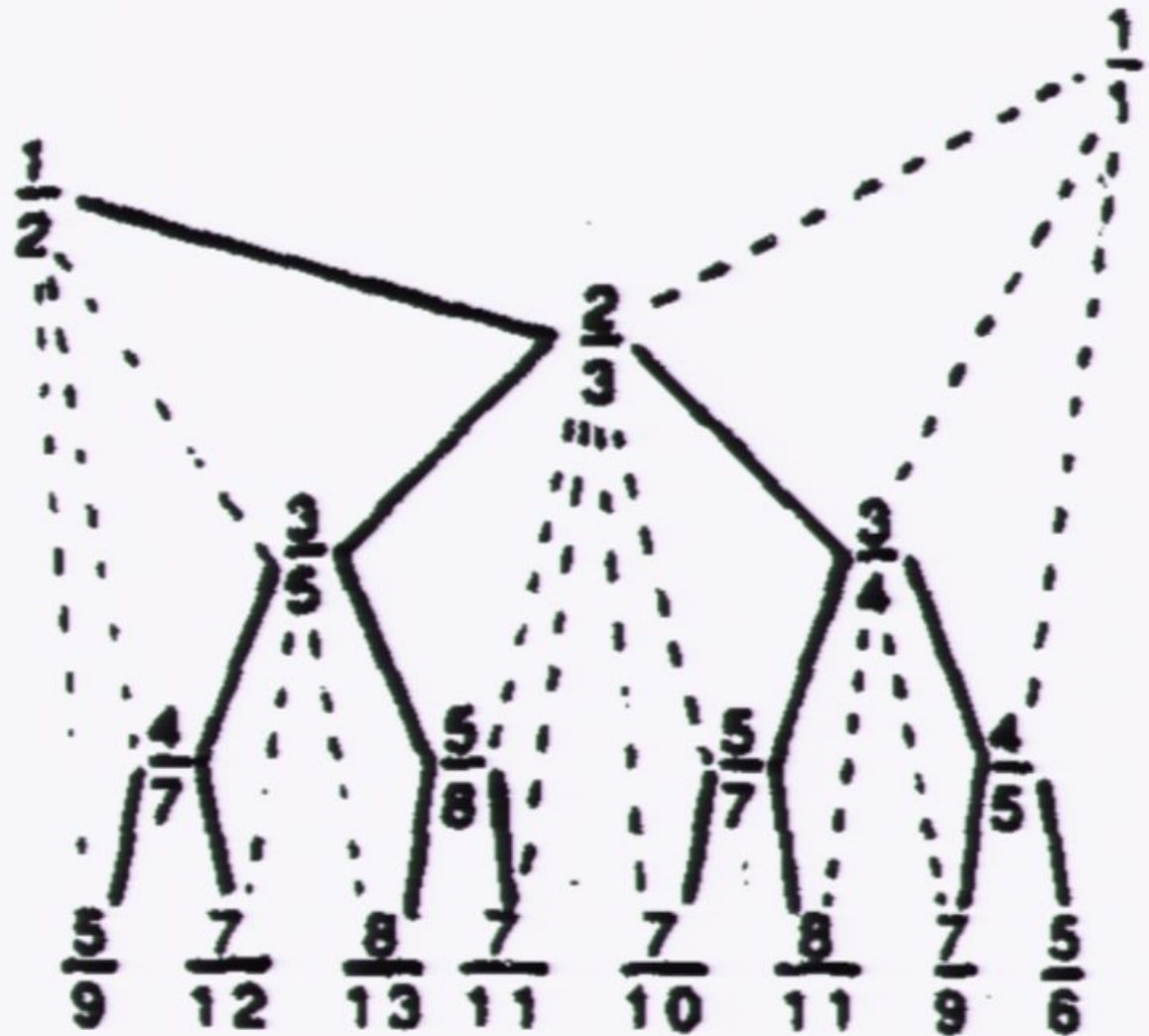
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

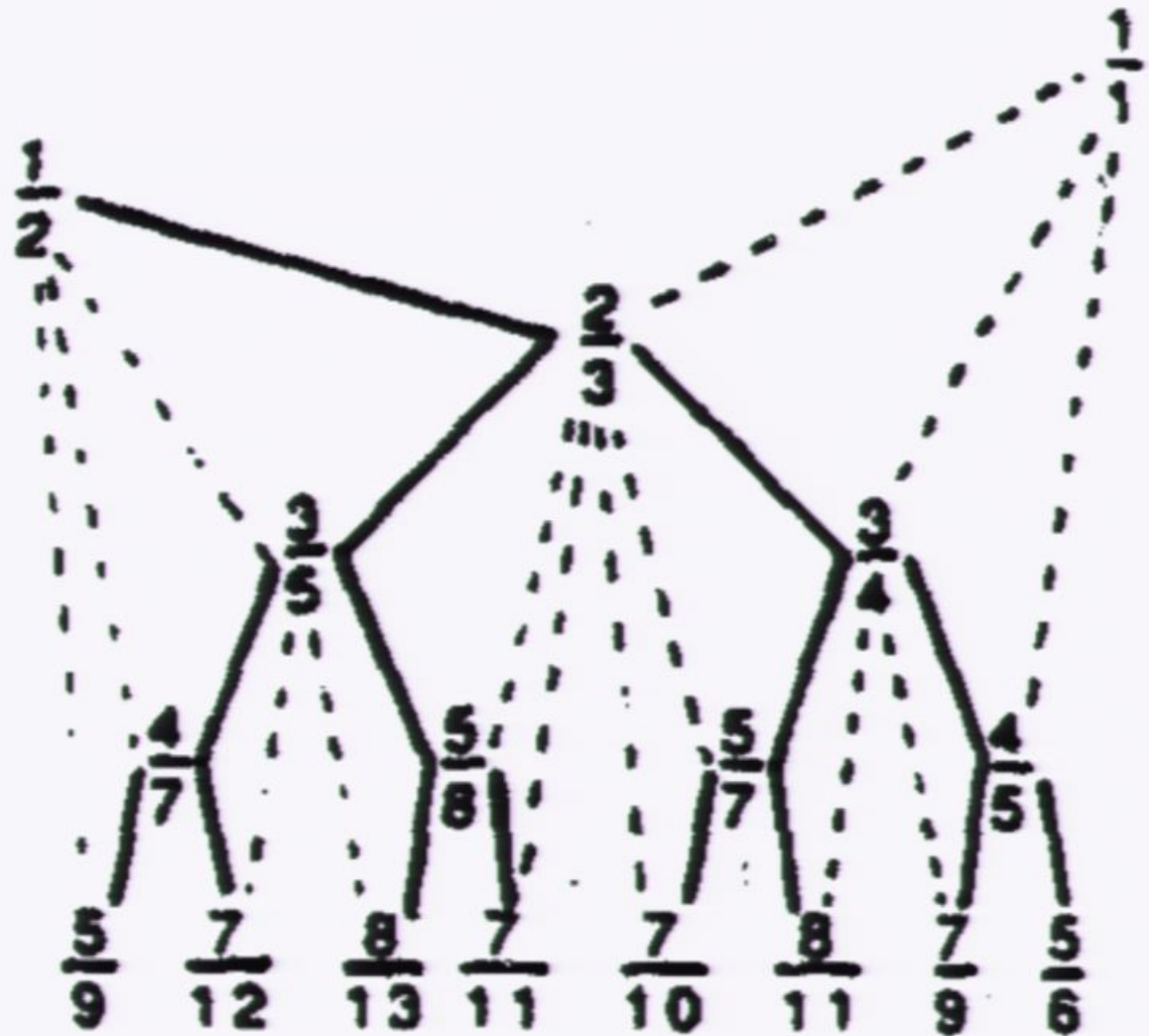
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

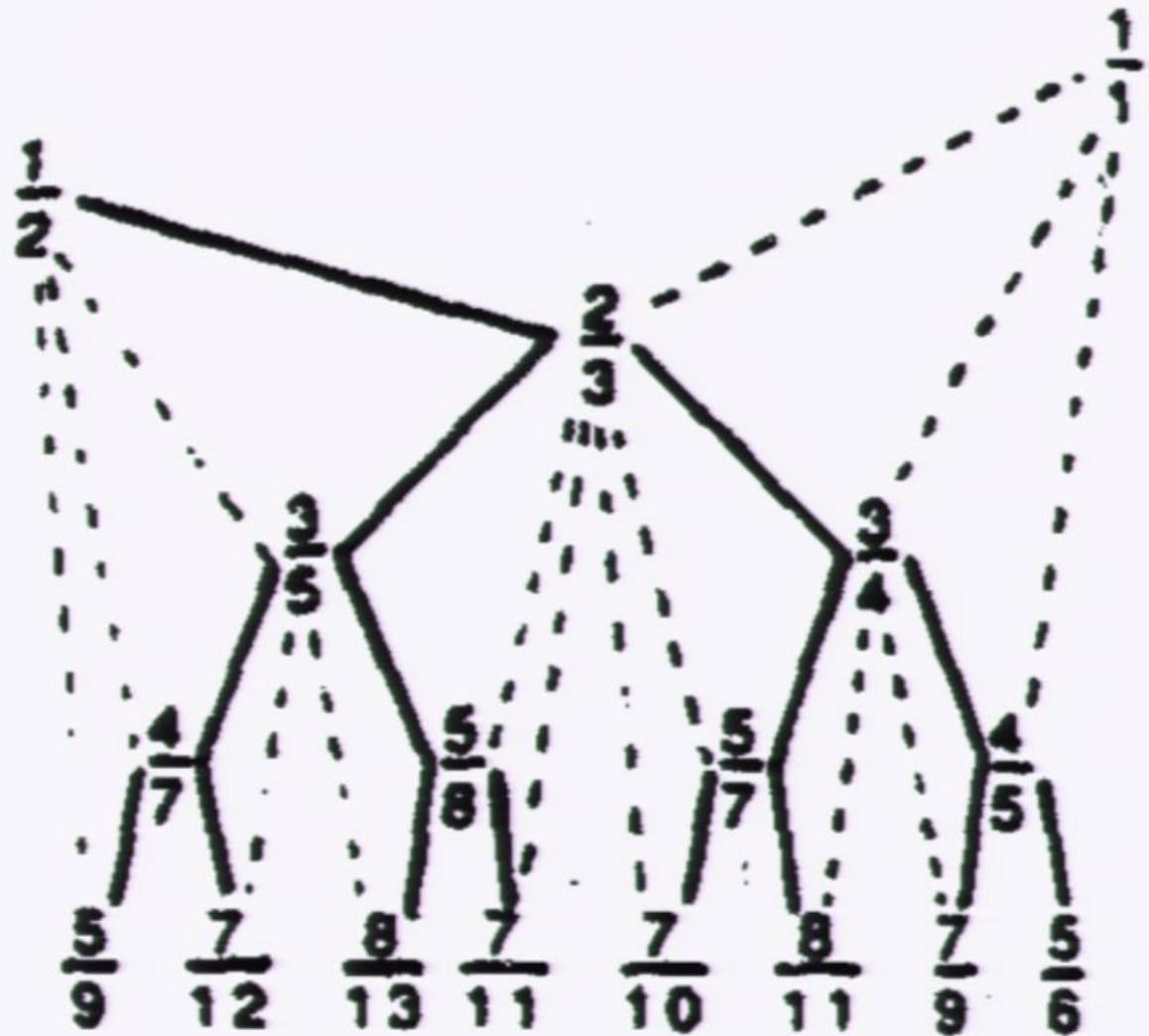




Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

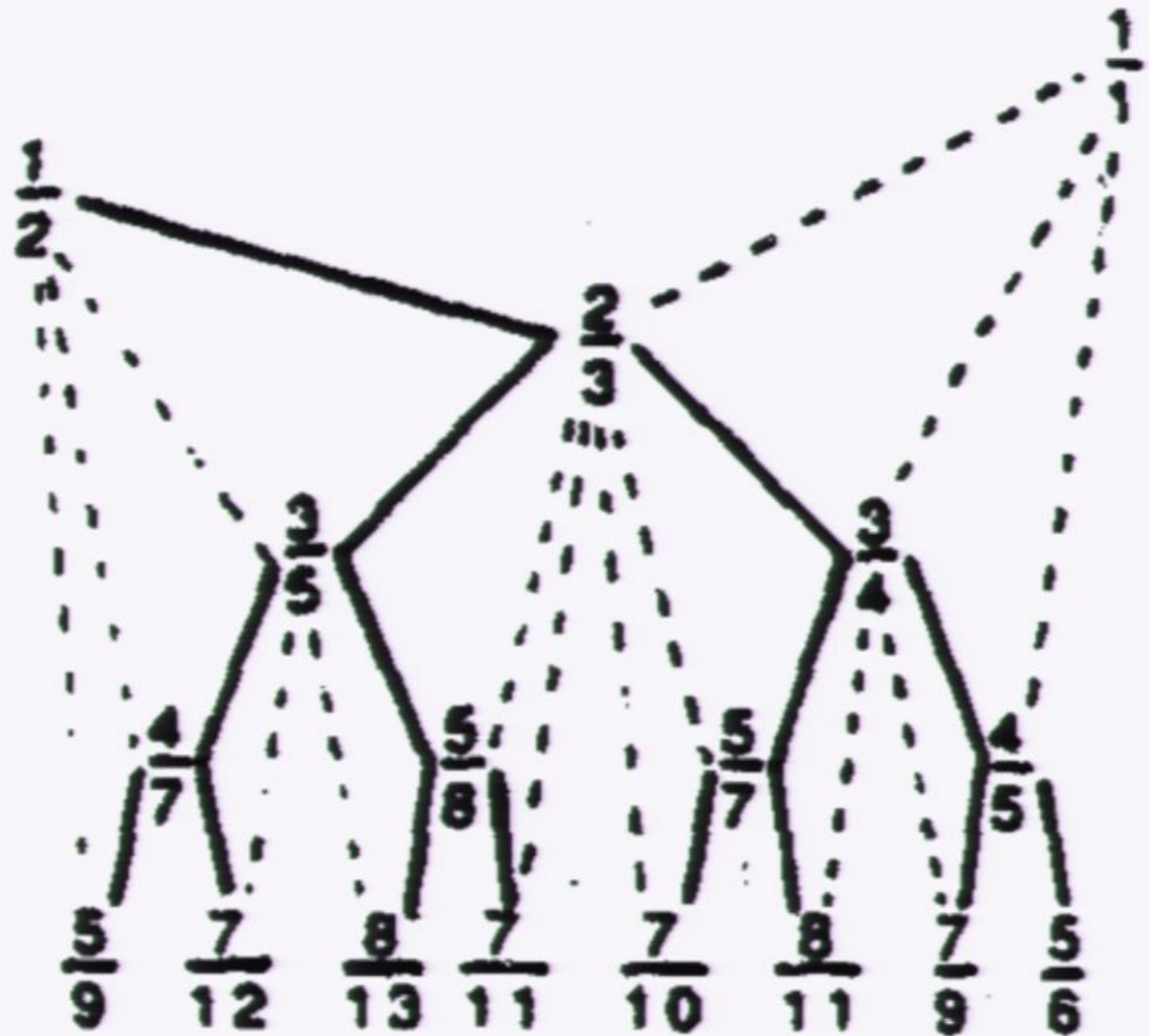
- Note that it is already  
topologically  
equivalent to first  
(would be, if not for the  
quasi bifurcations)



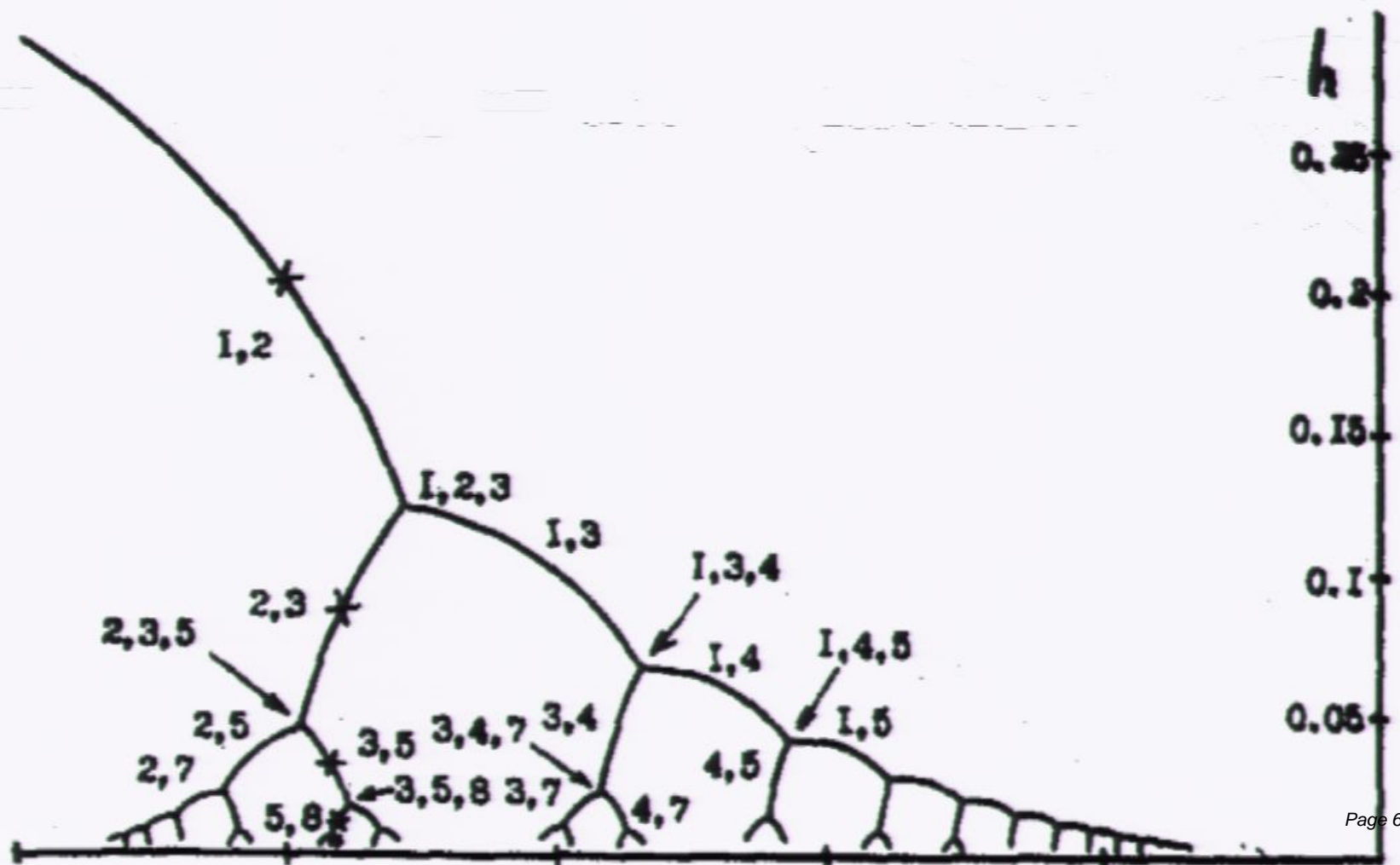
Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

- Note that it is already  
topologically  
equivalent to first  
(would be, if not for the  
quasi bifurcations)

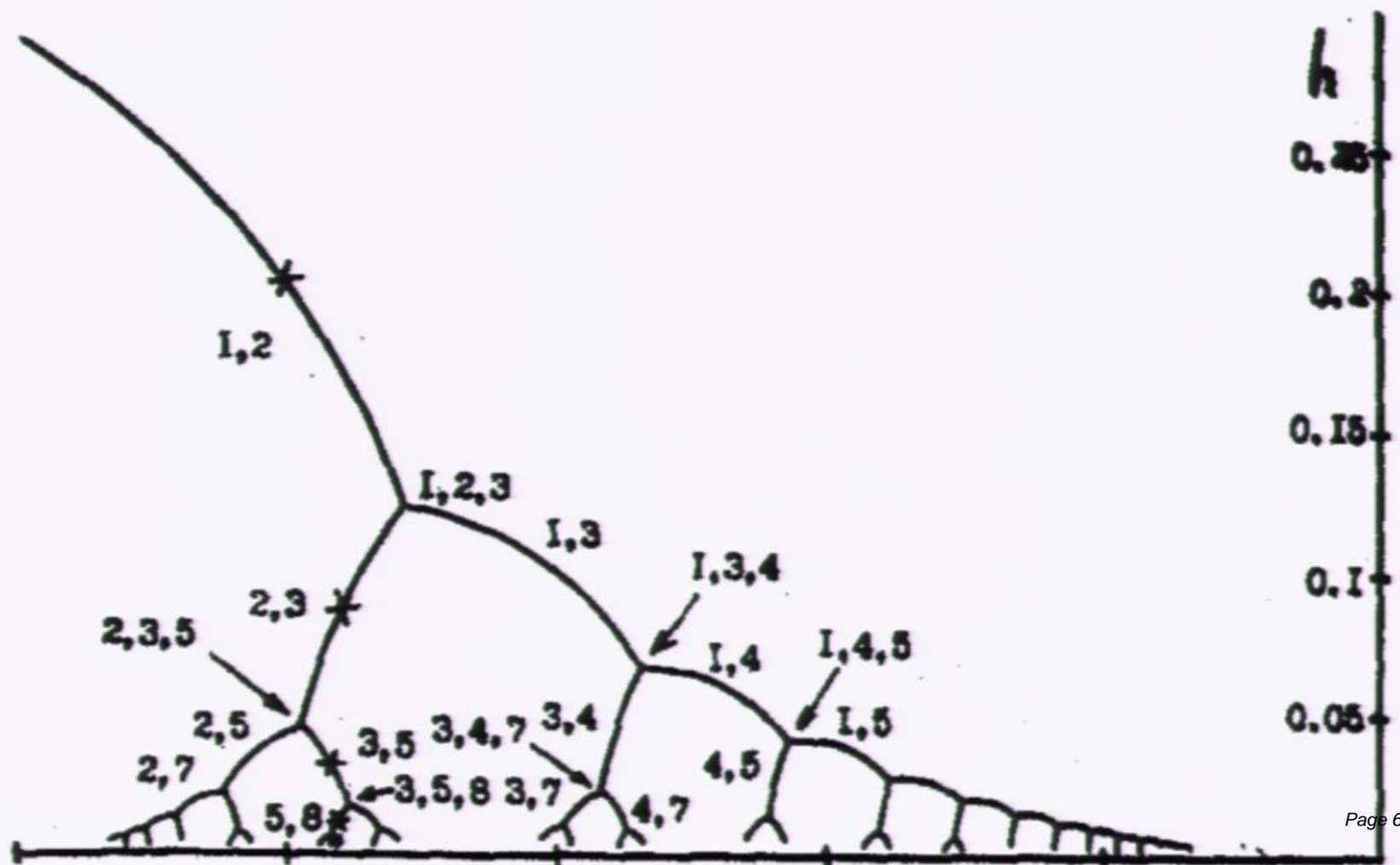


# Cayley tree for lattices





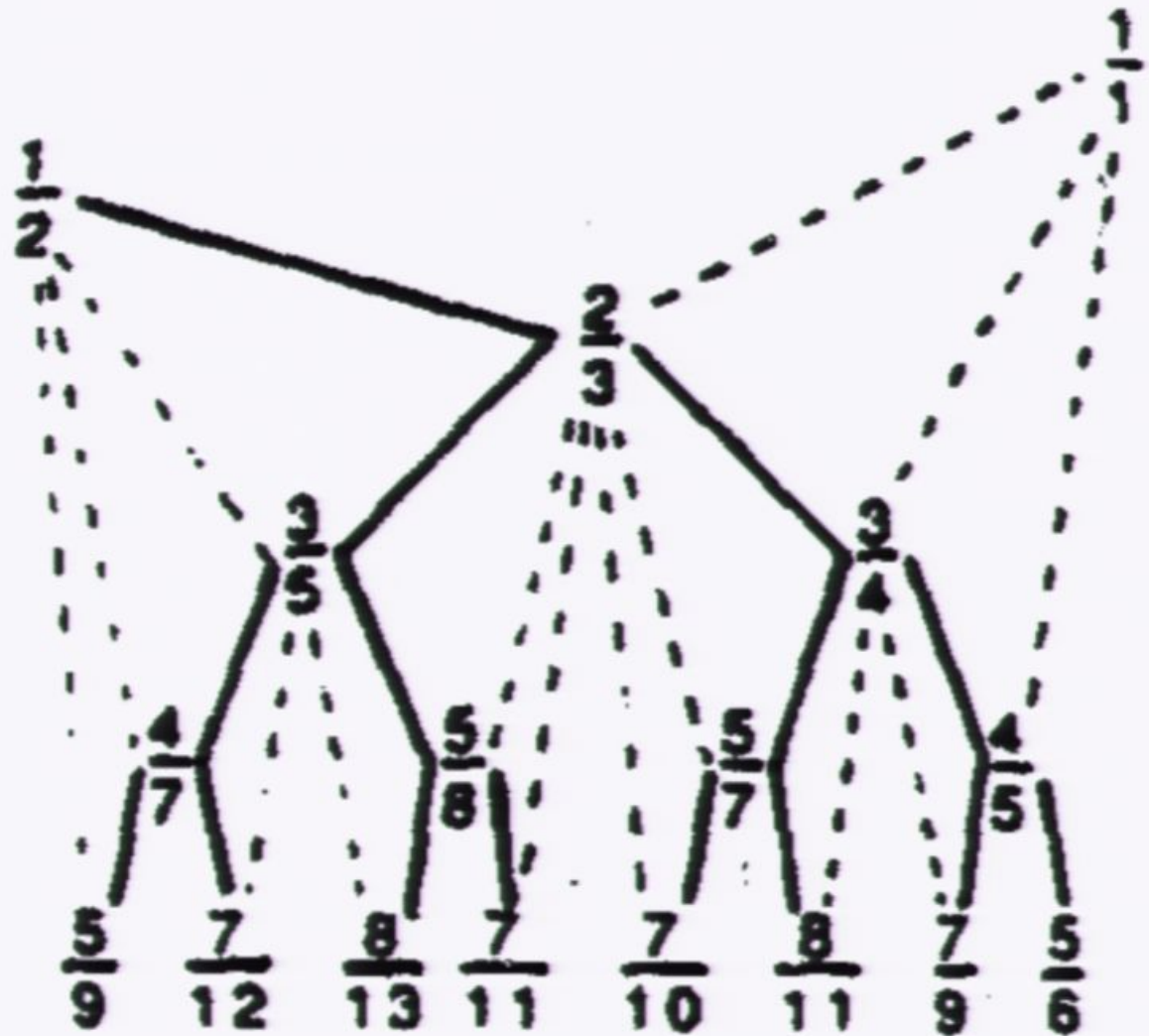
# Cayley tree for lattices



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

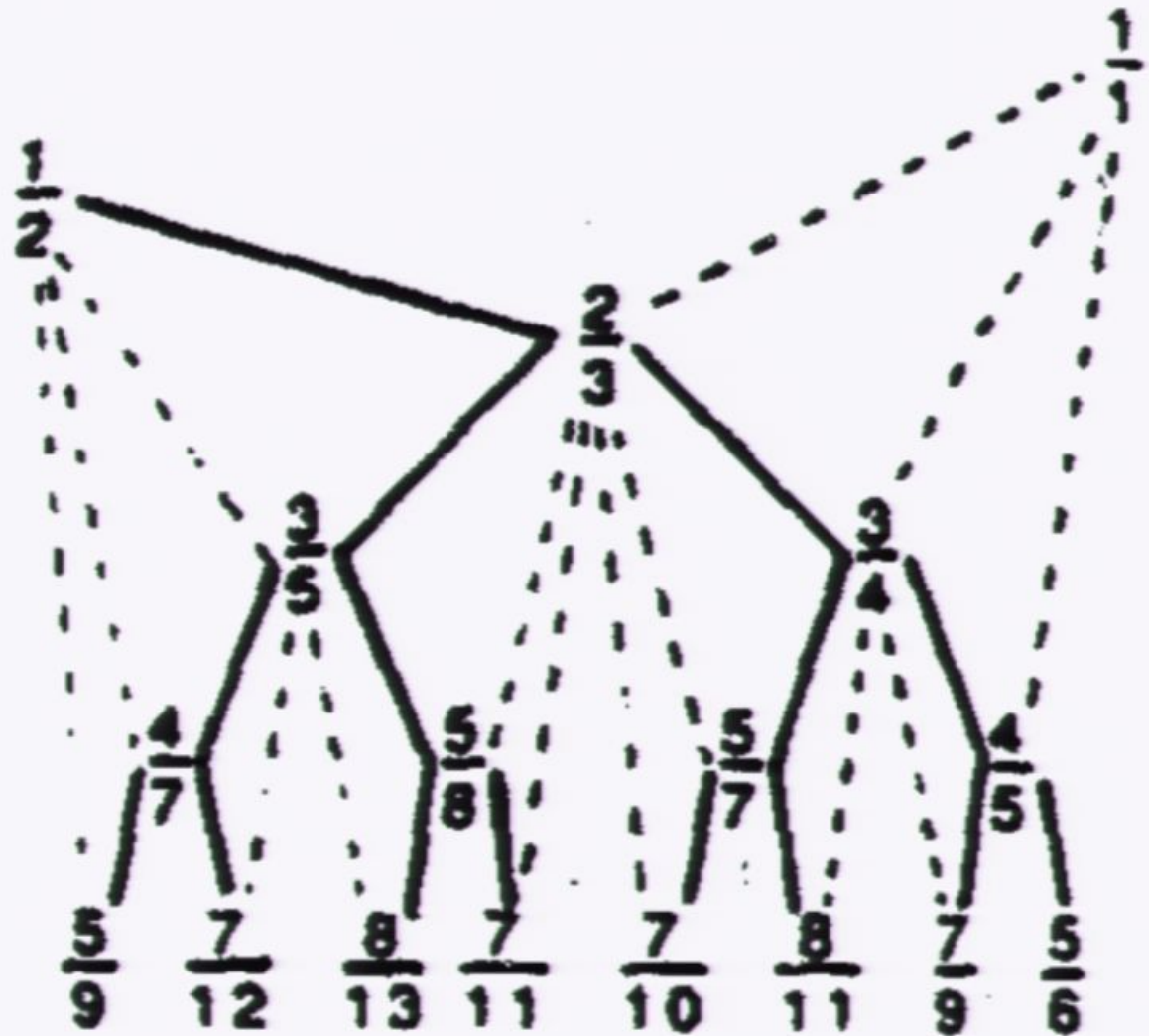
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

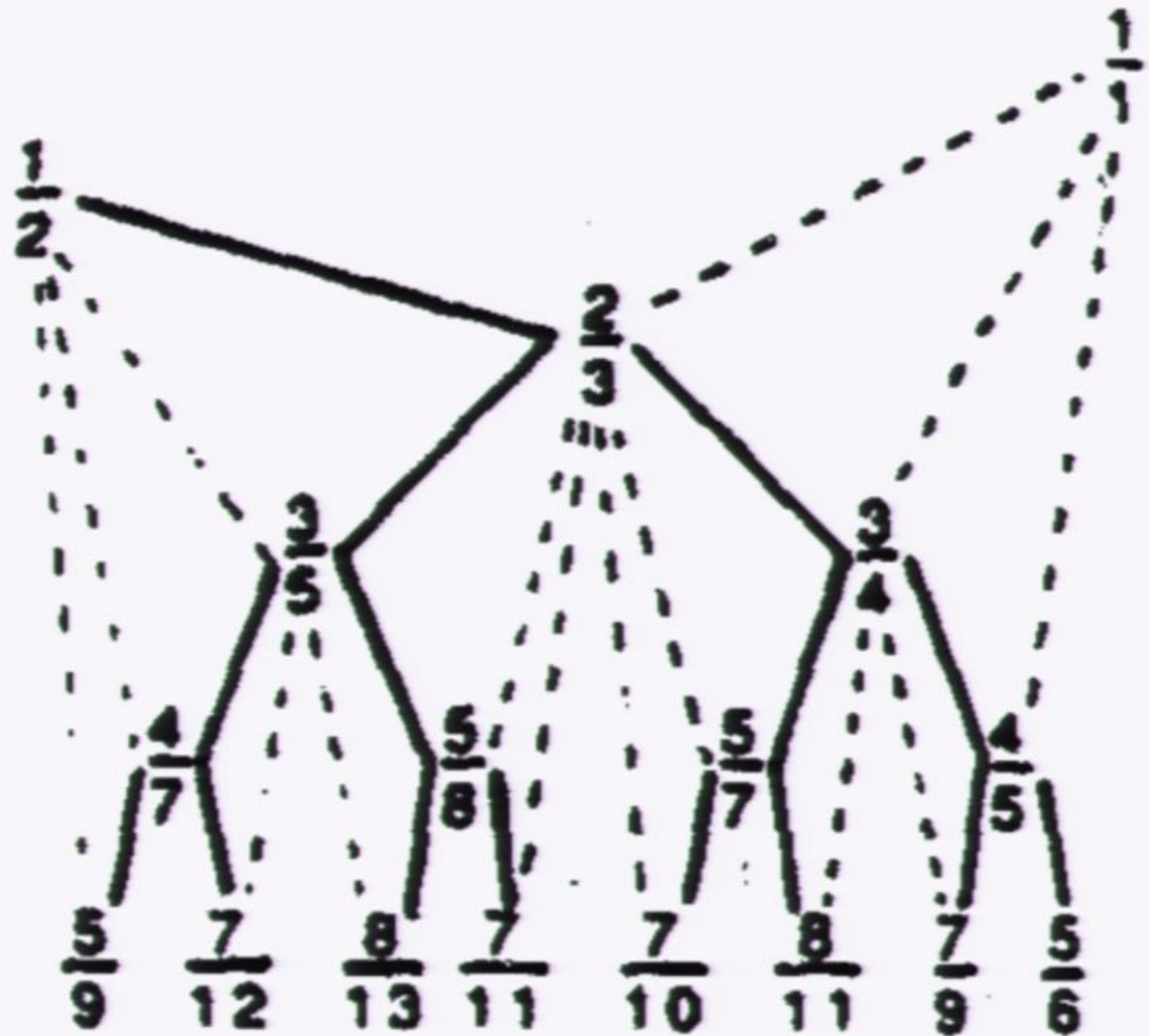




Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

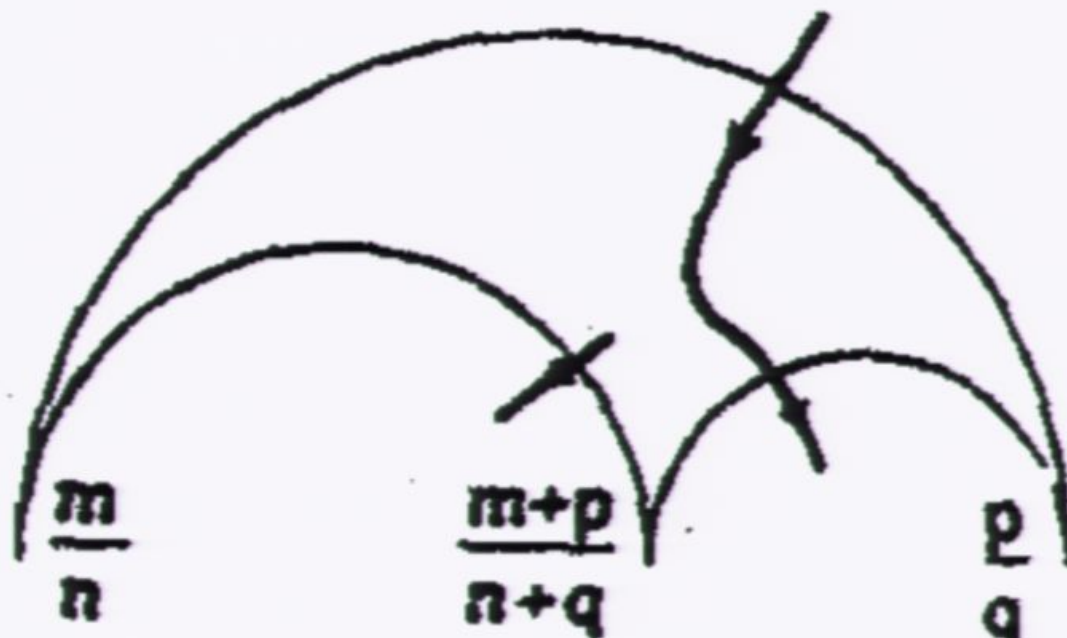
- Note that it is already  
topologically  
equivalent to first  
(would be, if not for the  
quasi bifurcations)



# Construct circles

$$m/n, (m+p)/(n+q), p/q$$

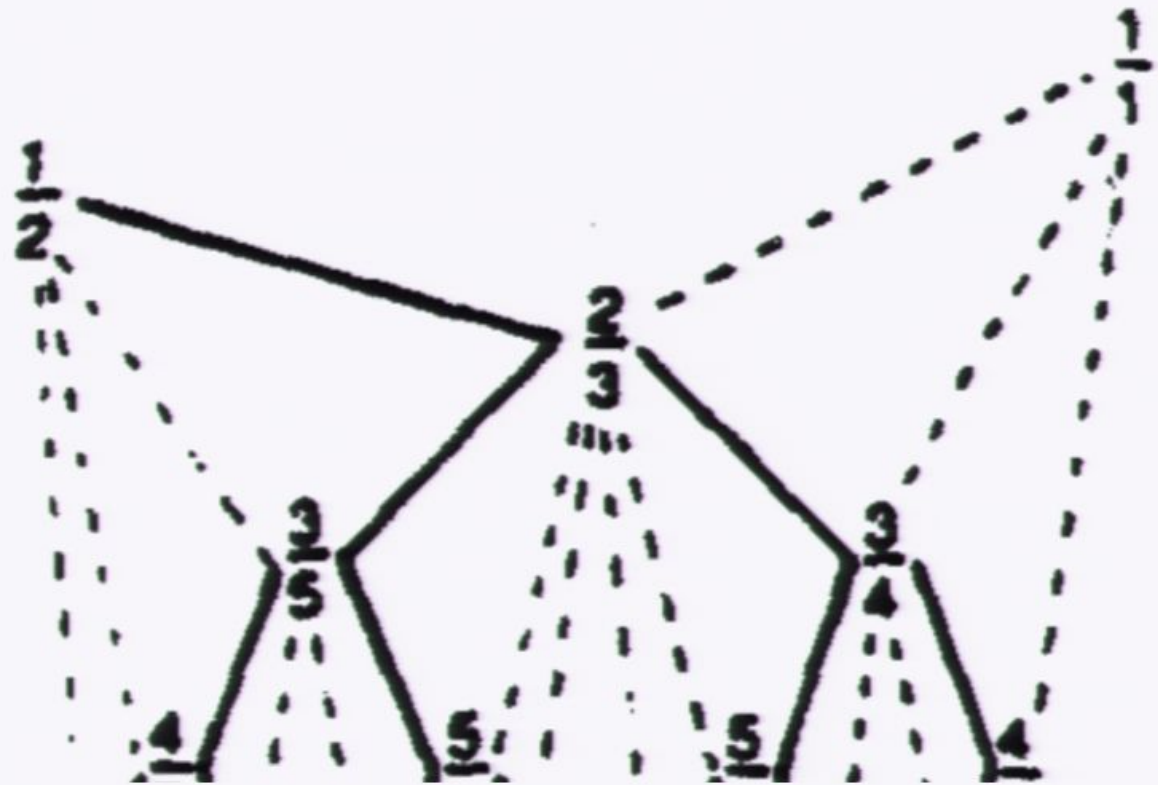
$$mq - np = \pm 1$$



Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

- Note that it is already  
topologically  
equivalent to first



0/1, 1/2, 1/1

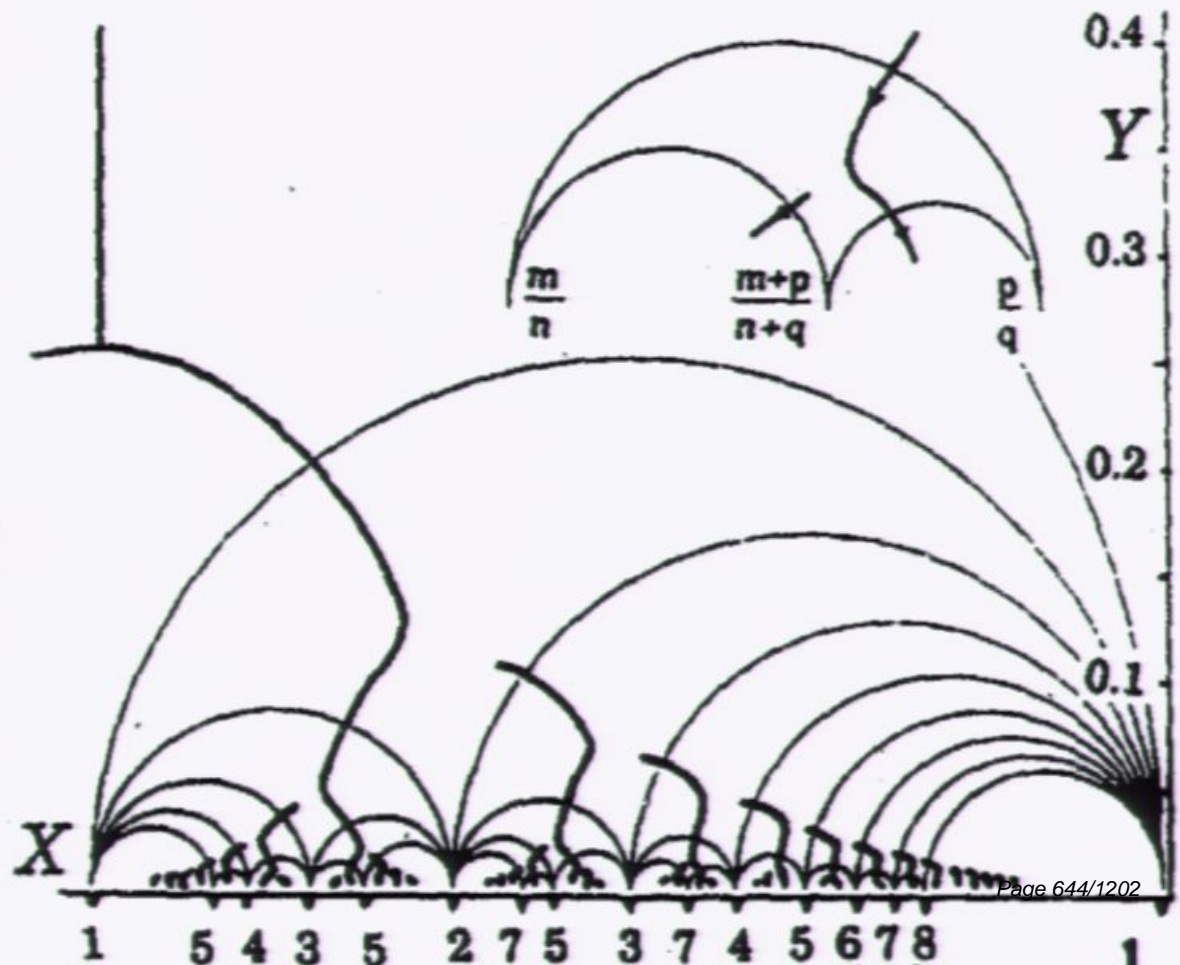
0/1, 1/3, 1/2, 2/3, 1/1



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

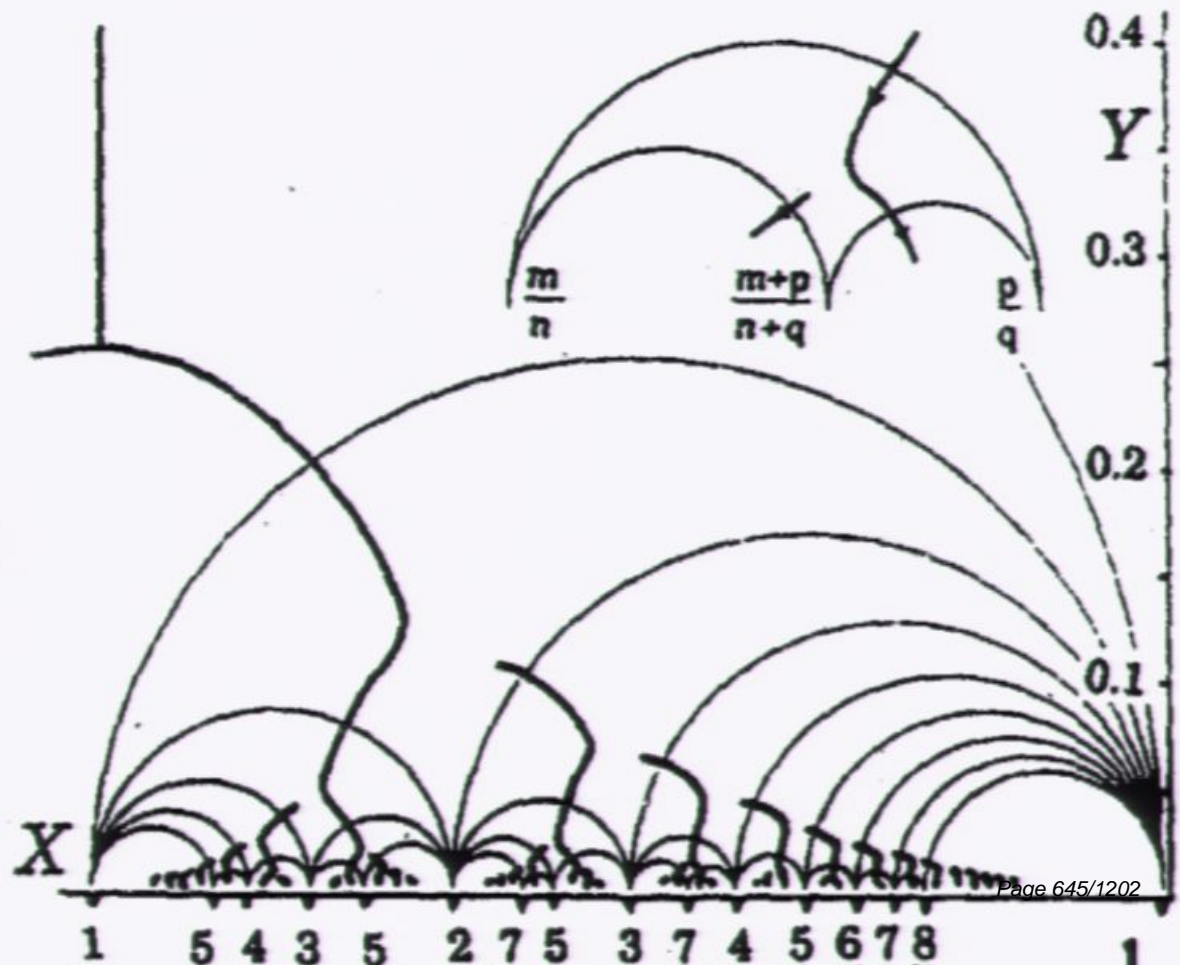
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

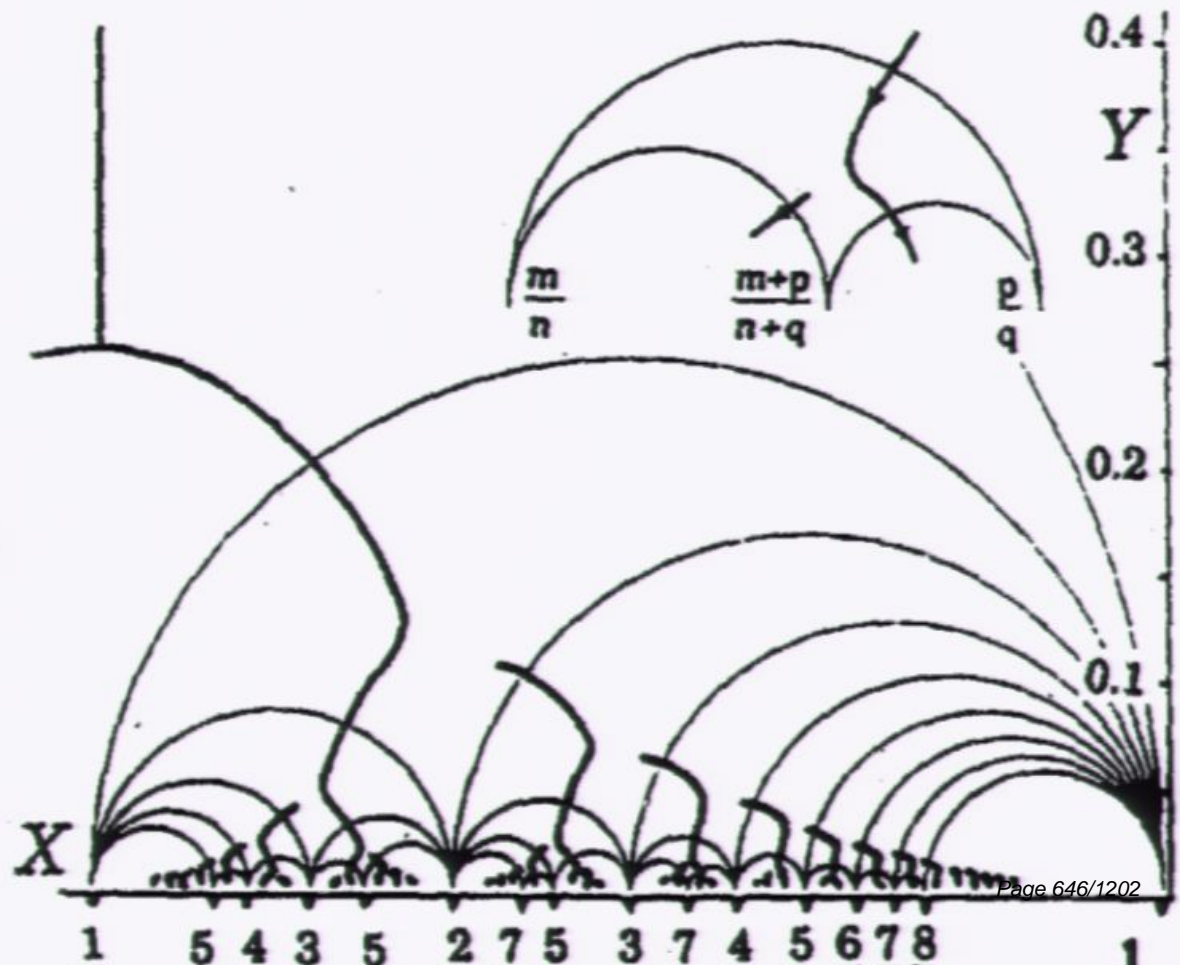
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path

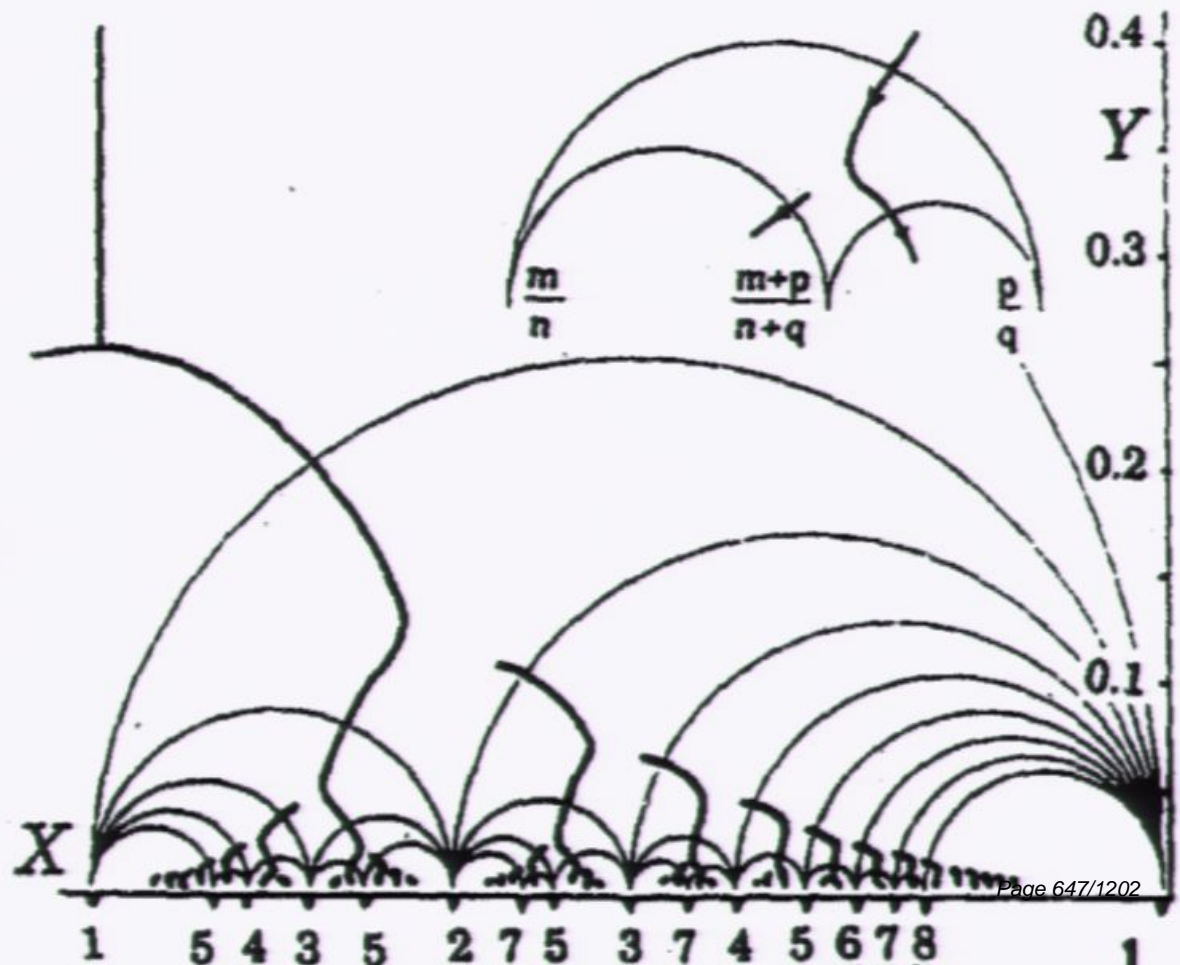




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

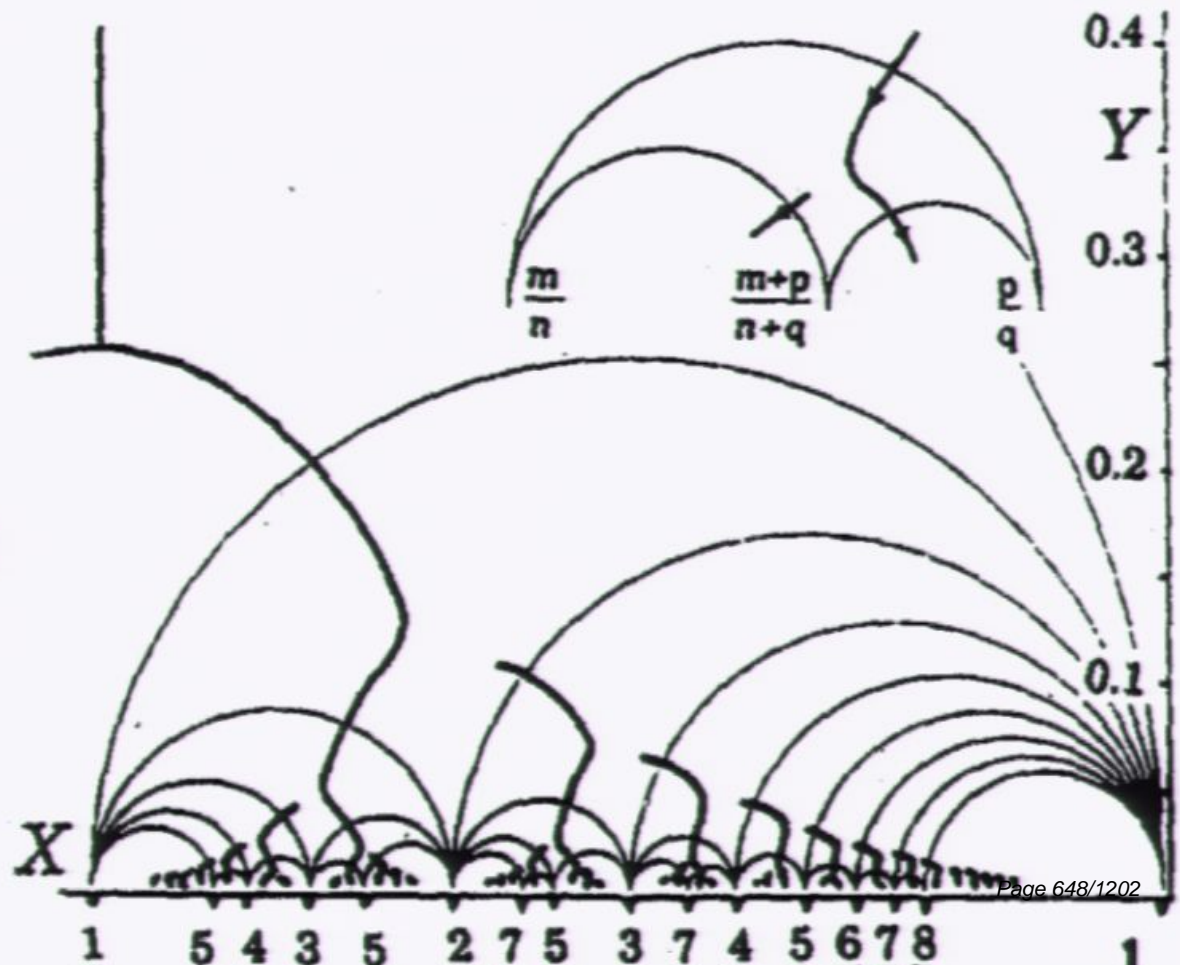
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

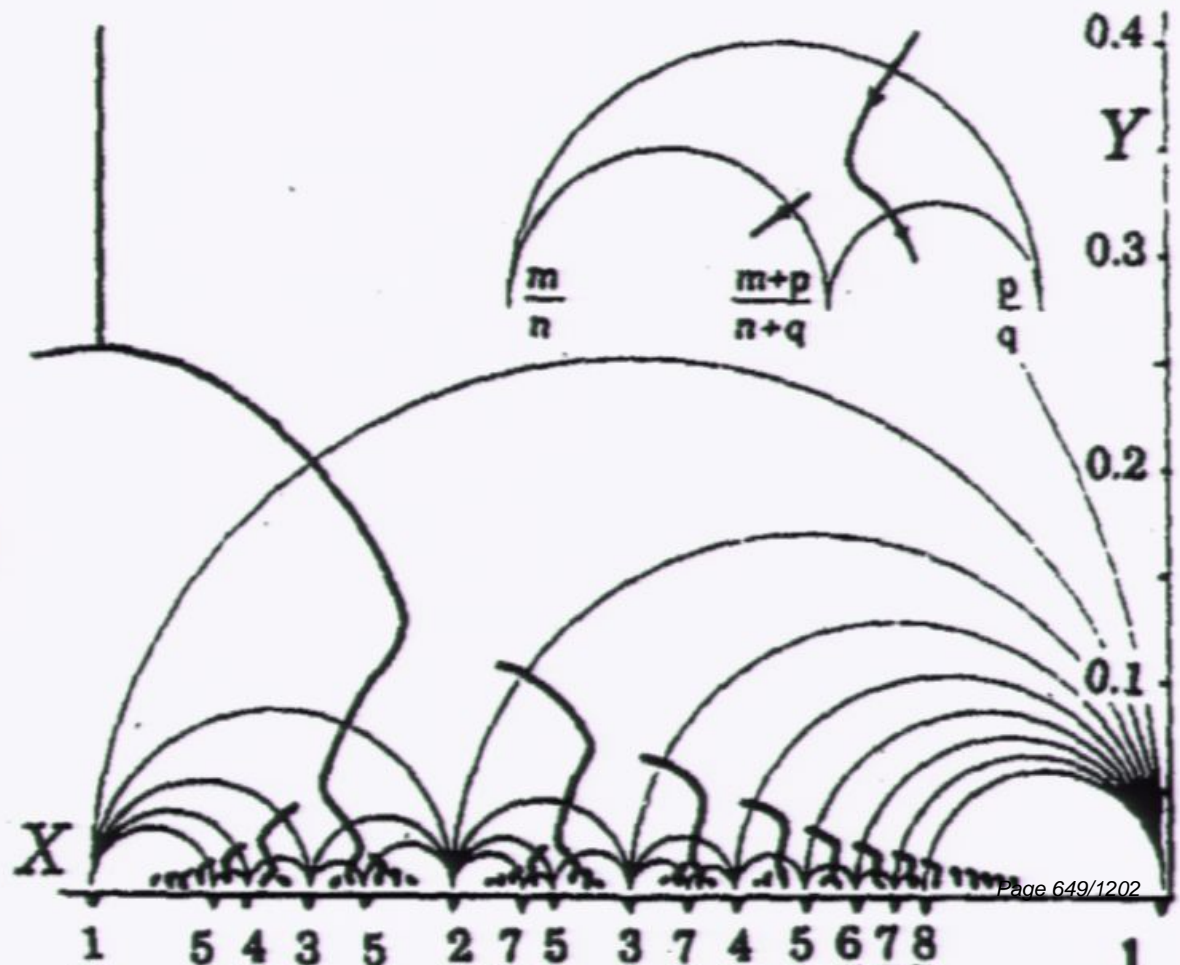
Quasi bifurcations lead  
to single visible path



# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

Quasi bifurcations lead  
to single visible path

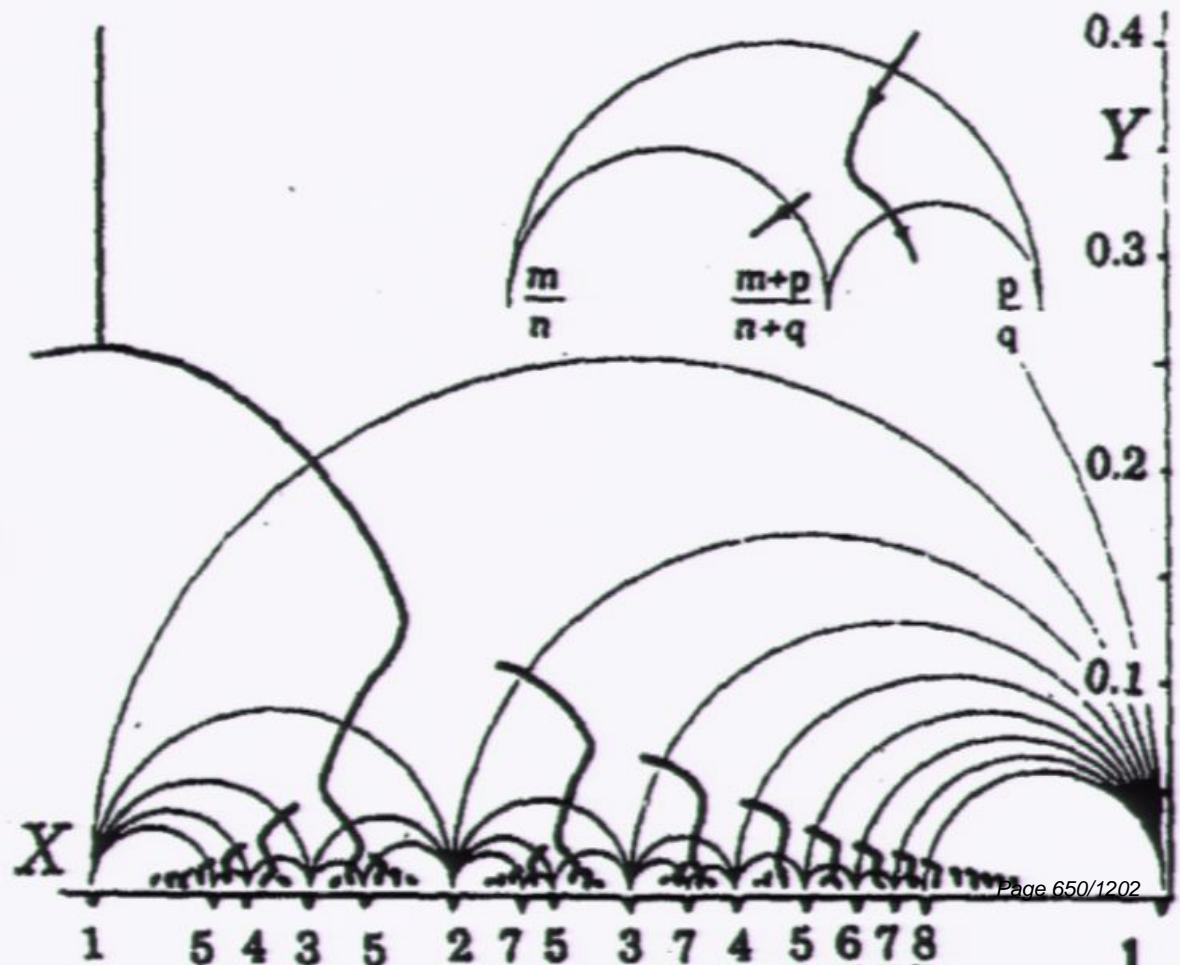




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

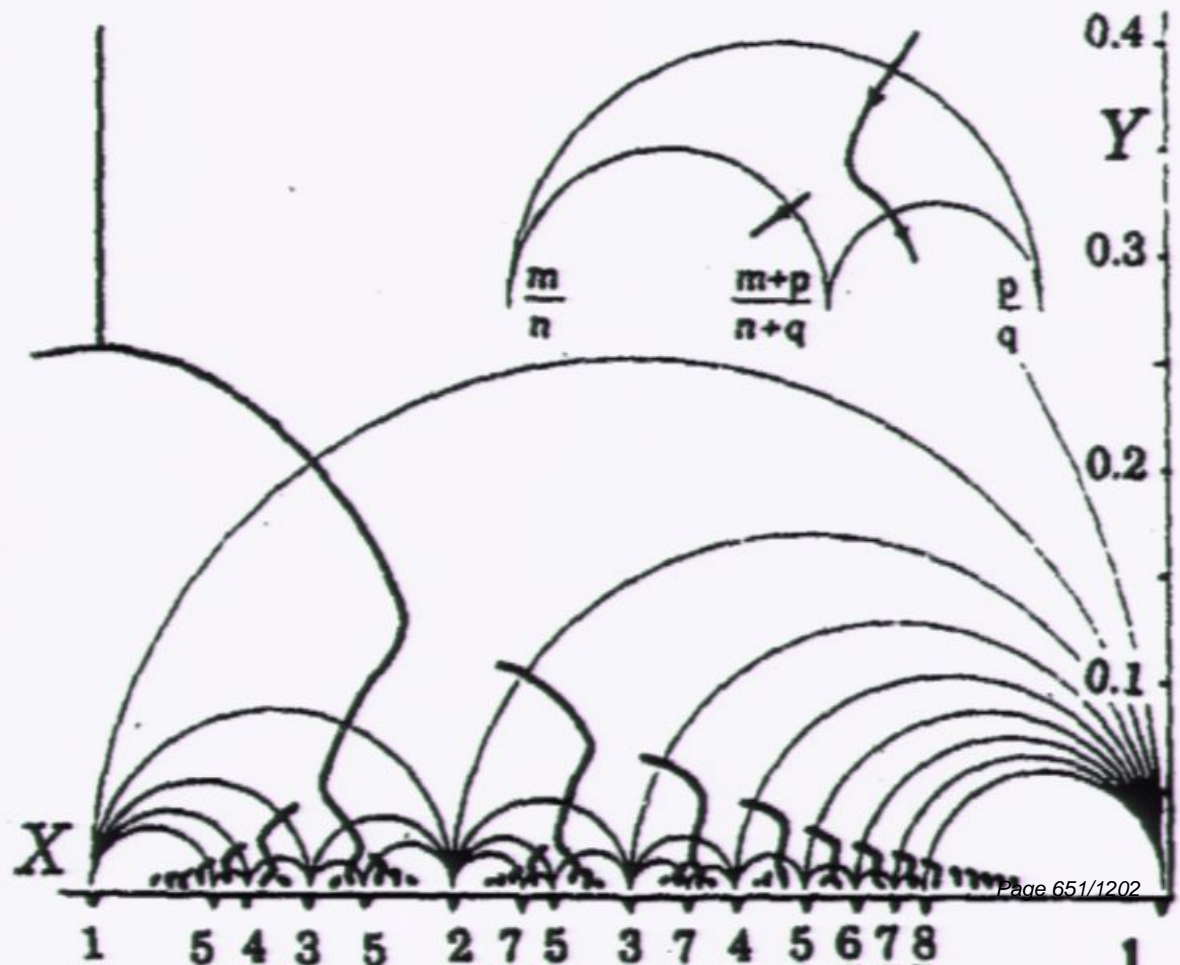
Quasi bifurcations lead  
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# Energy minima

Vary  $y$  from  
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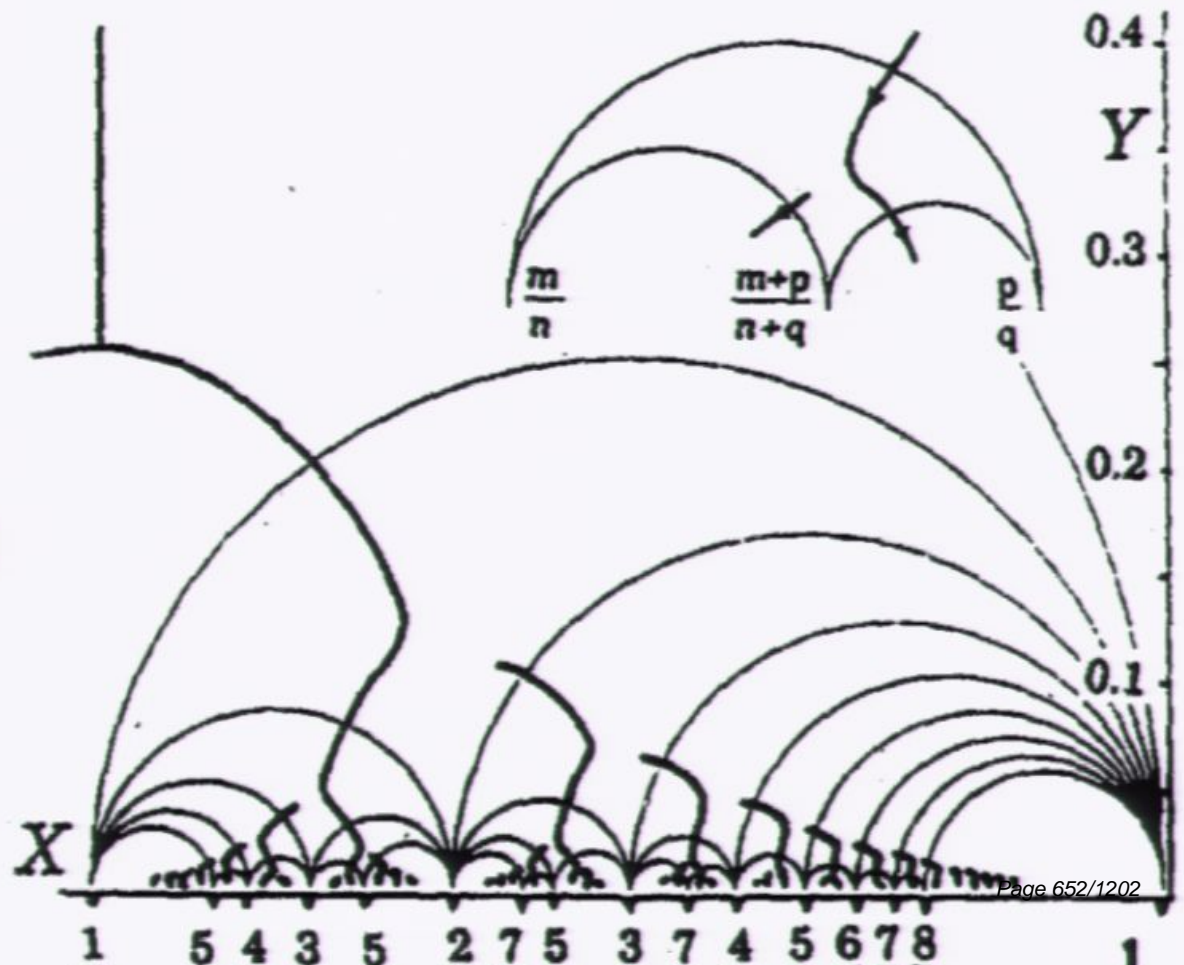
Quasi bifurcations lead  
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# Energy minima

Vary  $y$  from  
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Quasi bifurcations lead  
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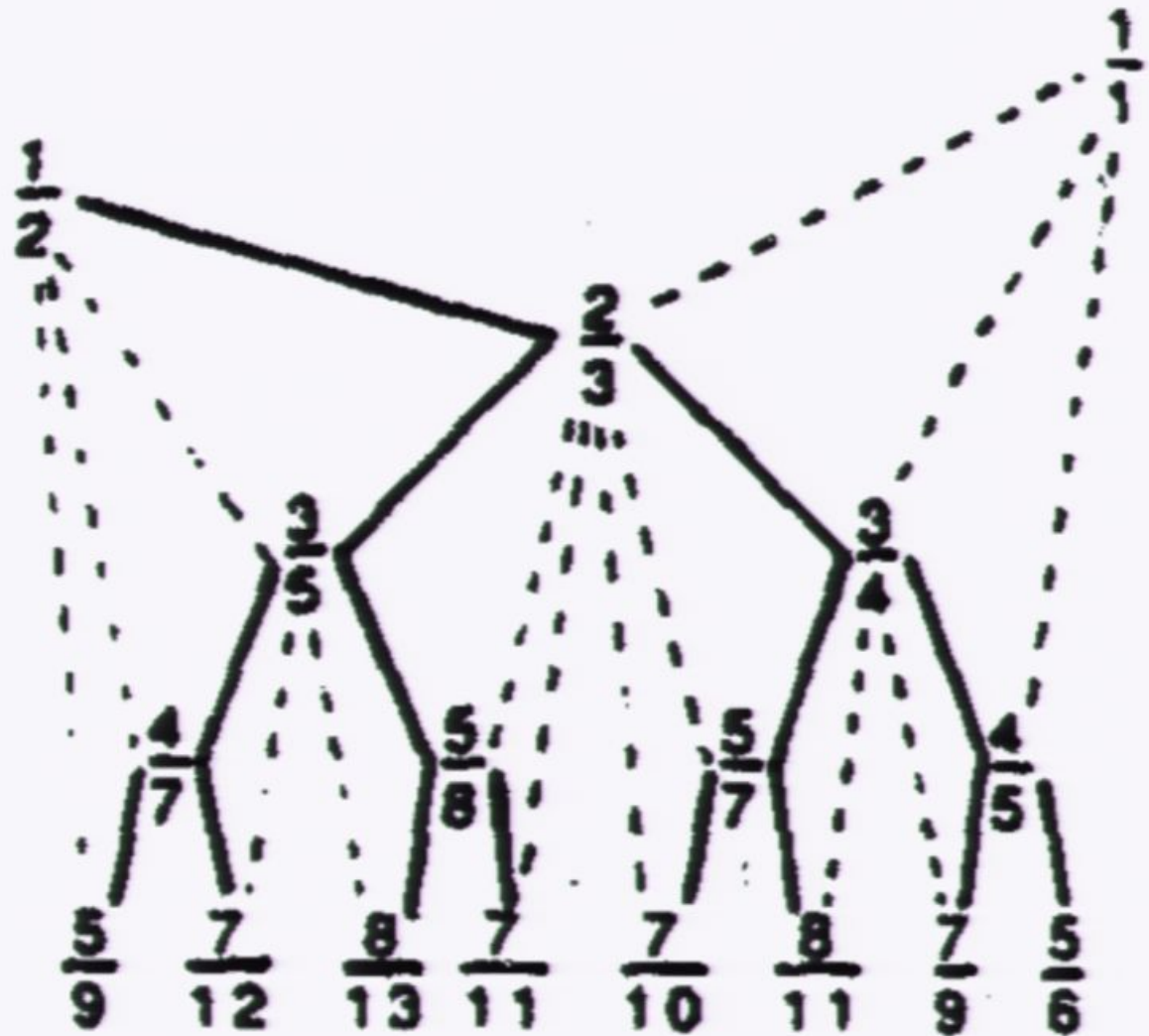




Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

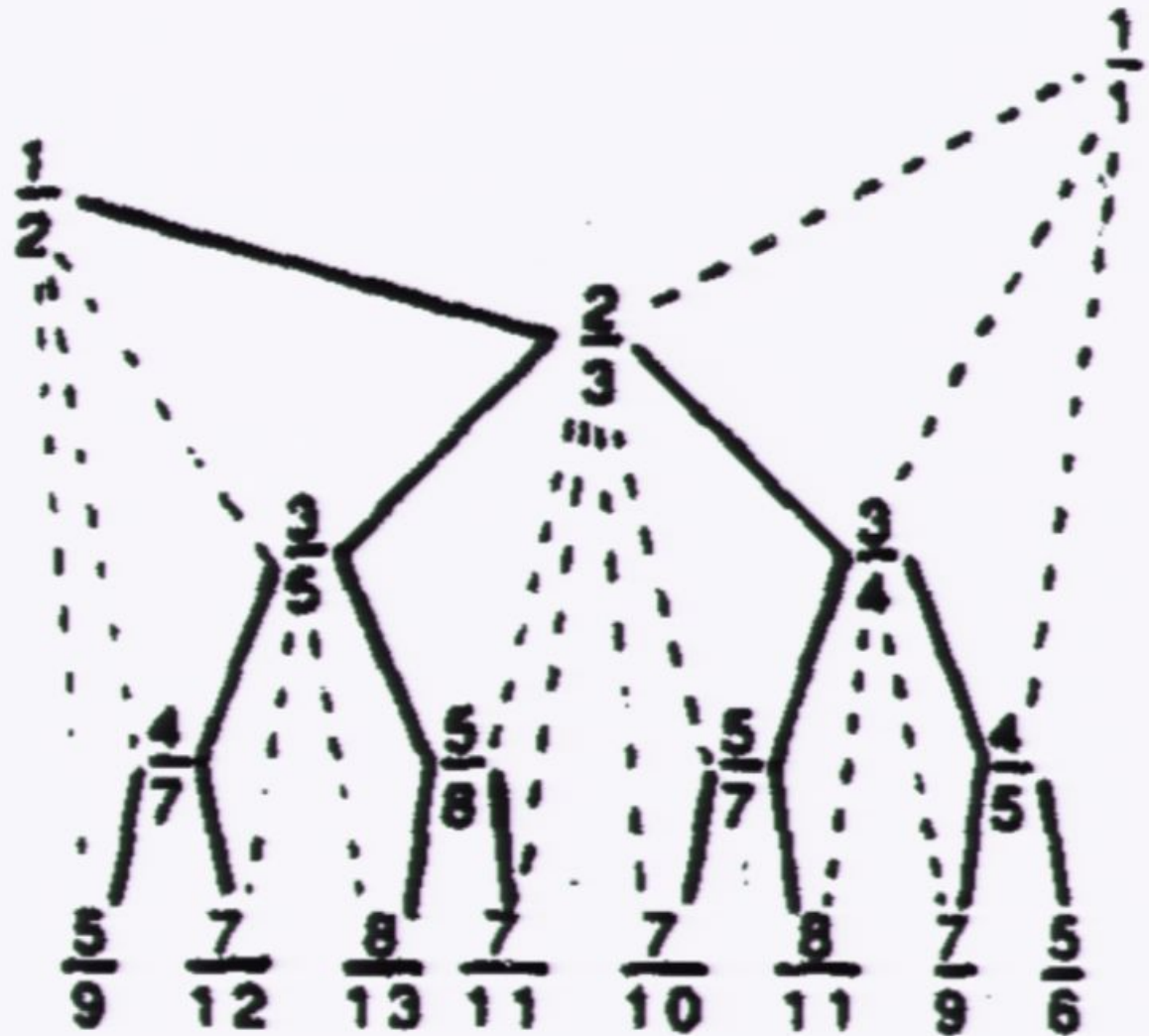
- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)



Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

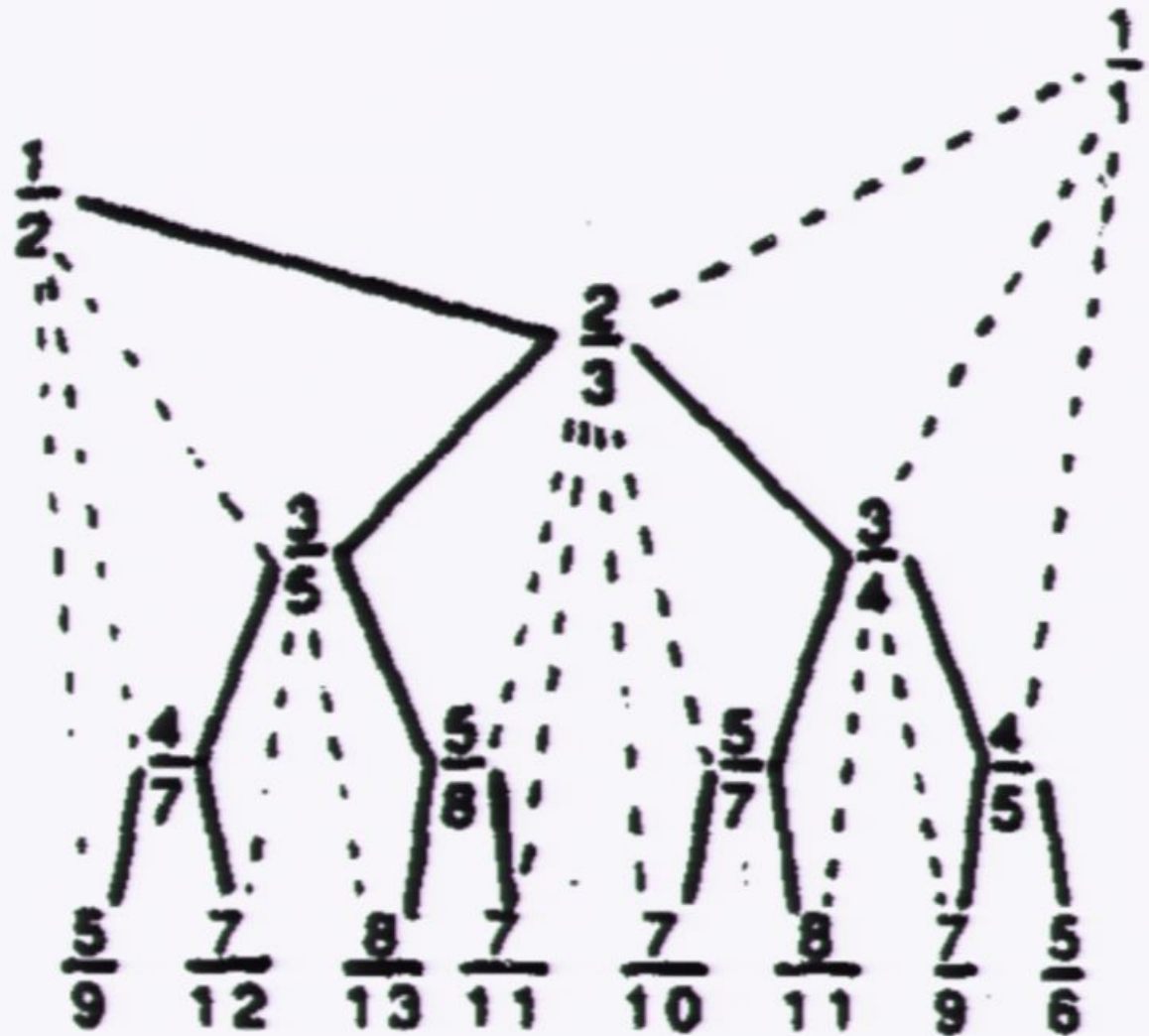
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Heavy lines: “young ancestors”

Dotted lines: “old ancestors”

- Note that it is already topologically equivalent to first (would be, if not for the quasi bifurcations)

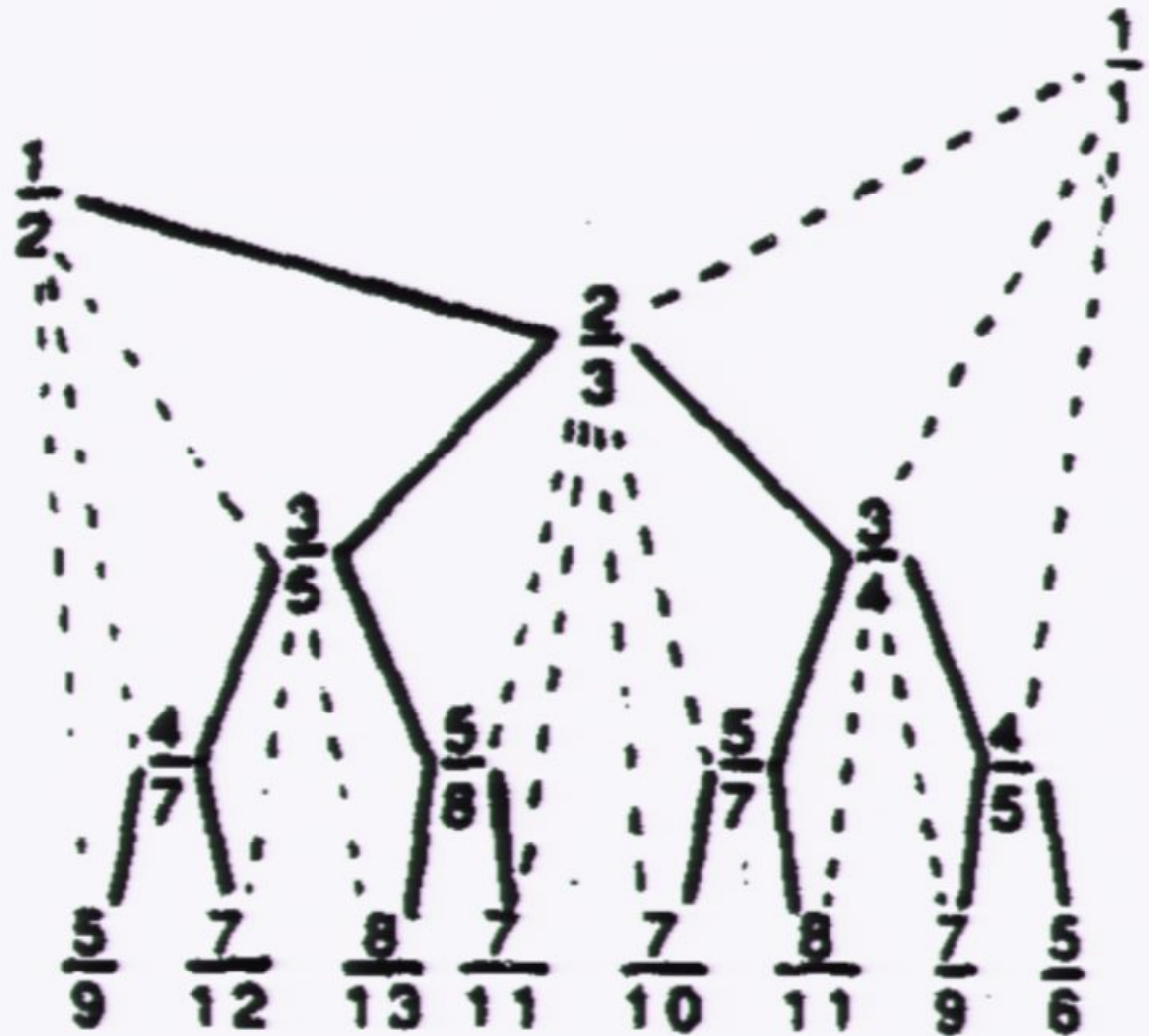




Heavy lines: “young  
ancestors”

Dotted lines: “old  
ancestors”

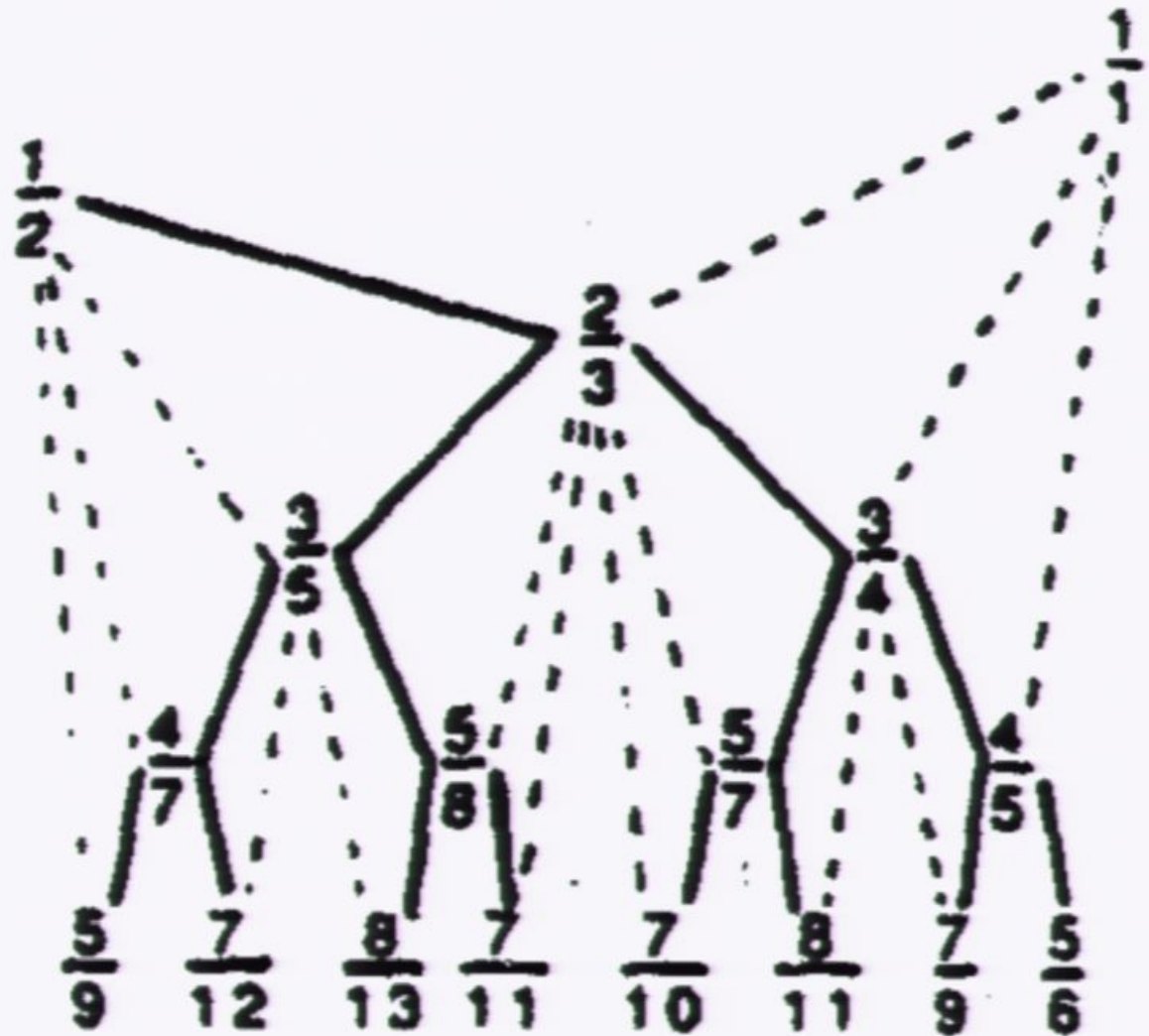
- Note that it is already  
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Heavy lines: “young  
ancestors”

Dotted lines: “old  
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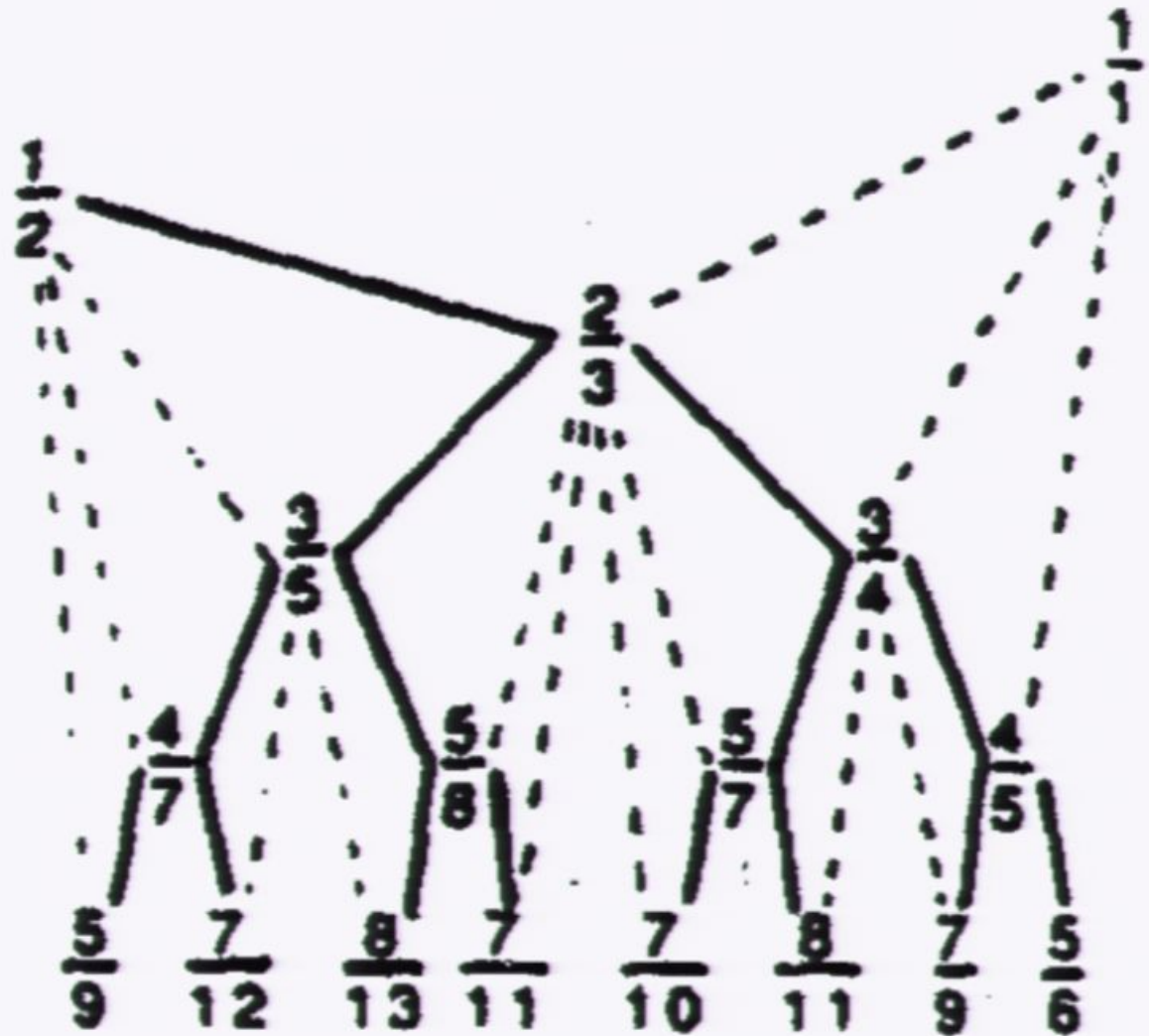
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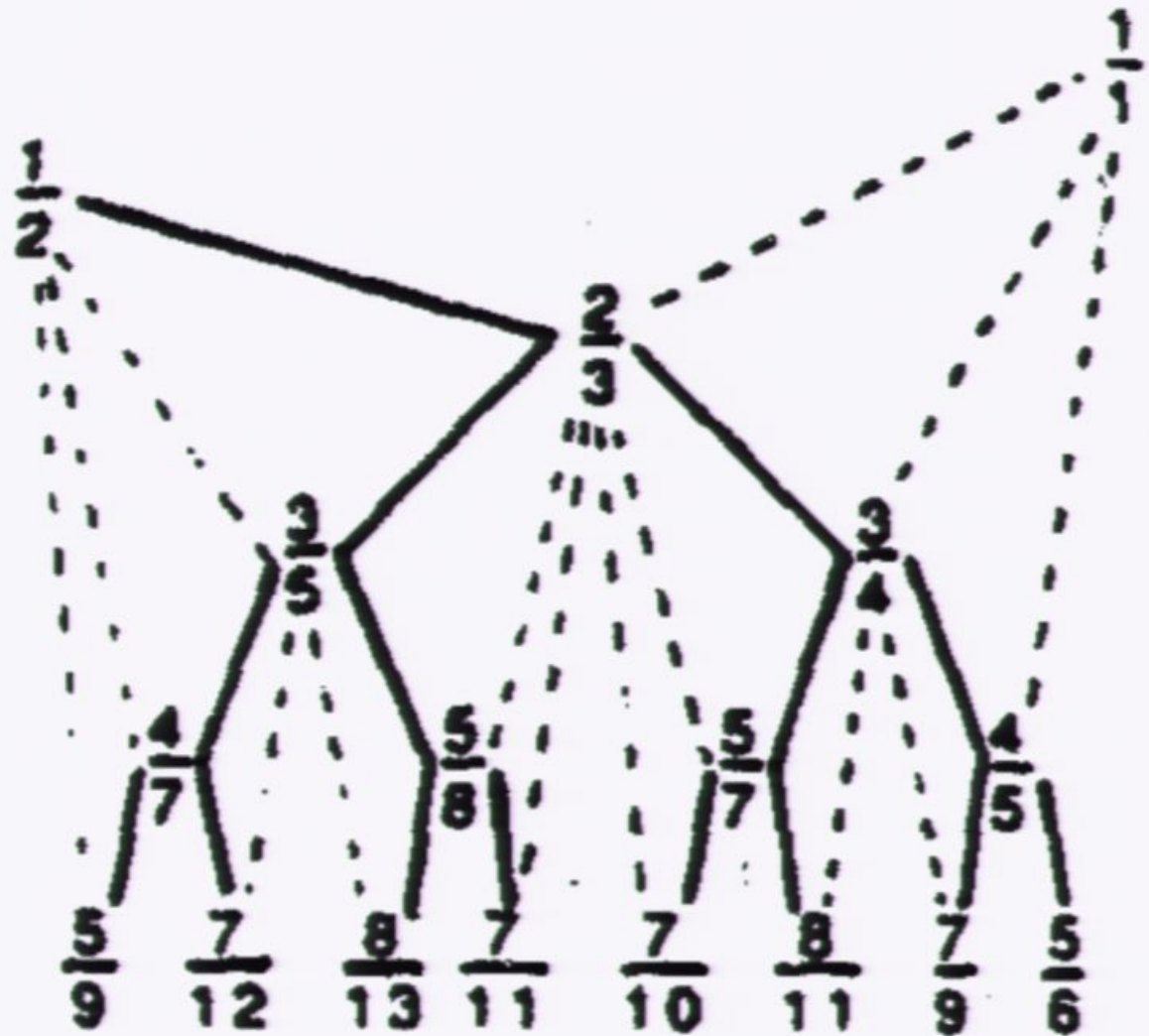




Heavy lines: “young  
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Dotted lines: “old  
ancestors”

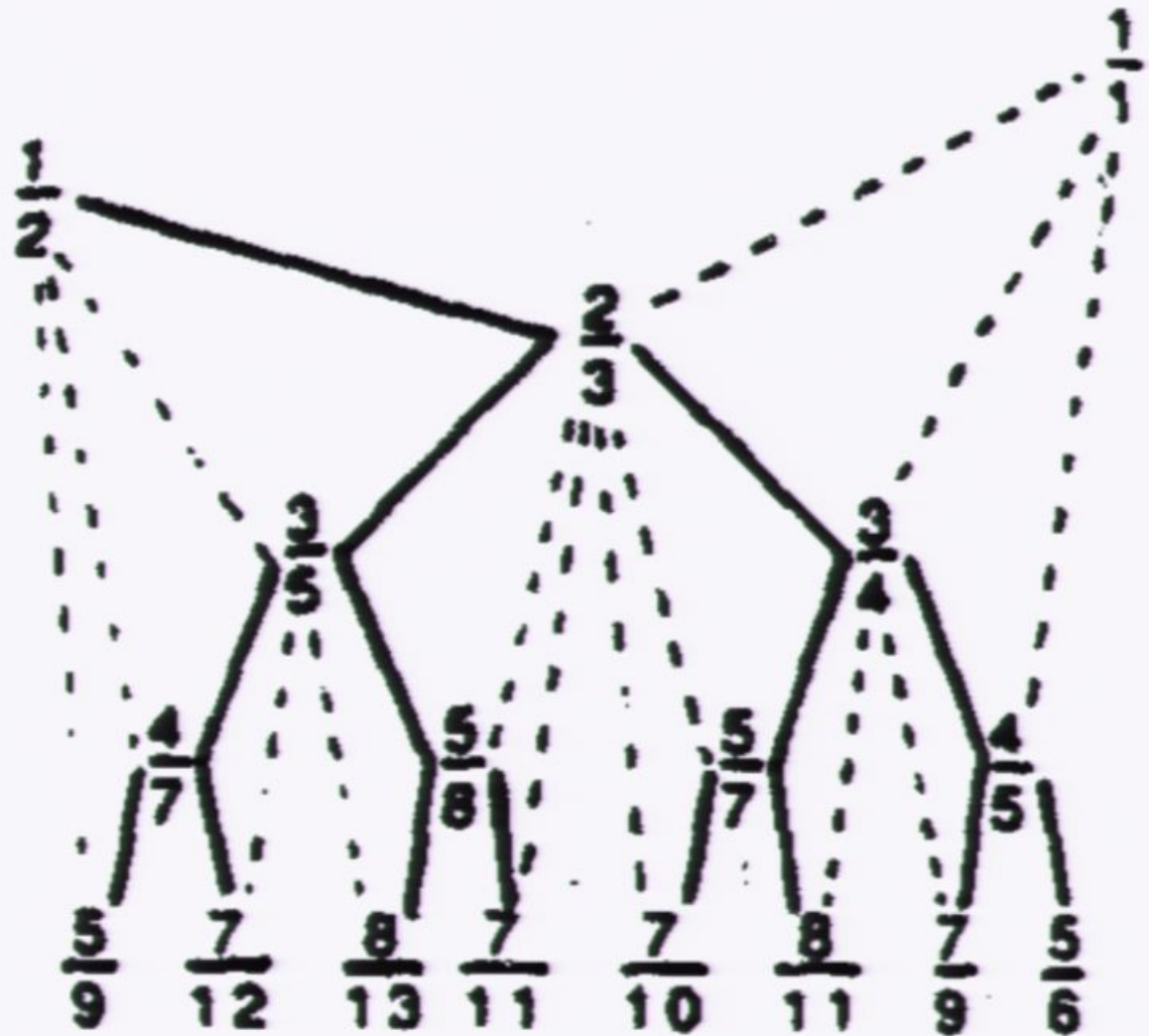
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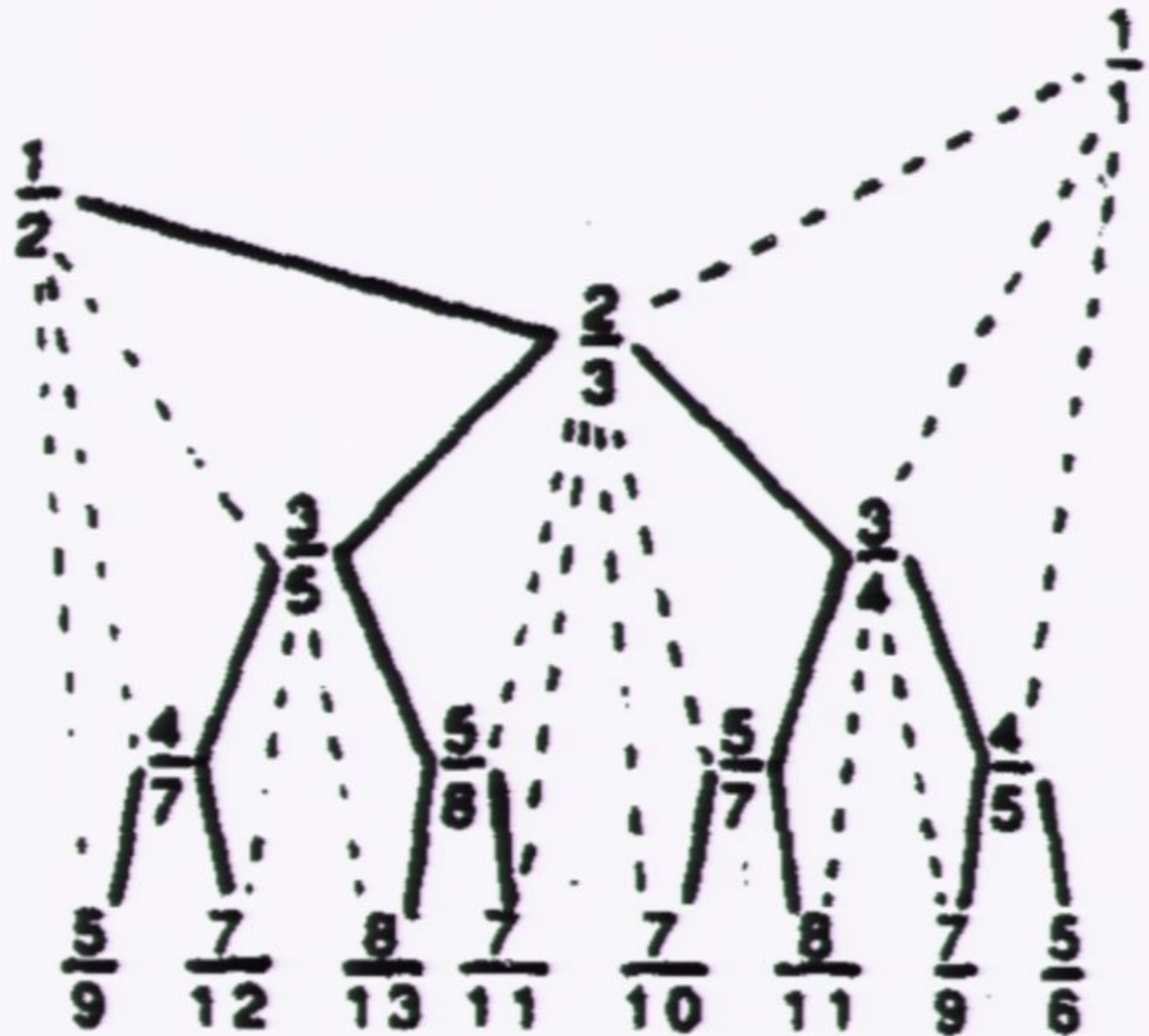
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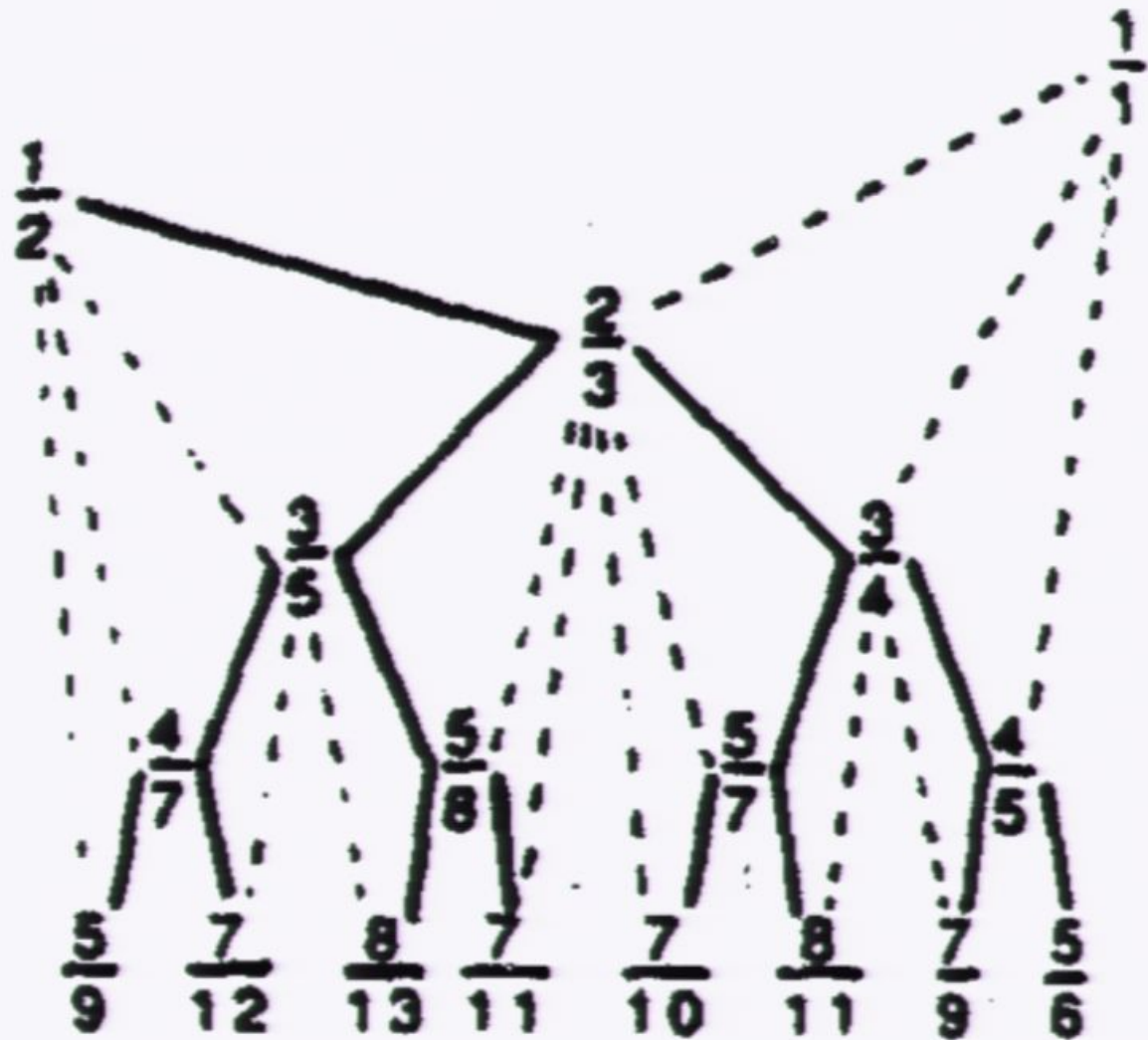




Heavy lines: “young ancestors”

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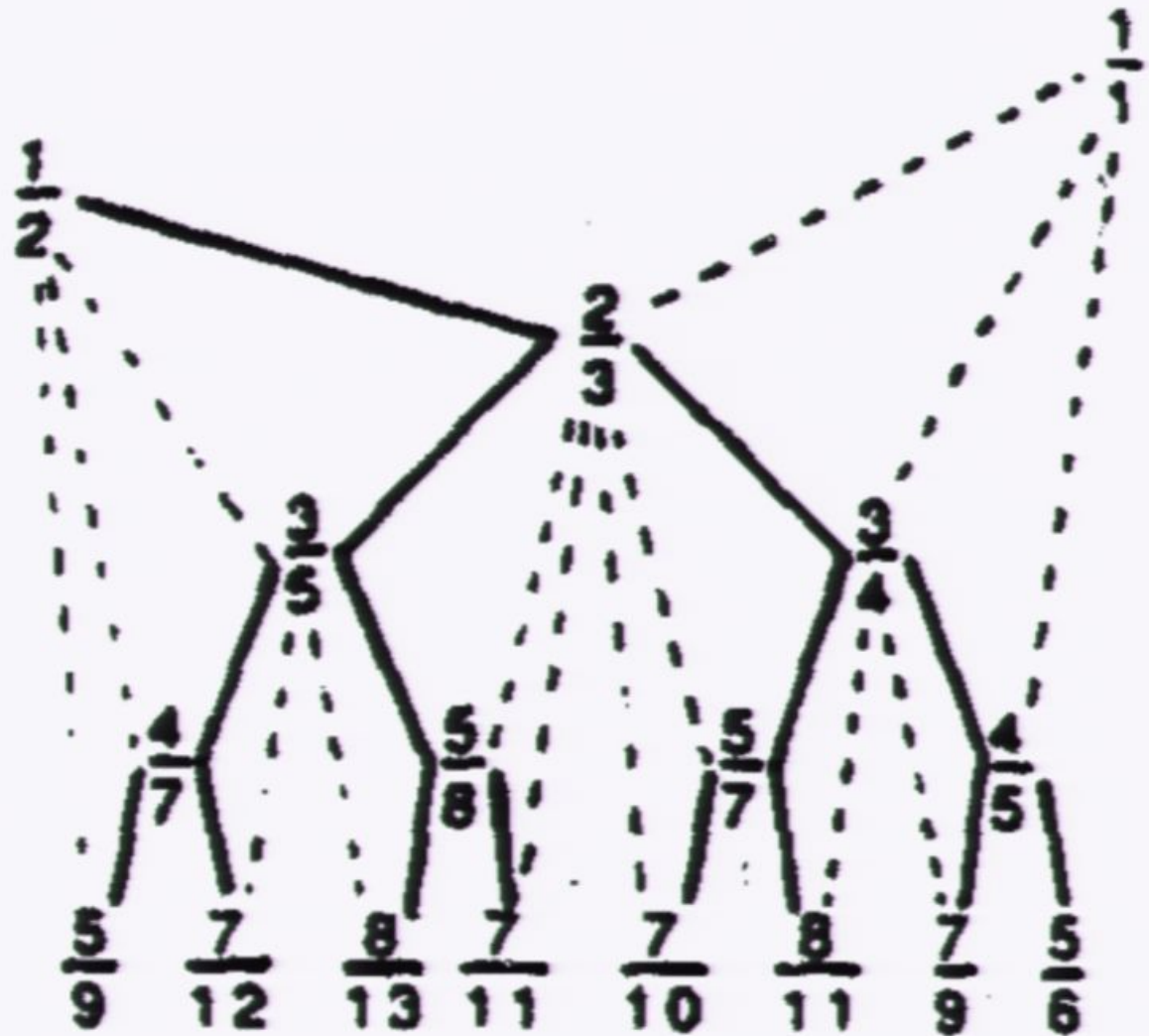
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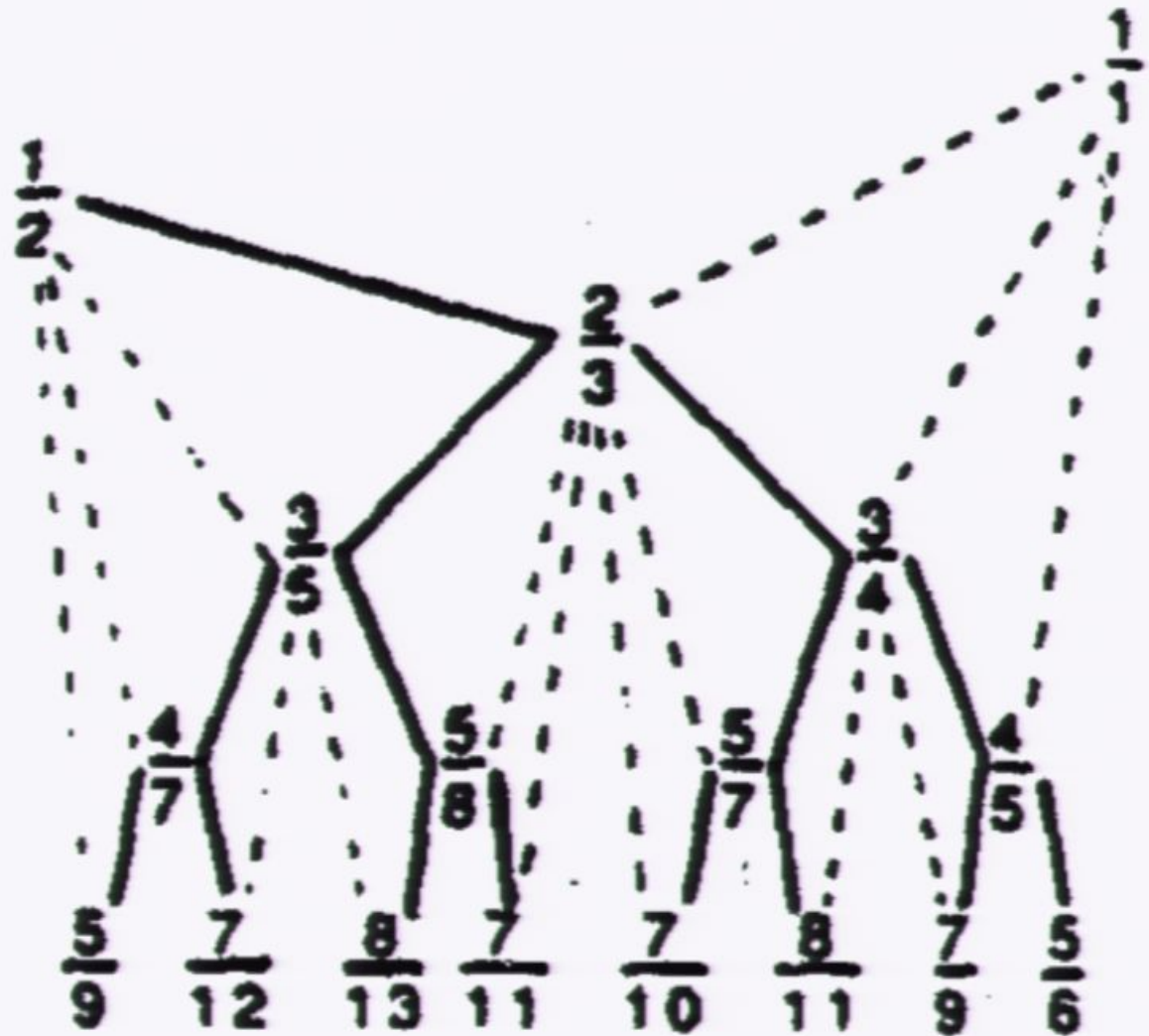
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 Farey graph  $\Leftrightarrow$  Cayley Tree       $\Leftrightarrow$   $\Updownarrow$   
    Cayley Tree

- So, upon decreasing  $y$ , the minimal energy configuration will follow the Fibonacci path

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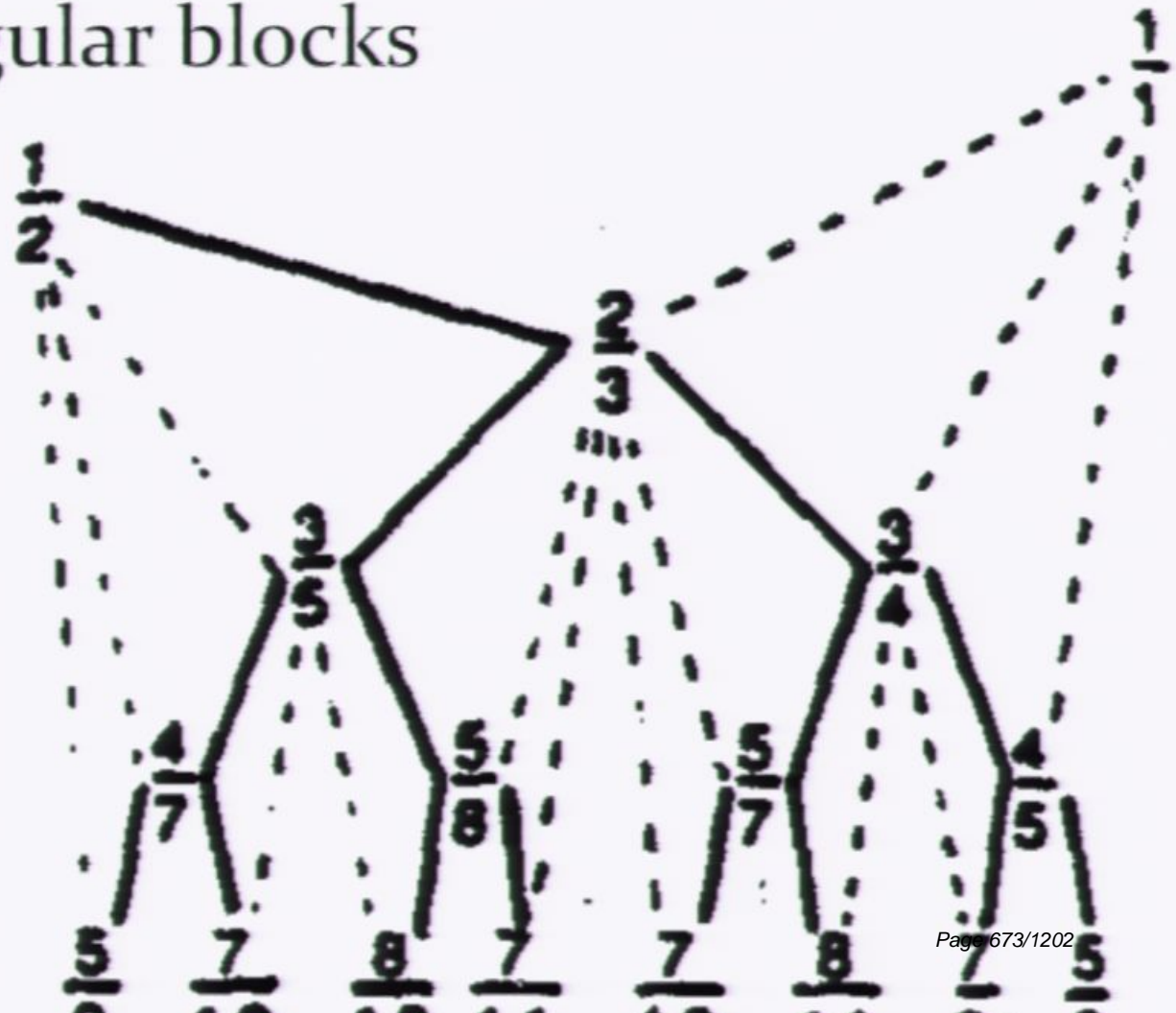
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So, entire second graph consists of standard triangular blocks

- Farey graph also consists of same blocks

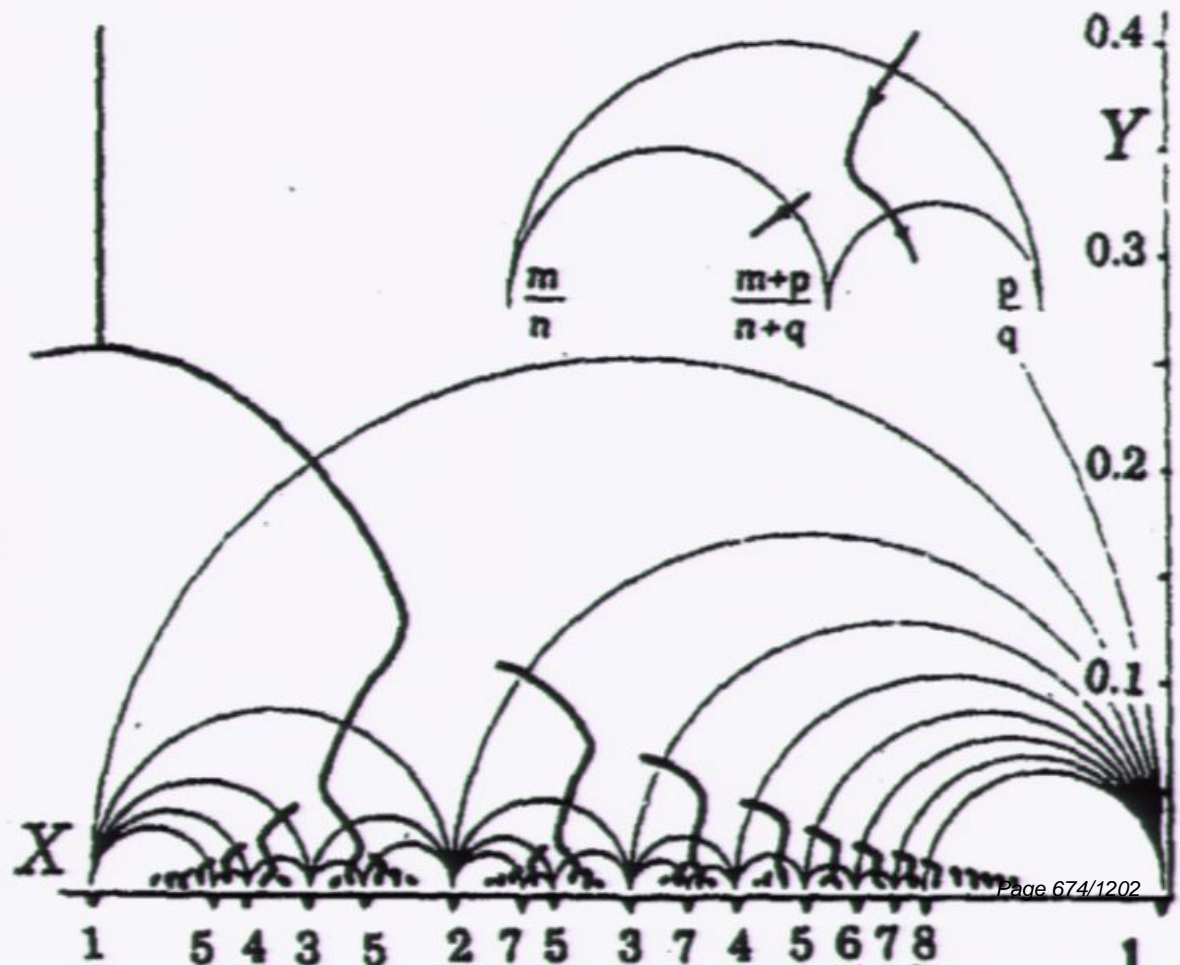




# Energy minima

Vary  $y$  from  
 $+\infty$  to 0

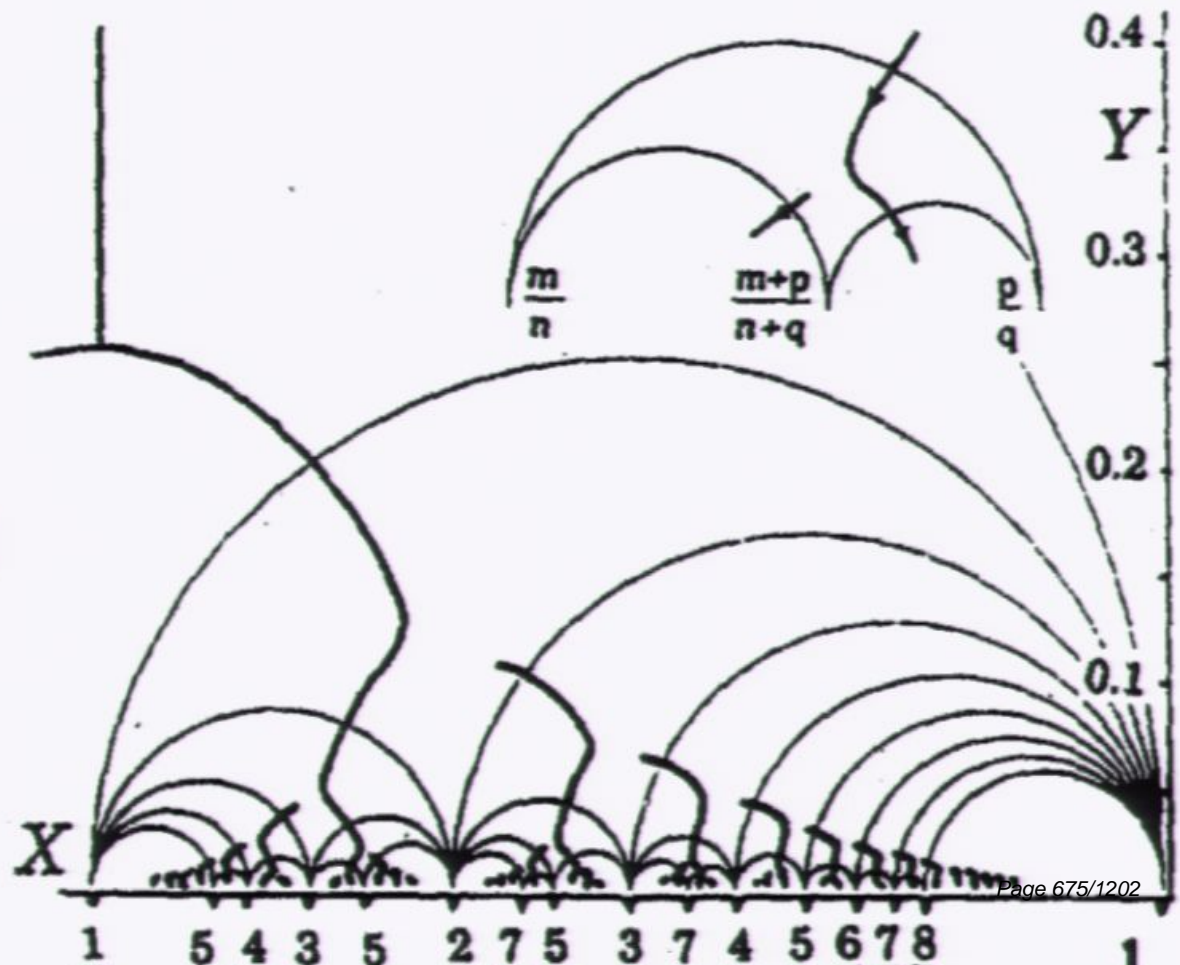
Quasi bifurcations lead  
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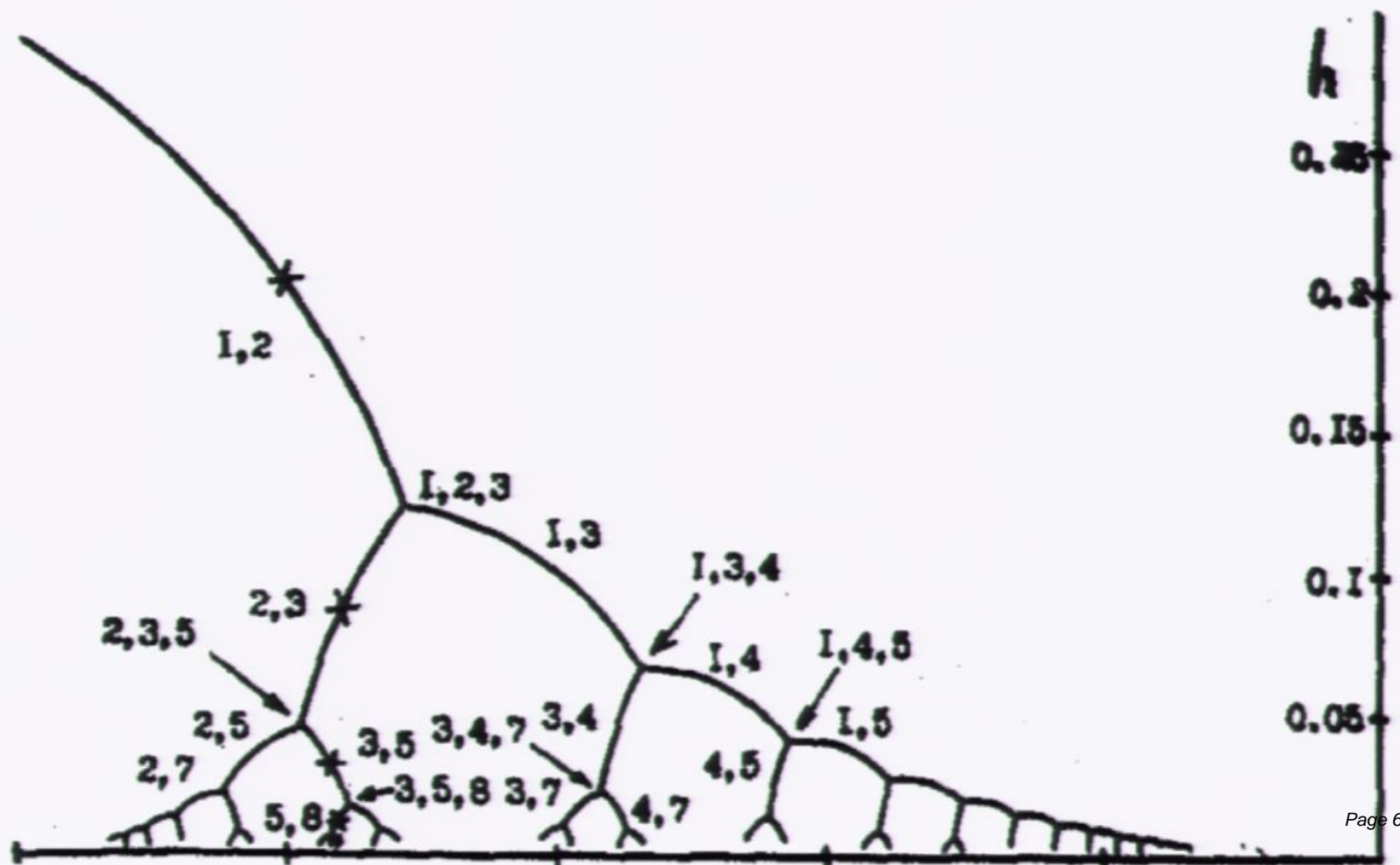
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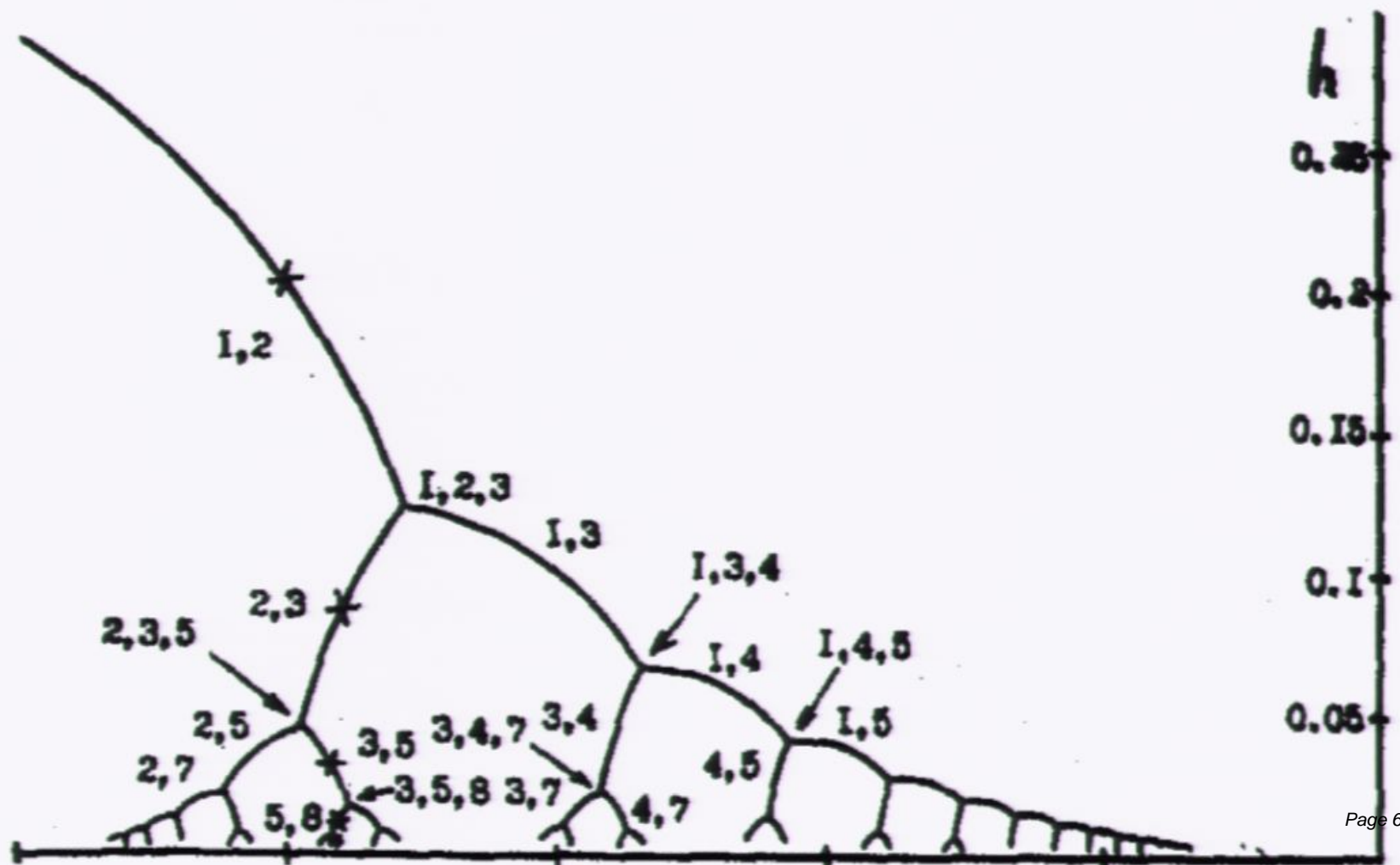


# Cayley tree for lattices

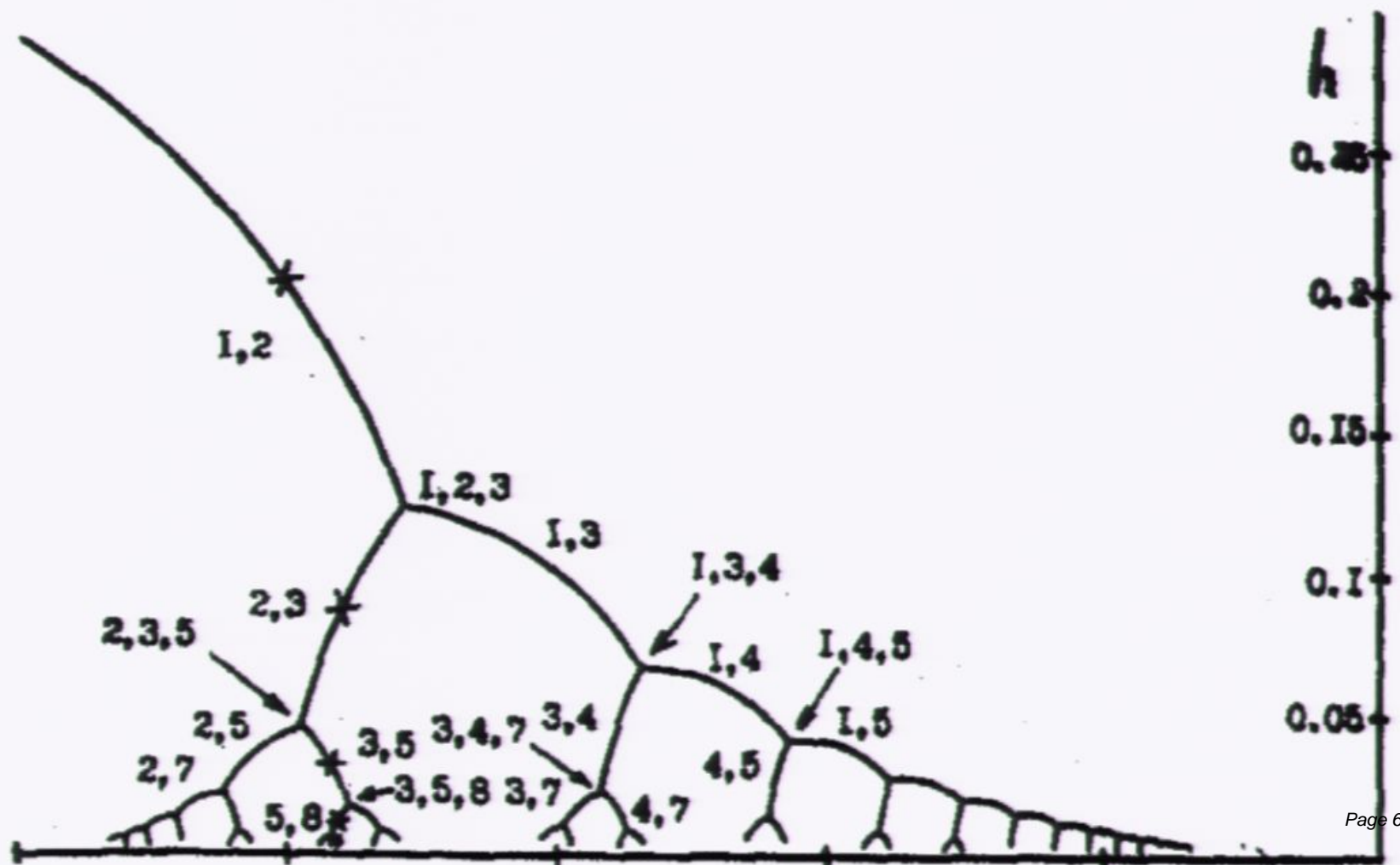




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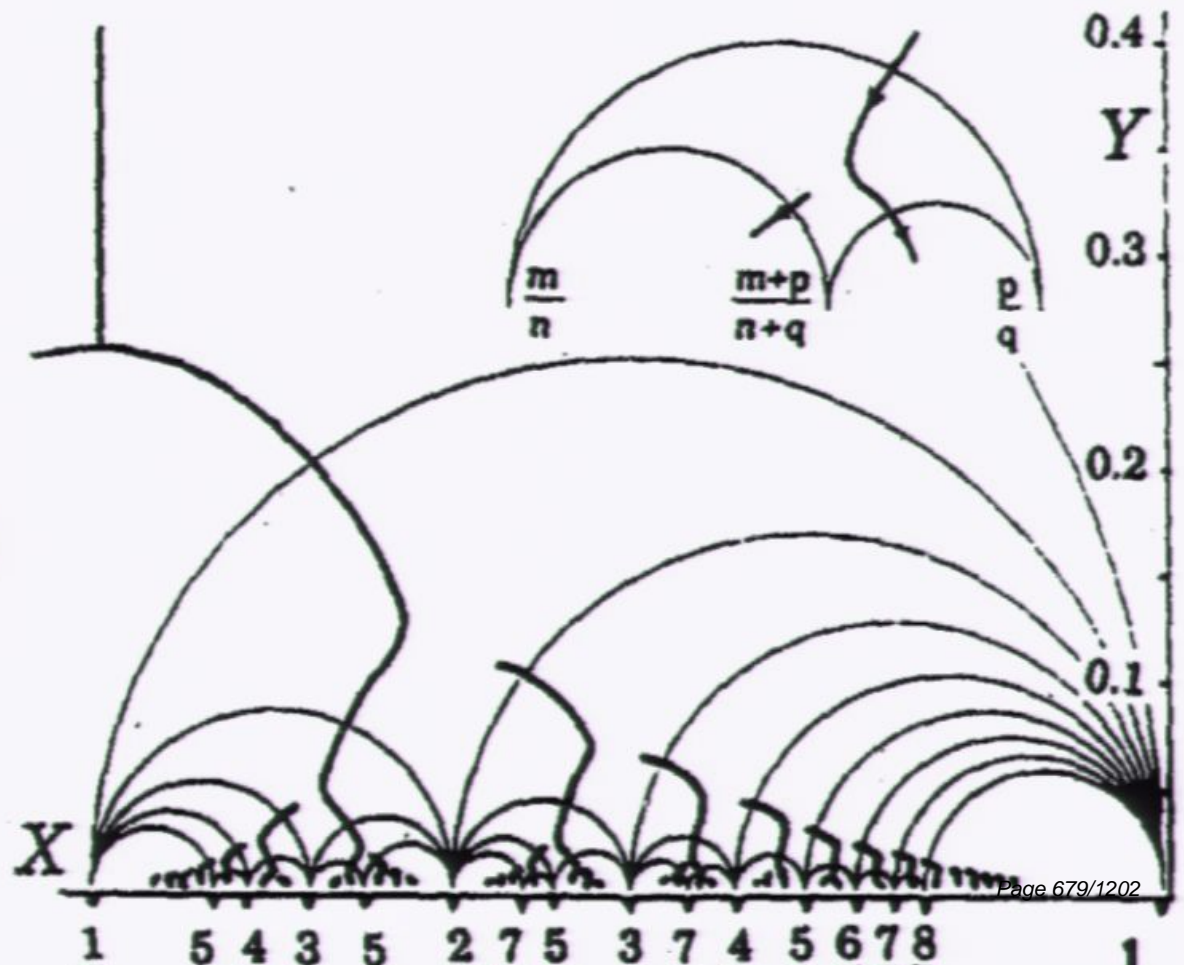
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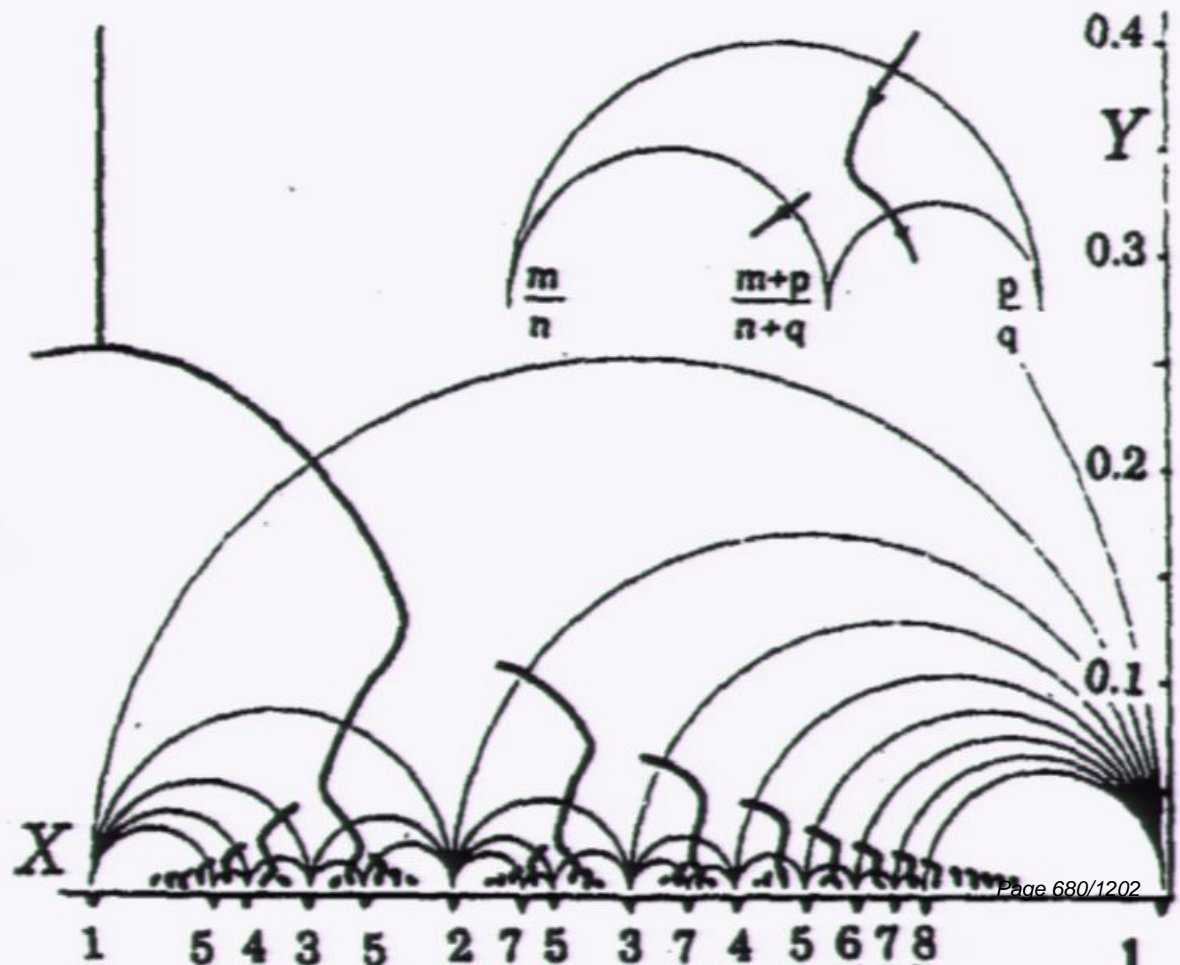




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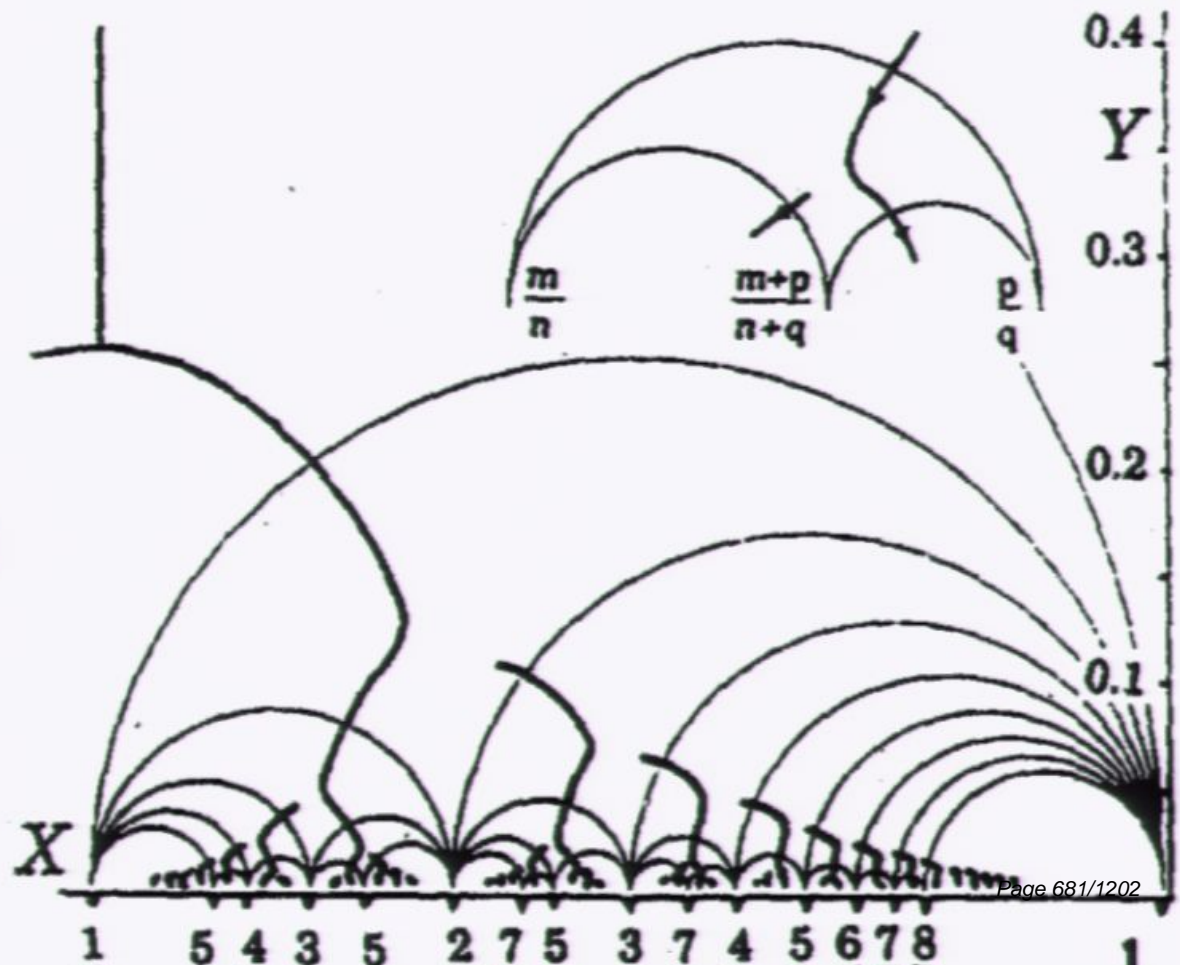
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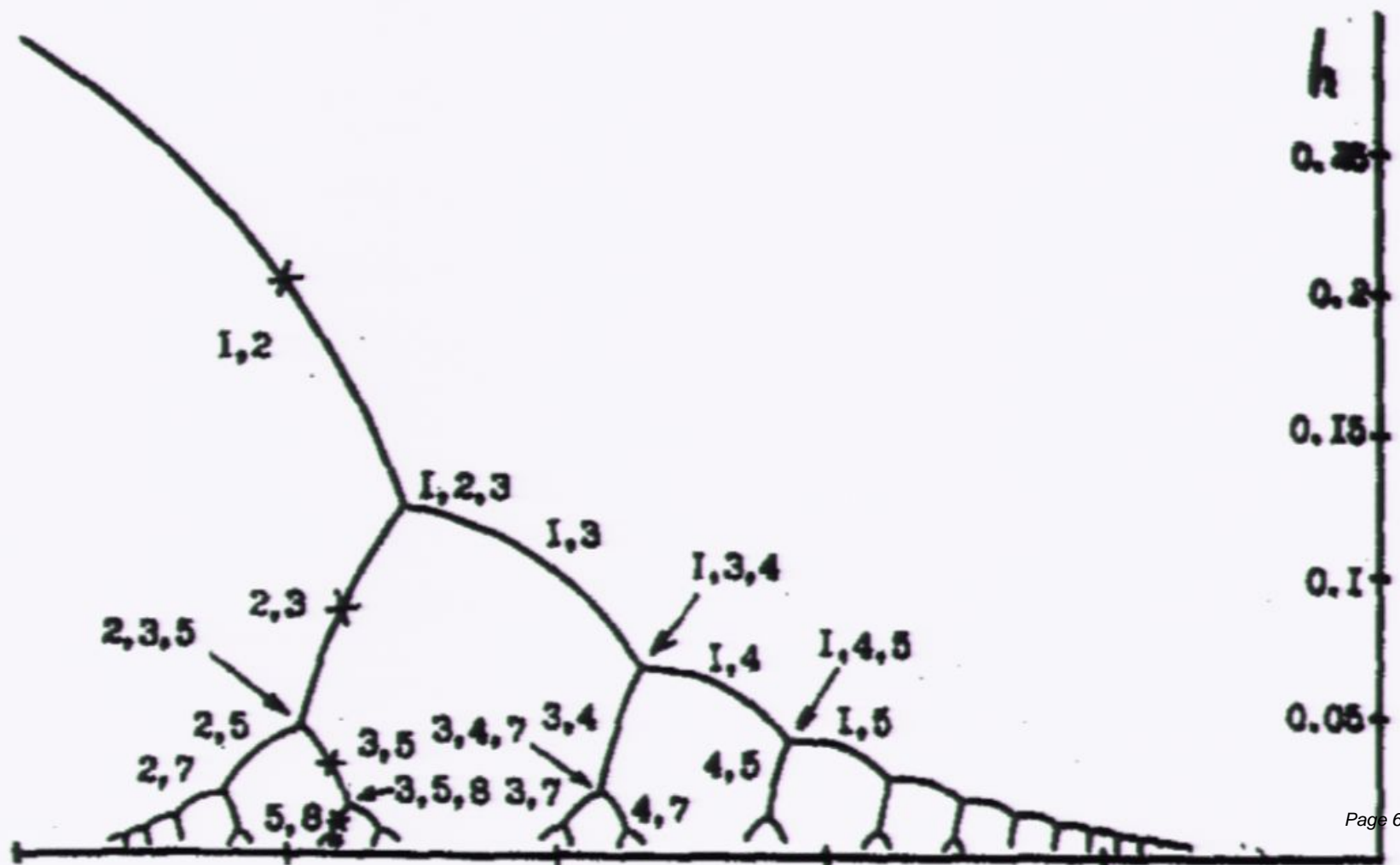
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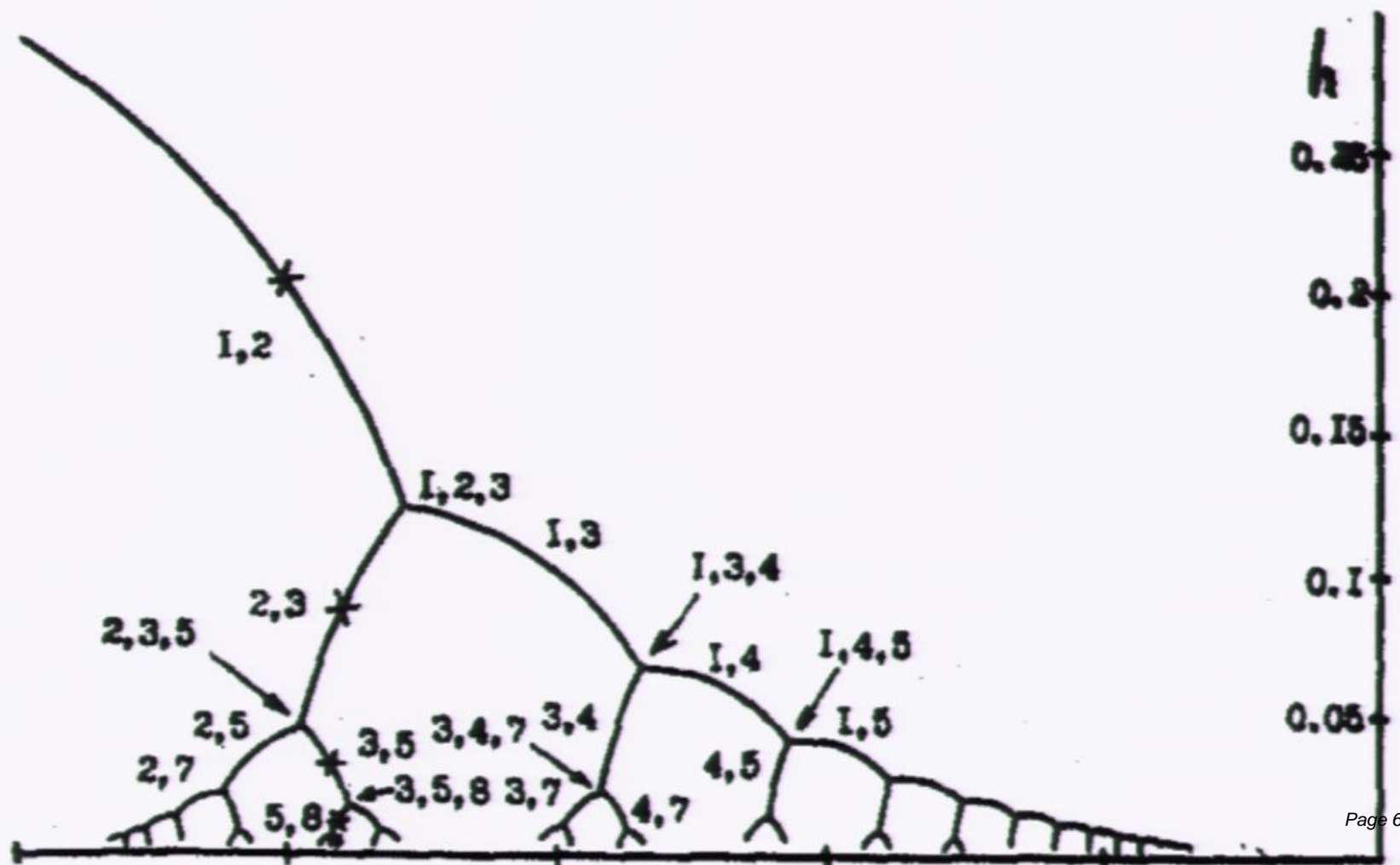


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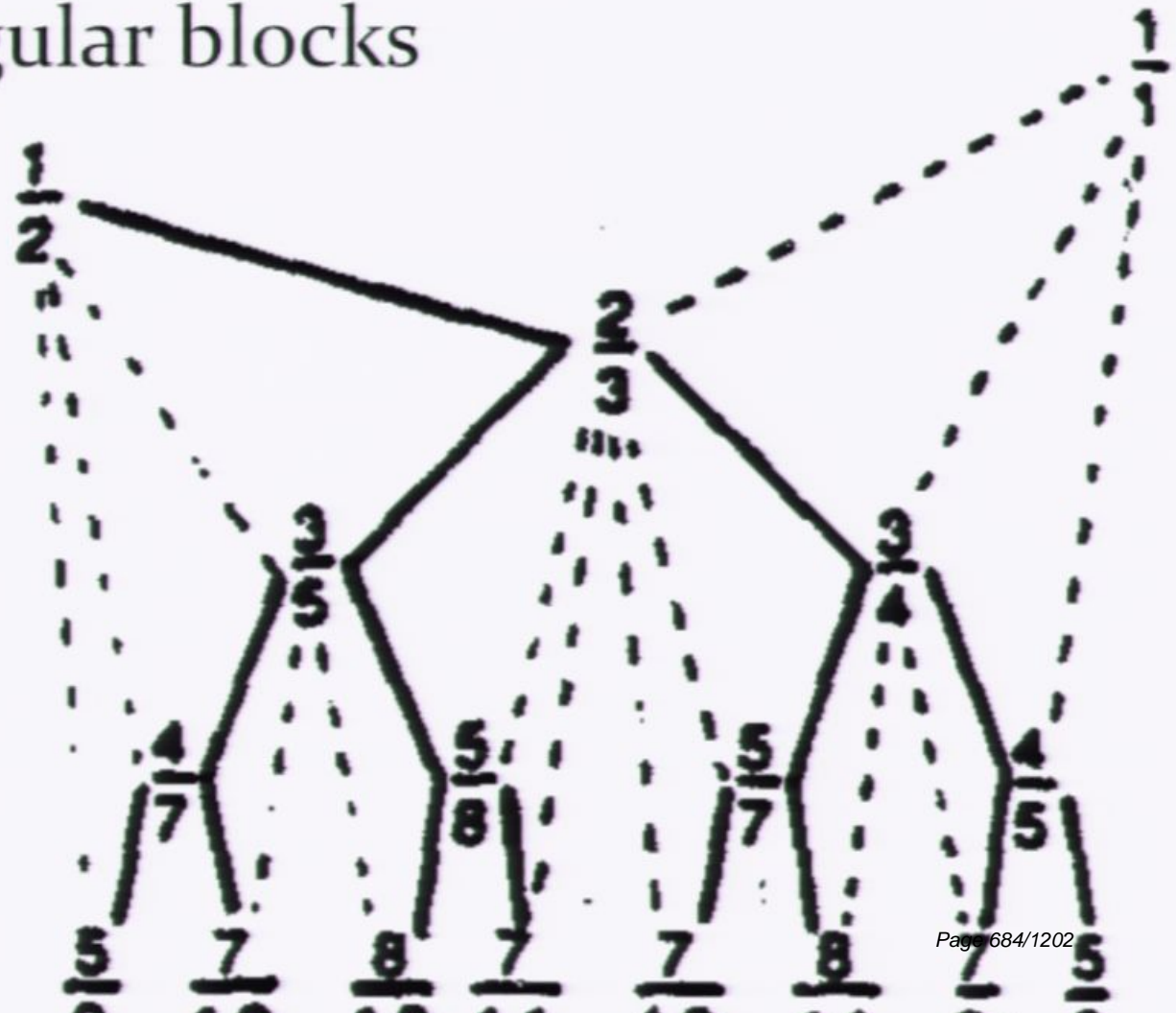


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Further mathematical arguments can prove that the trajectories are topologically stable under changes in  $U(\lambda)$  (Ref. 2)

This explains why this phyllotaxis is so prevalent in nature.



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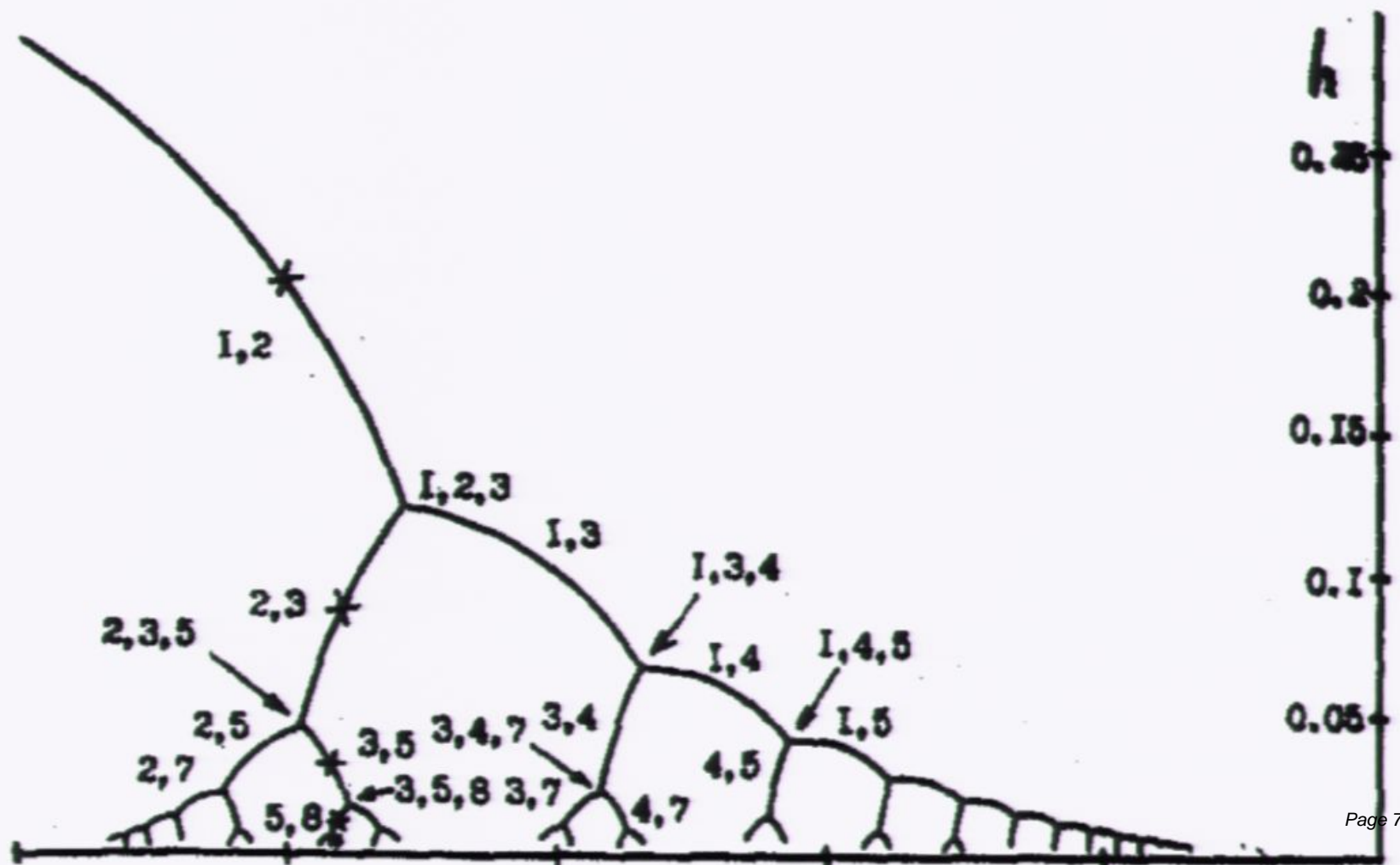
# Bibliography

- 1. L.S. Levitov, JETP Lett. **54**, 9 (1991)
- 2. L.S. Levitov, Europhys. Lett. **14**, 553 (1991)

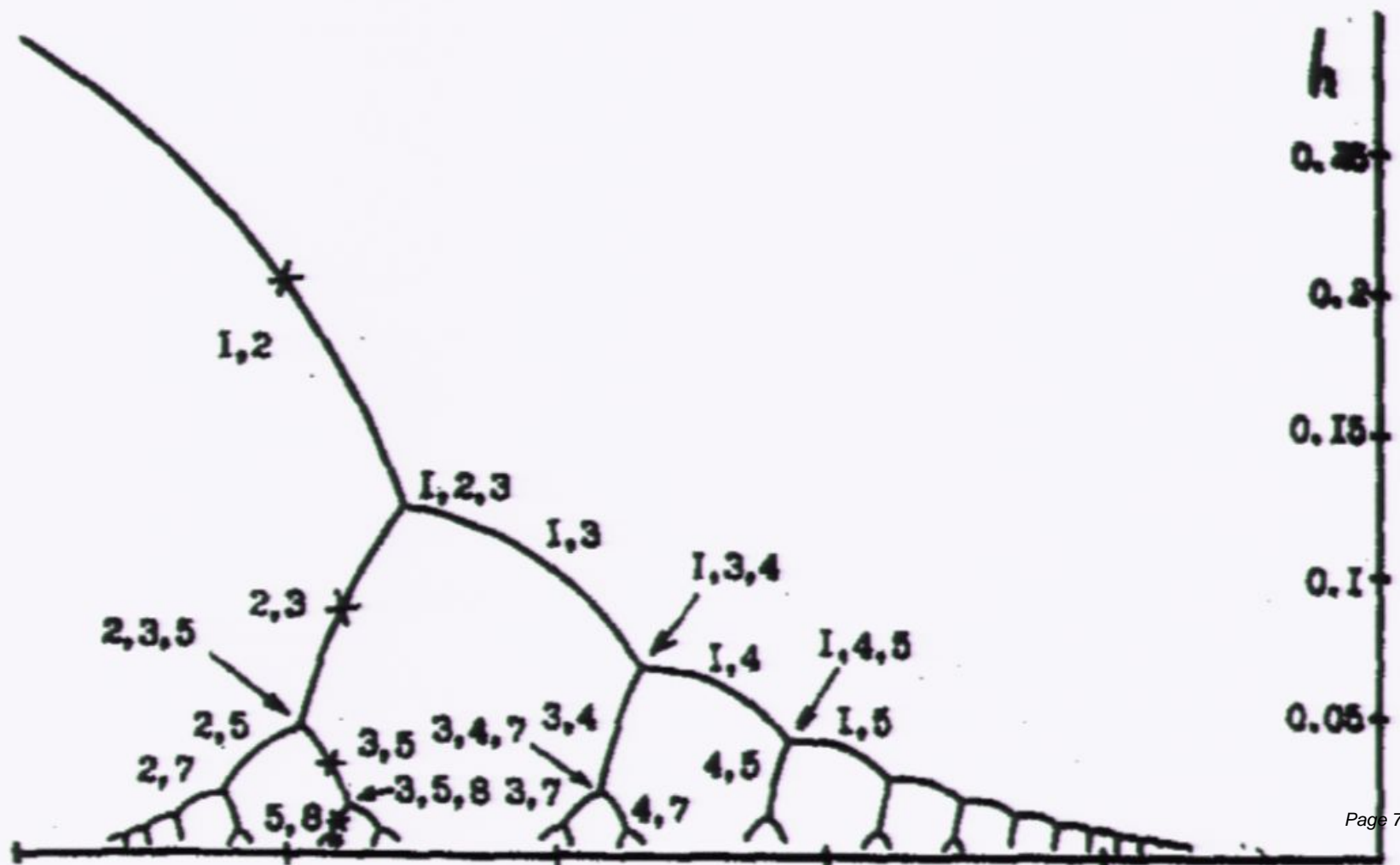
## Questions?



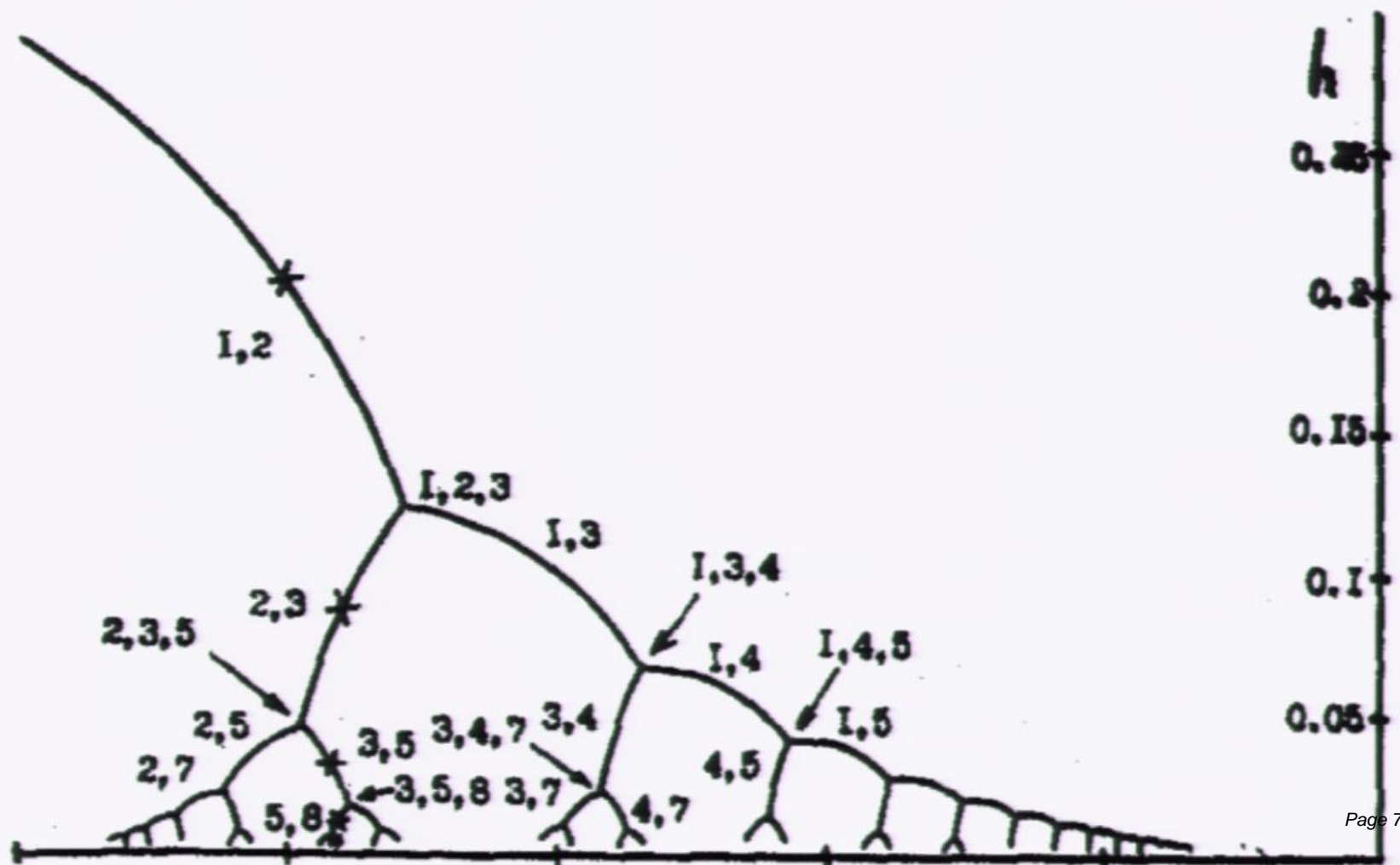
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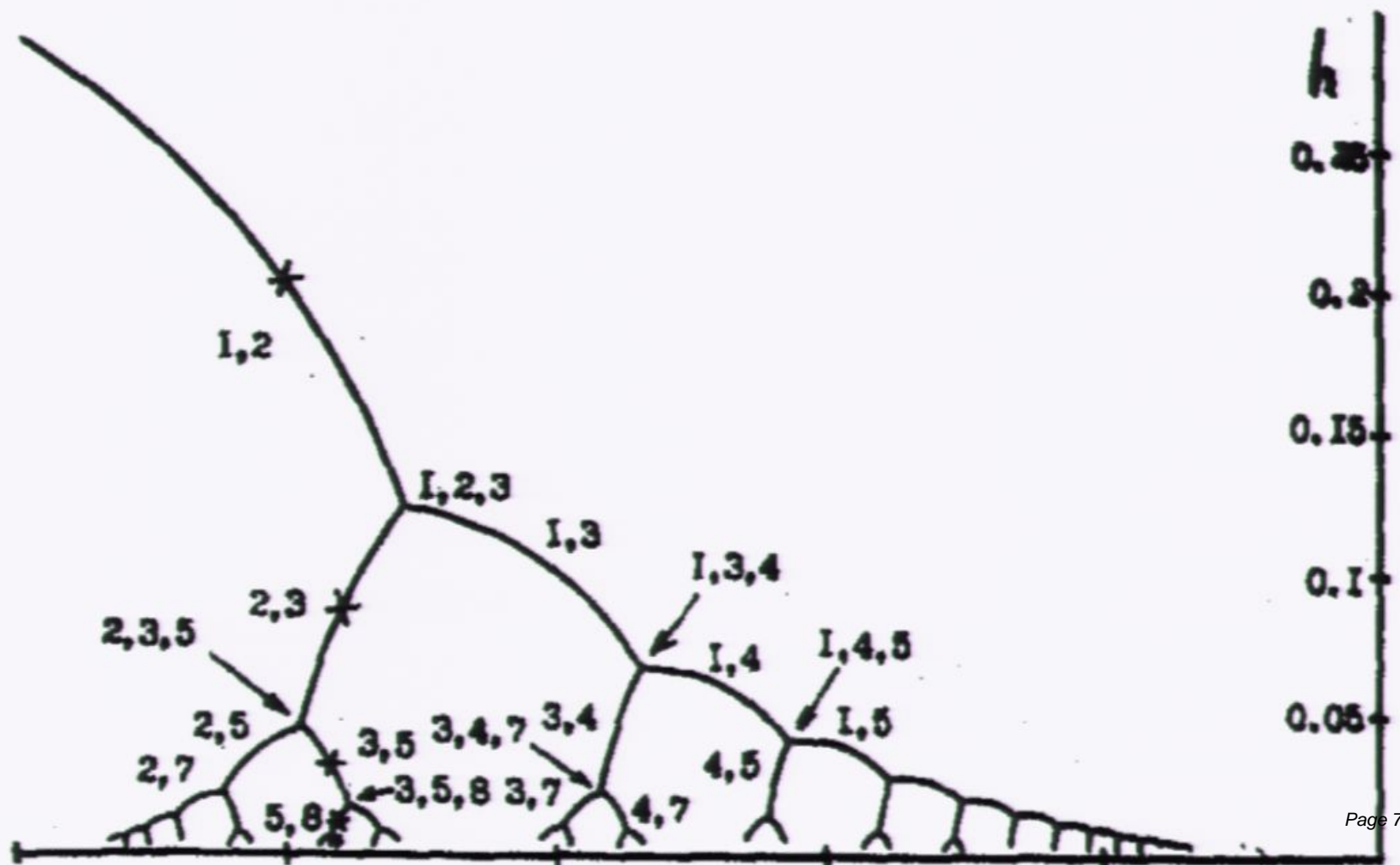


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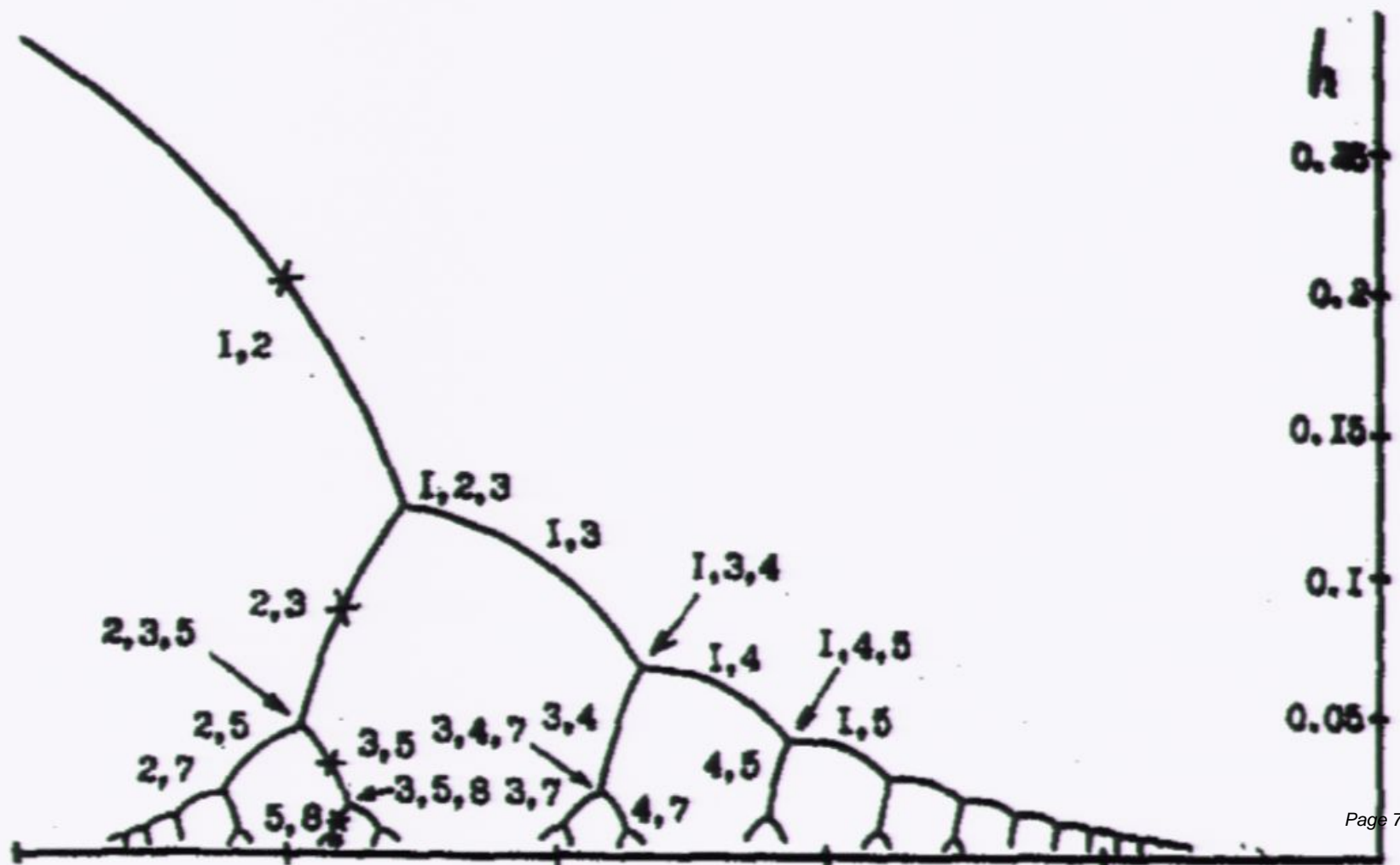




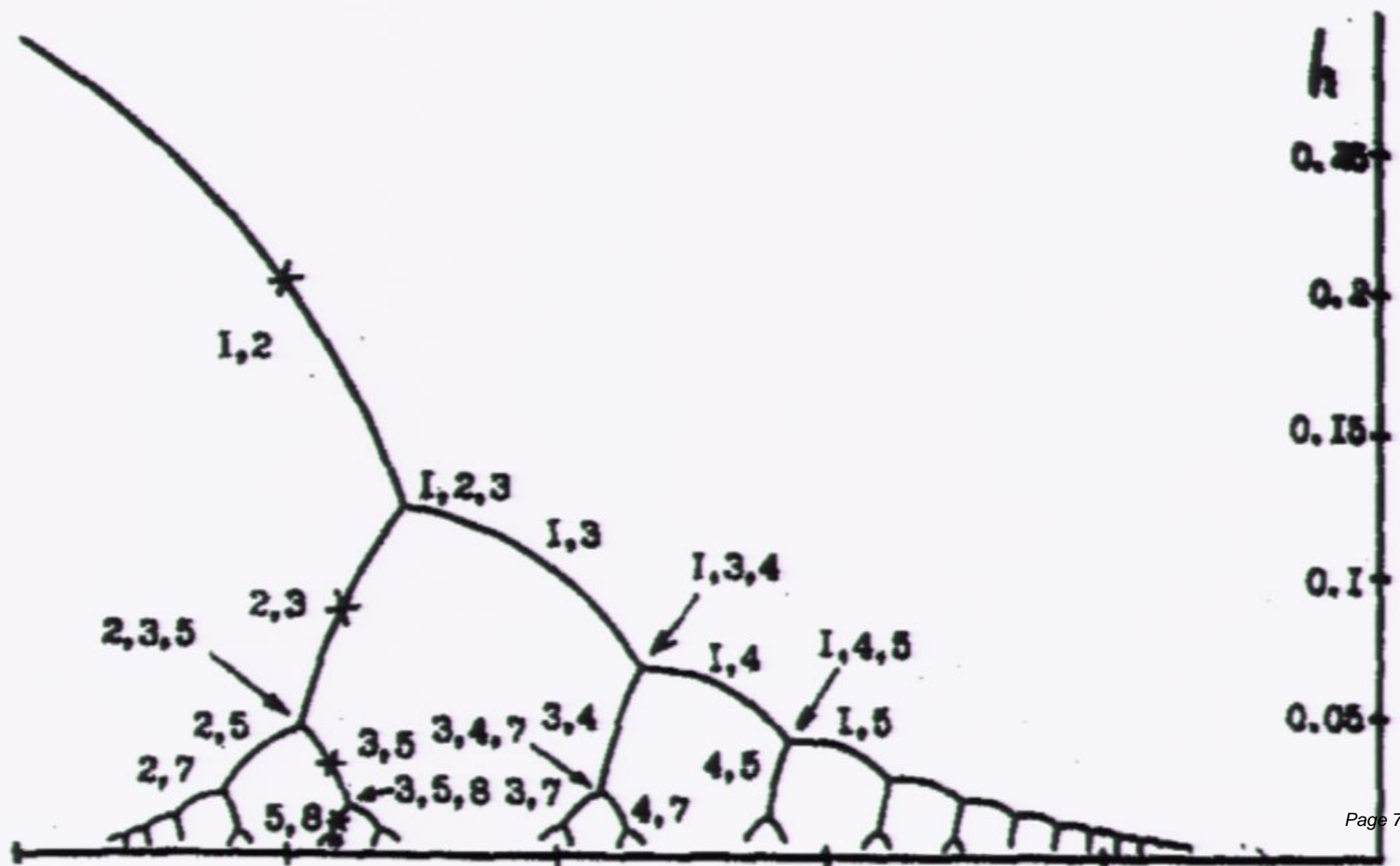
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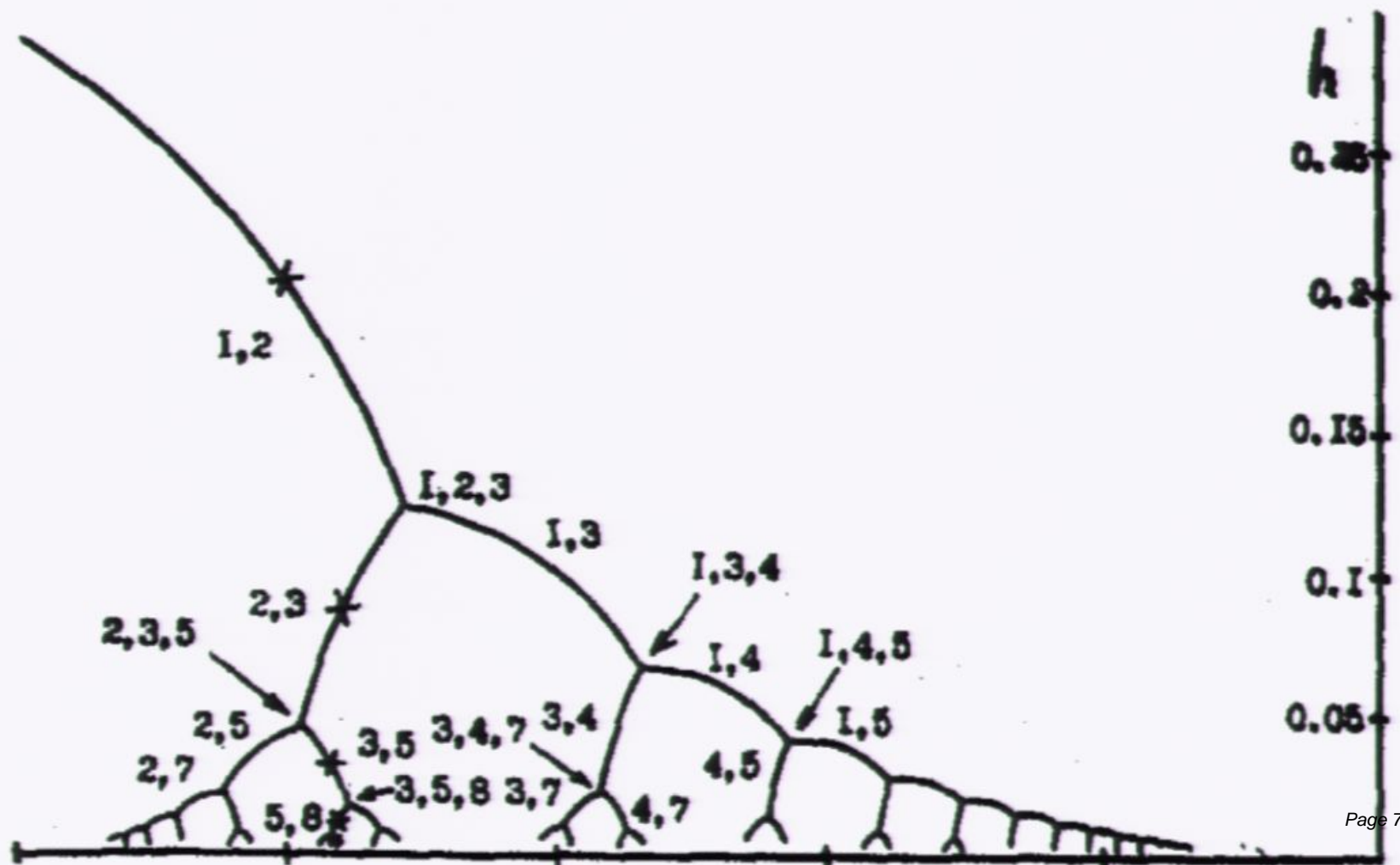


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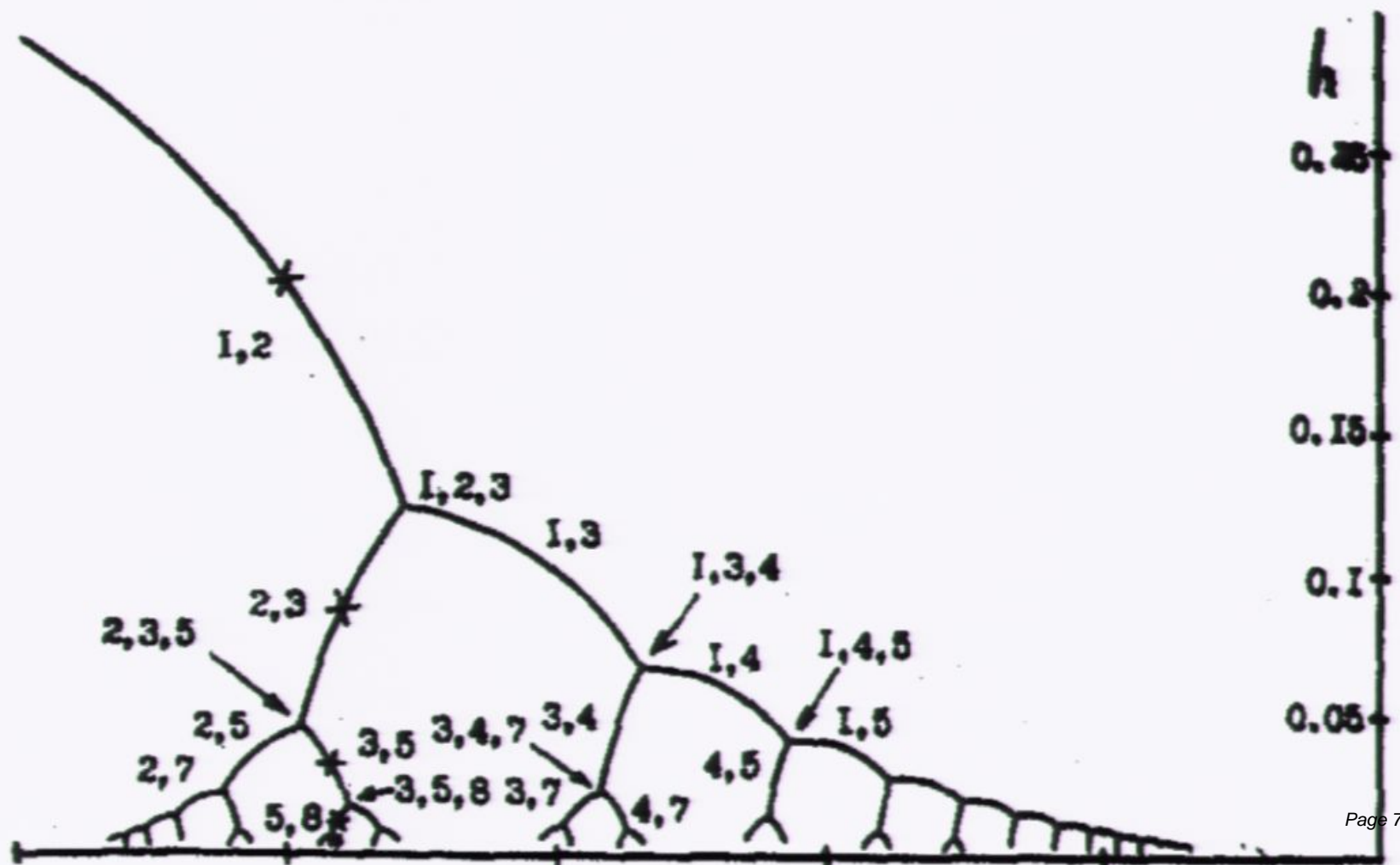




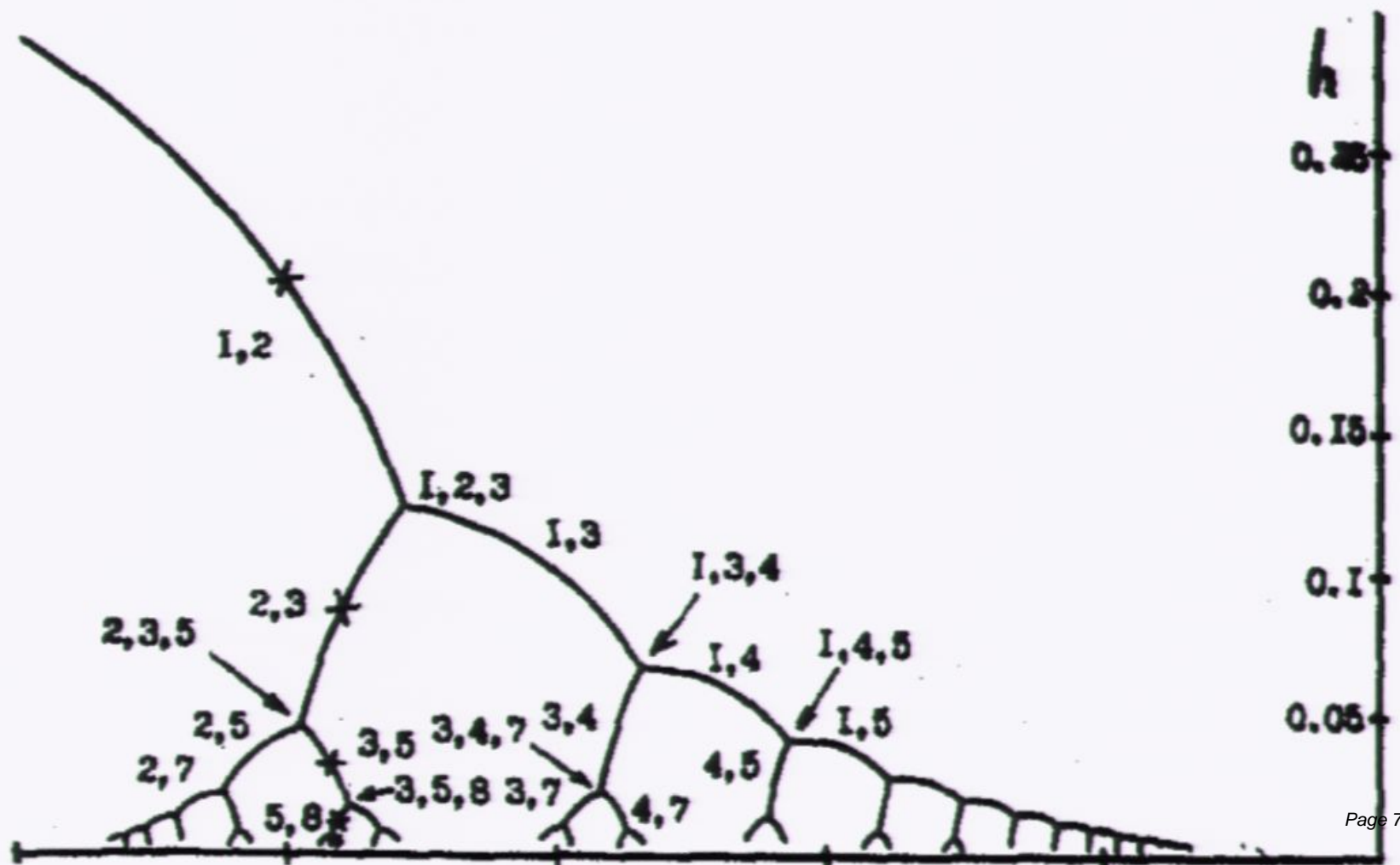
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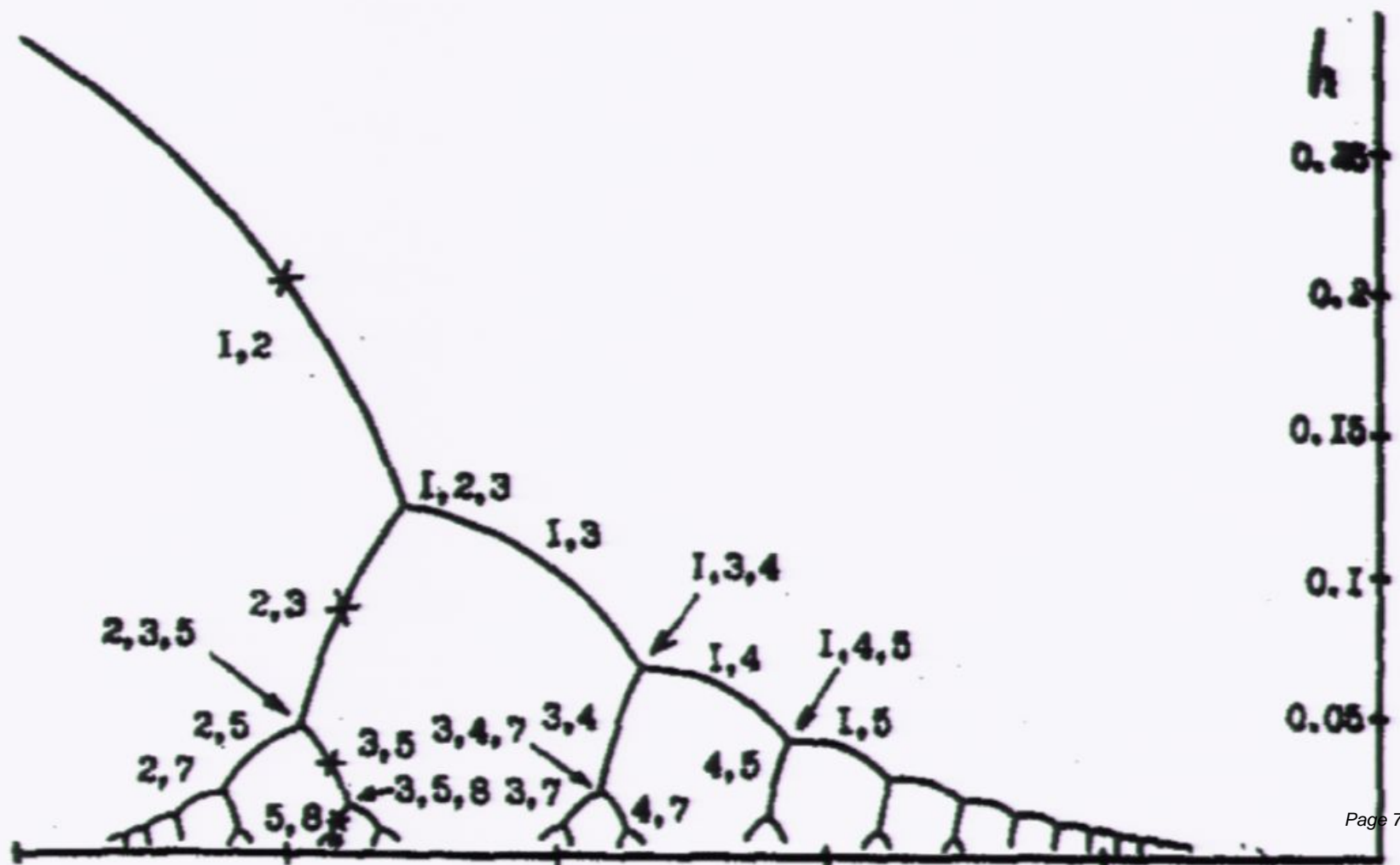


# Cayley tree for lattices

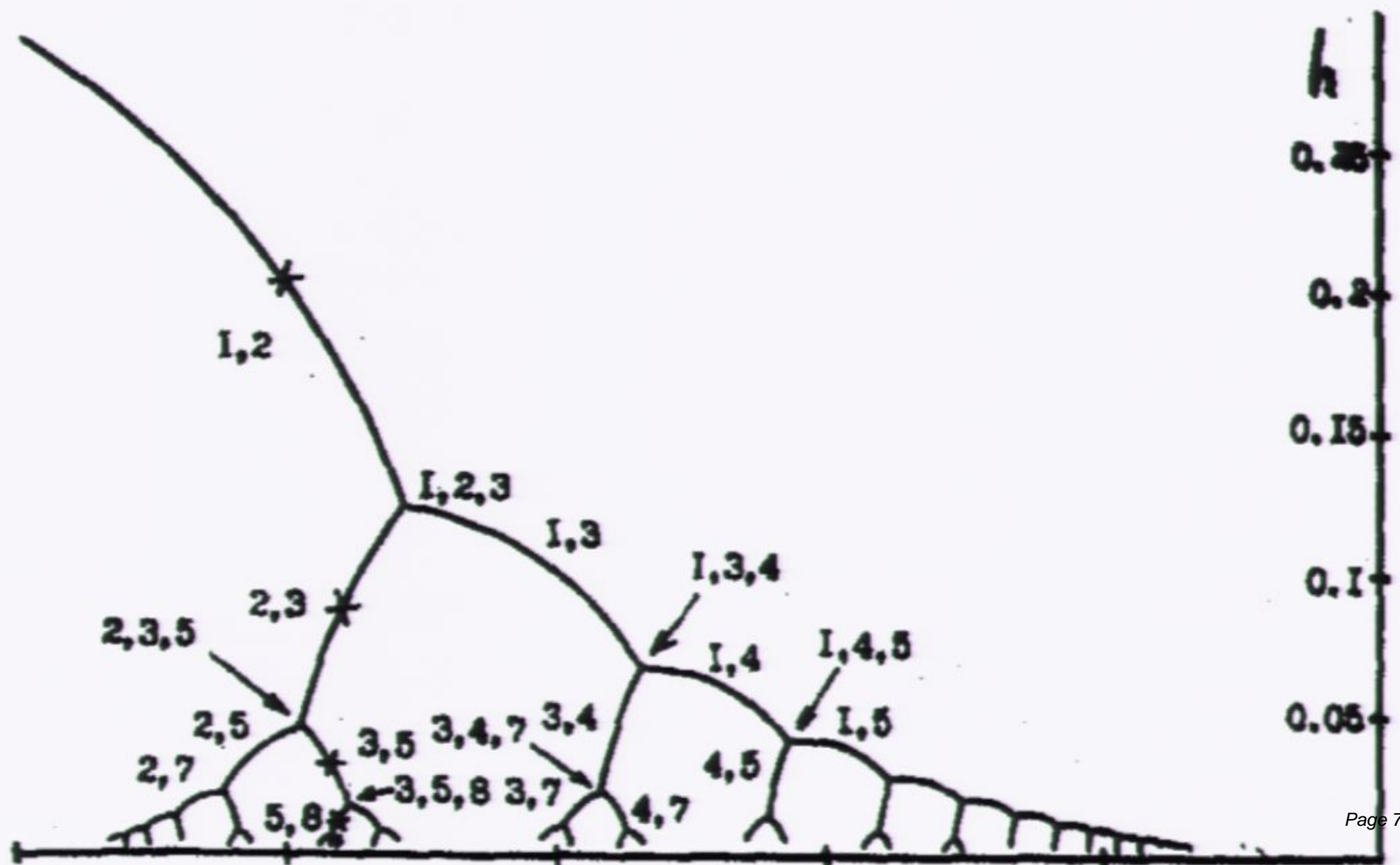




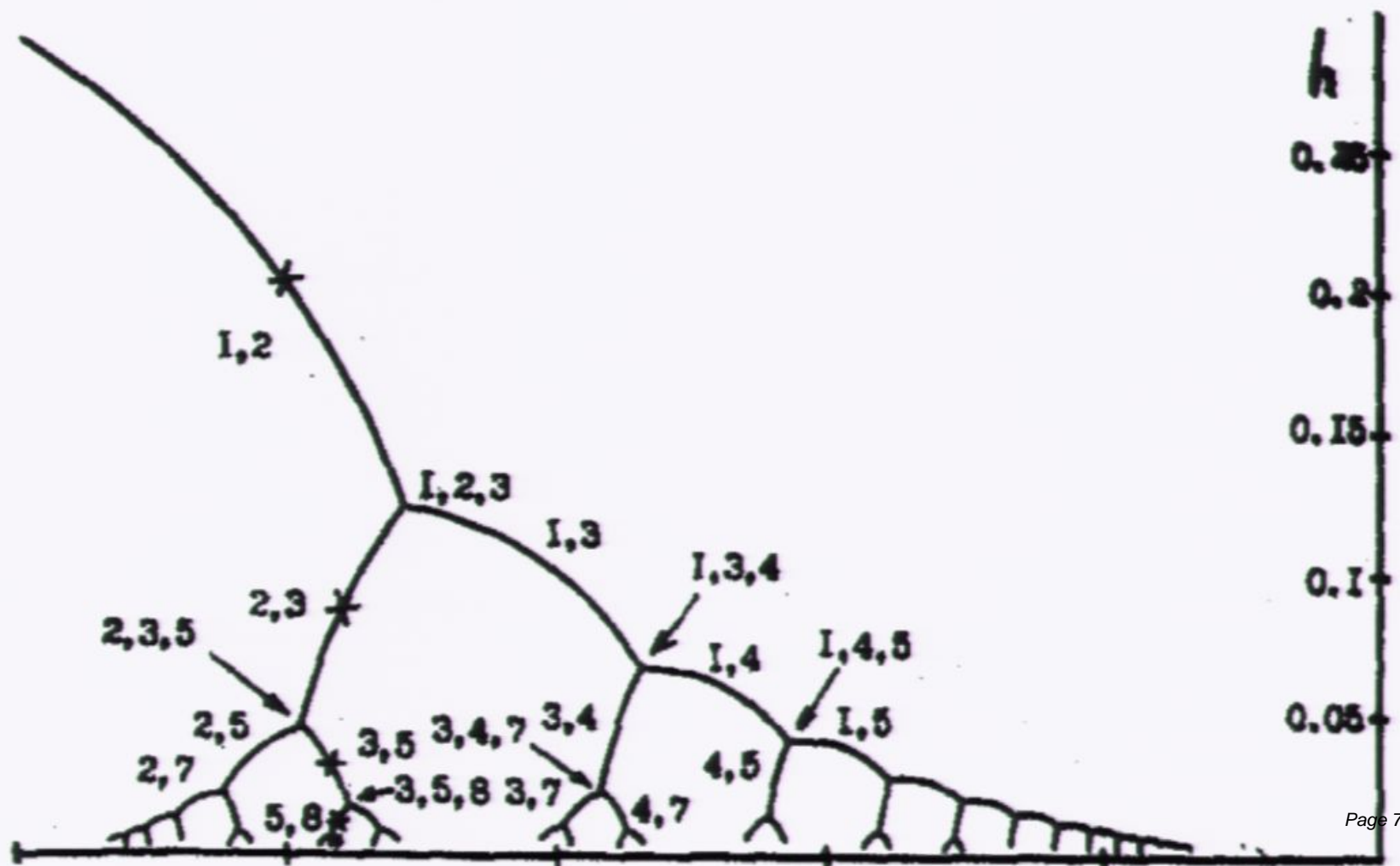
# Cayley tree for lattices



# Cayley tree for lattices

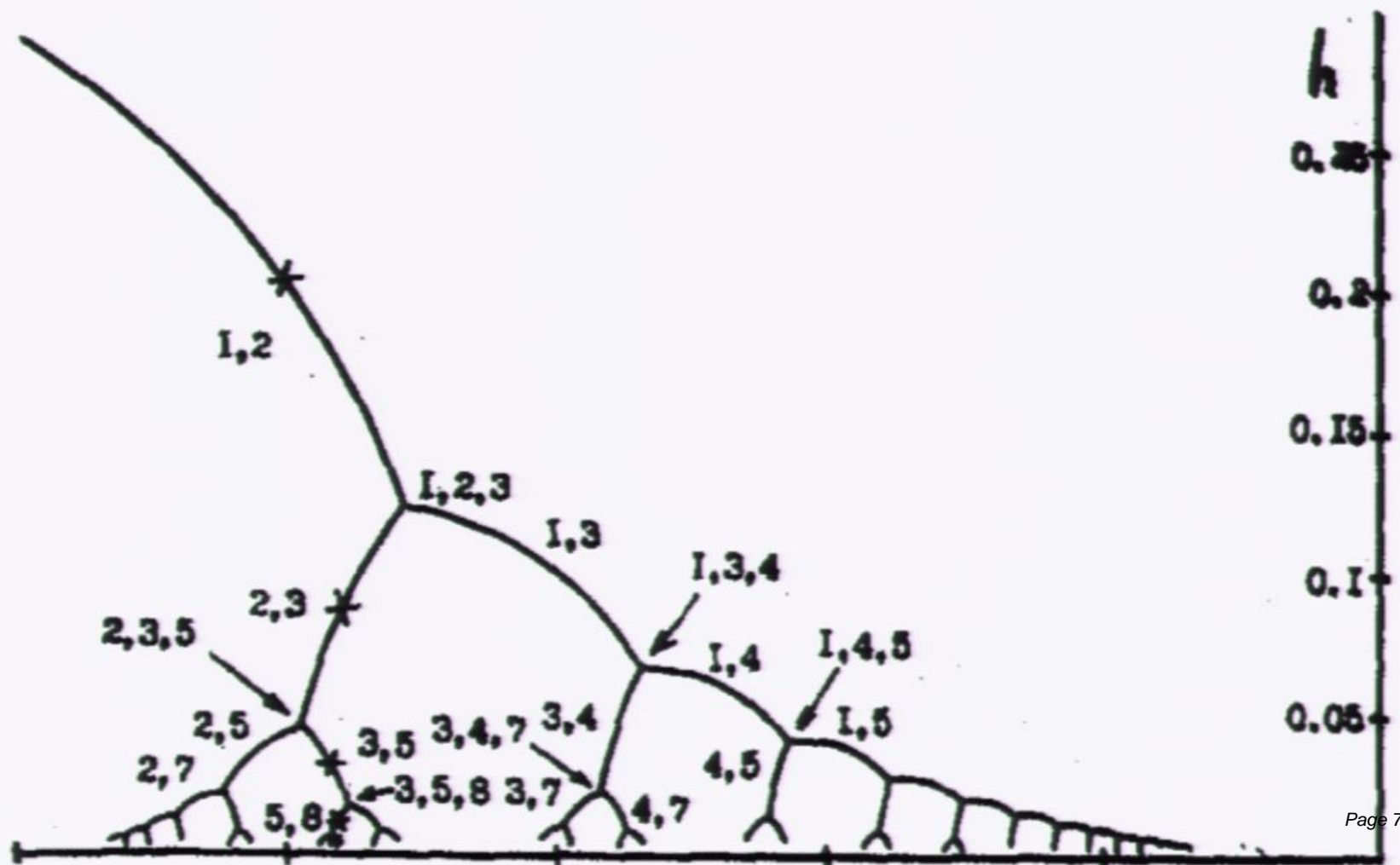


# Cayley tree for lattices

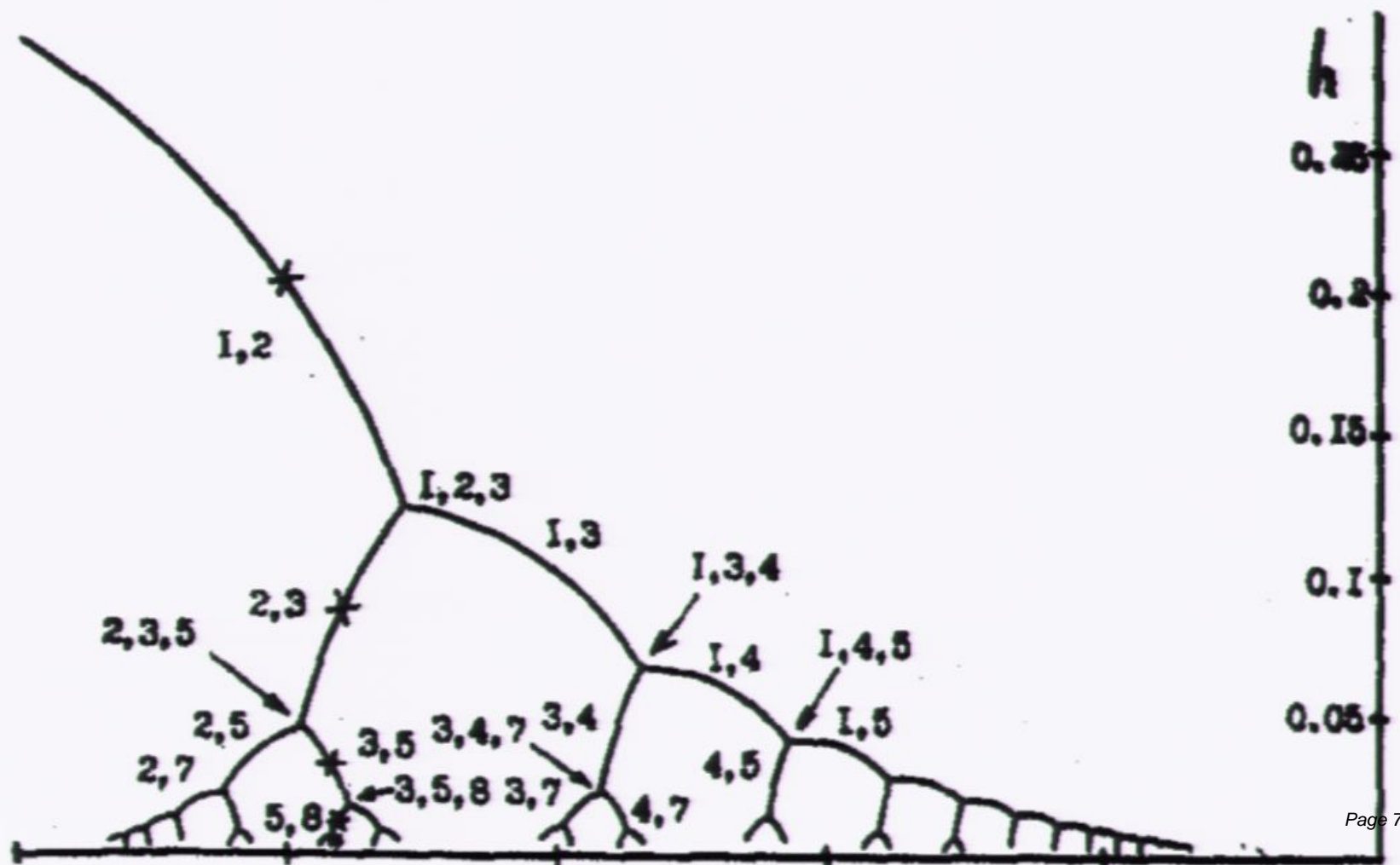




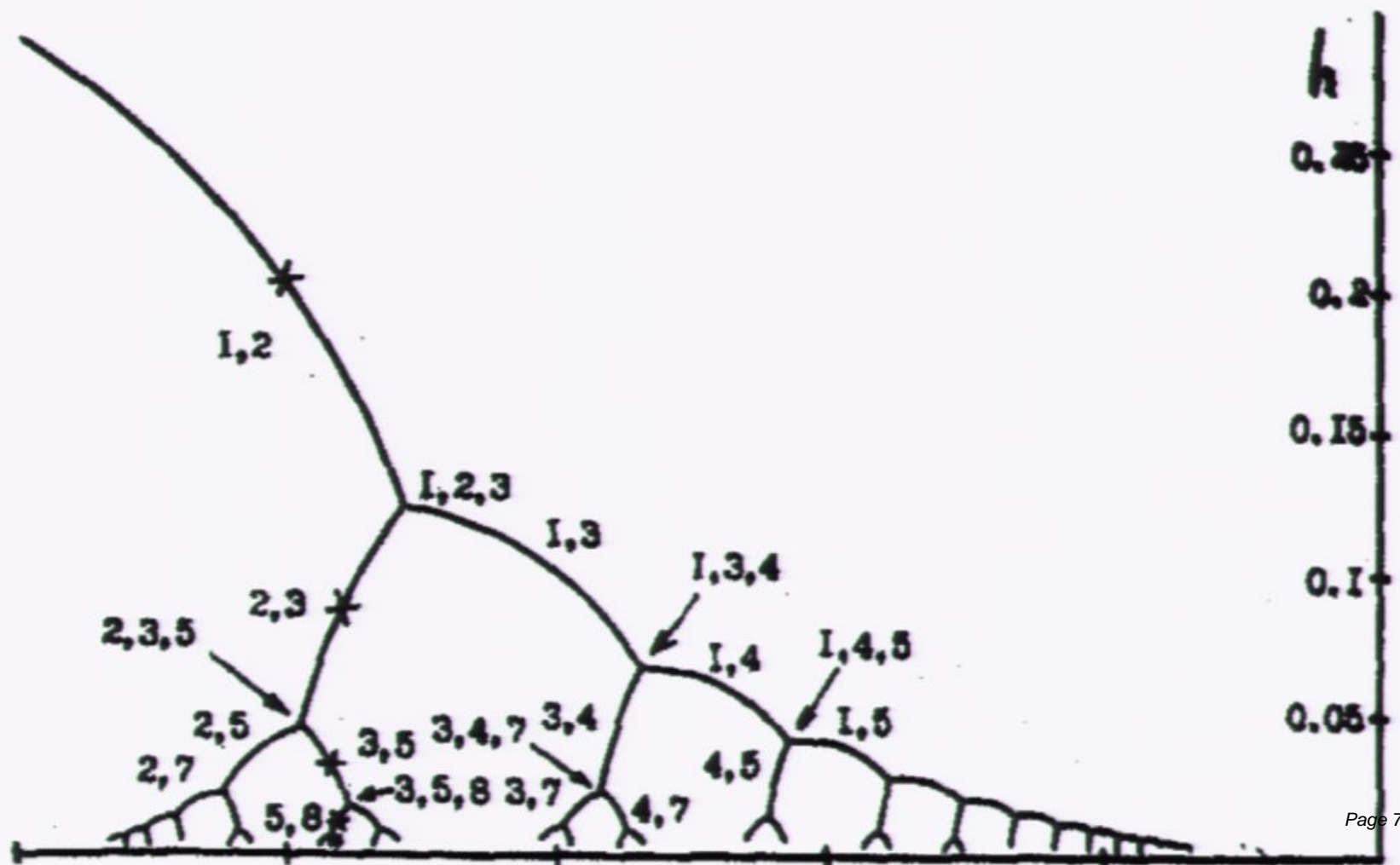
# Cayley tree for lattices



# Cayley tree for lattices

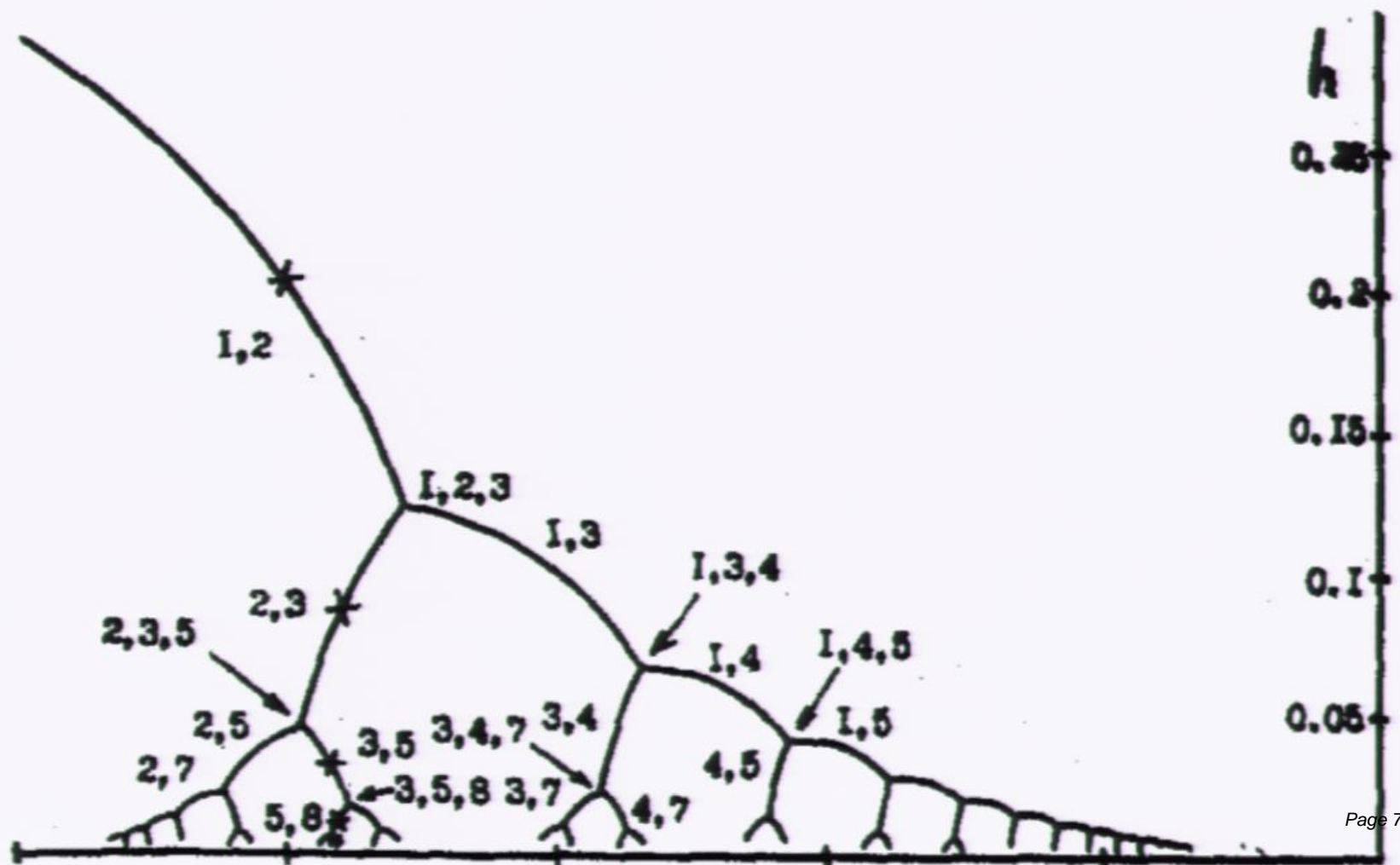


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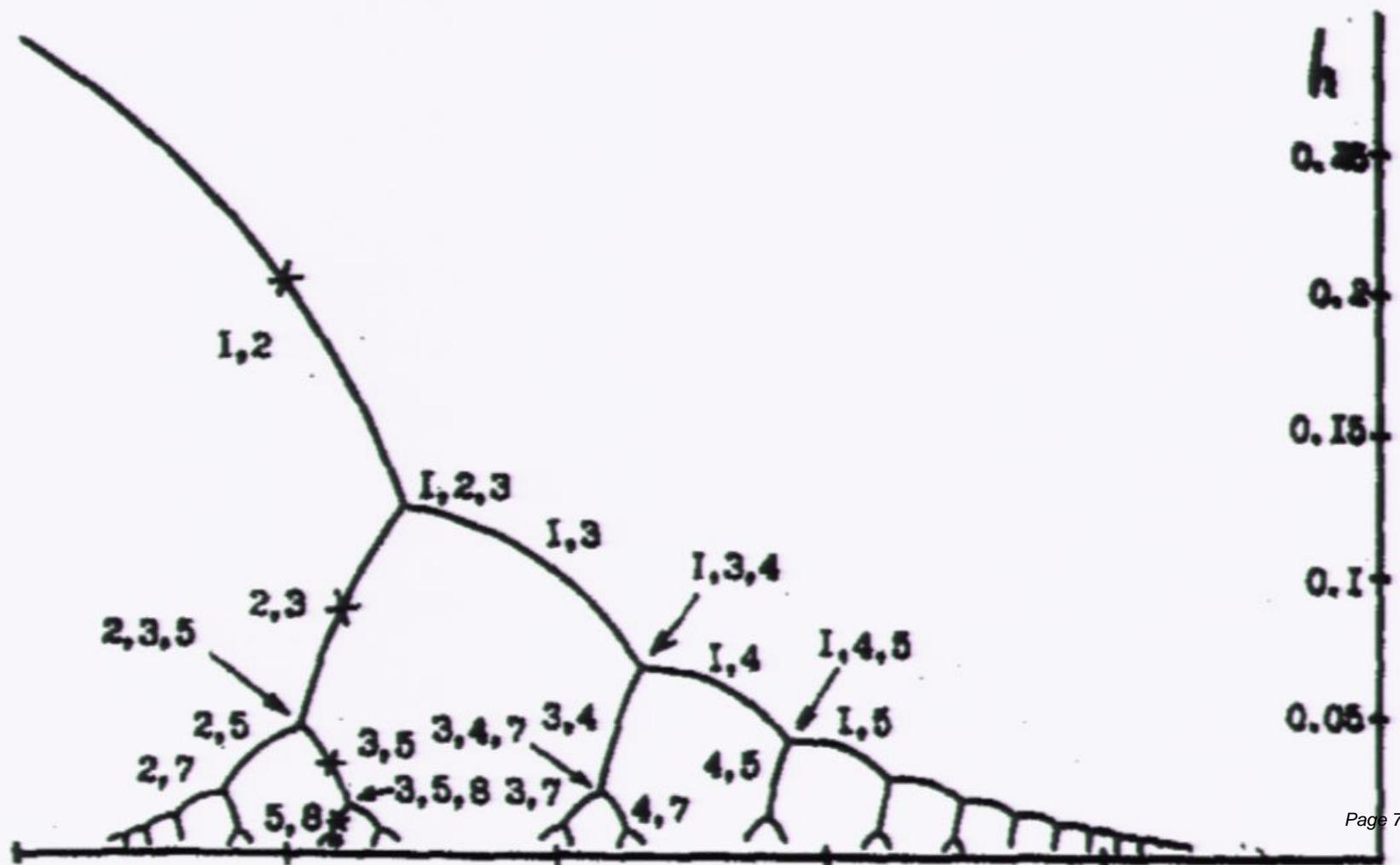




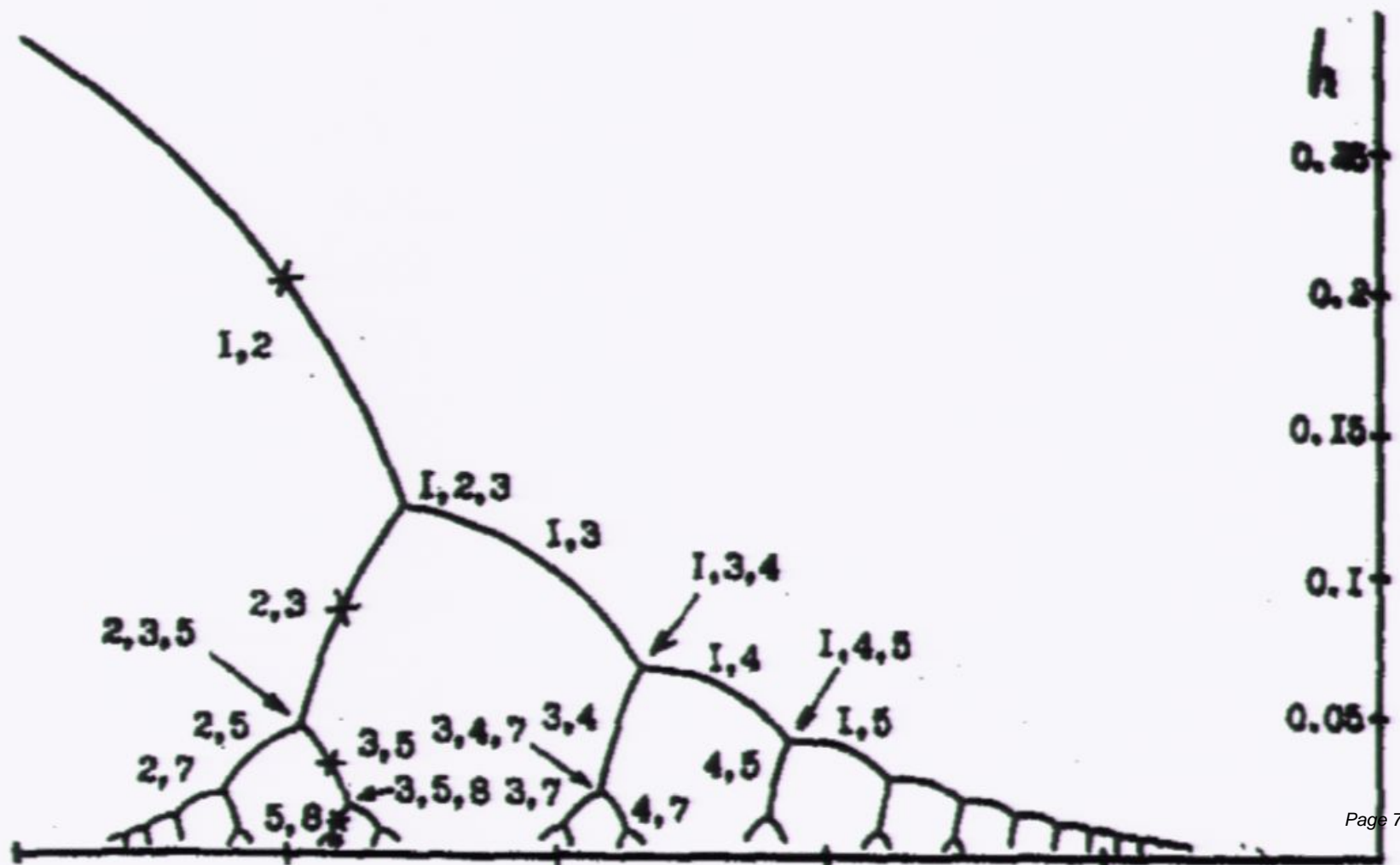
# Cayley tree for lattices



# Cayley tree for lattices

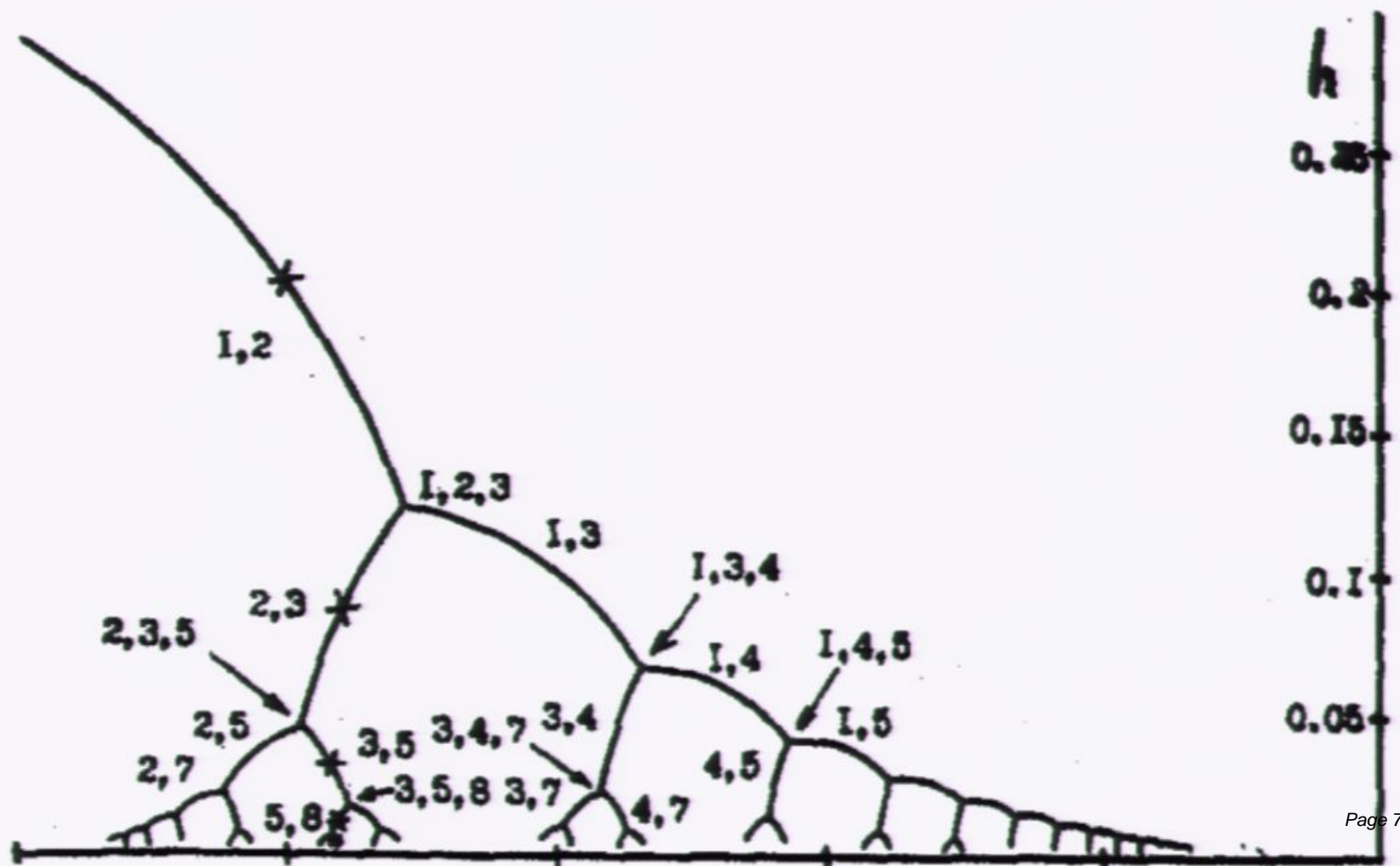


# Cayley tree for lattices

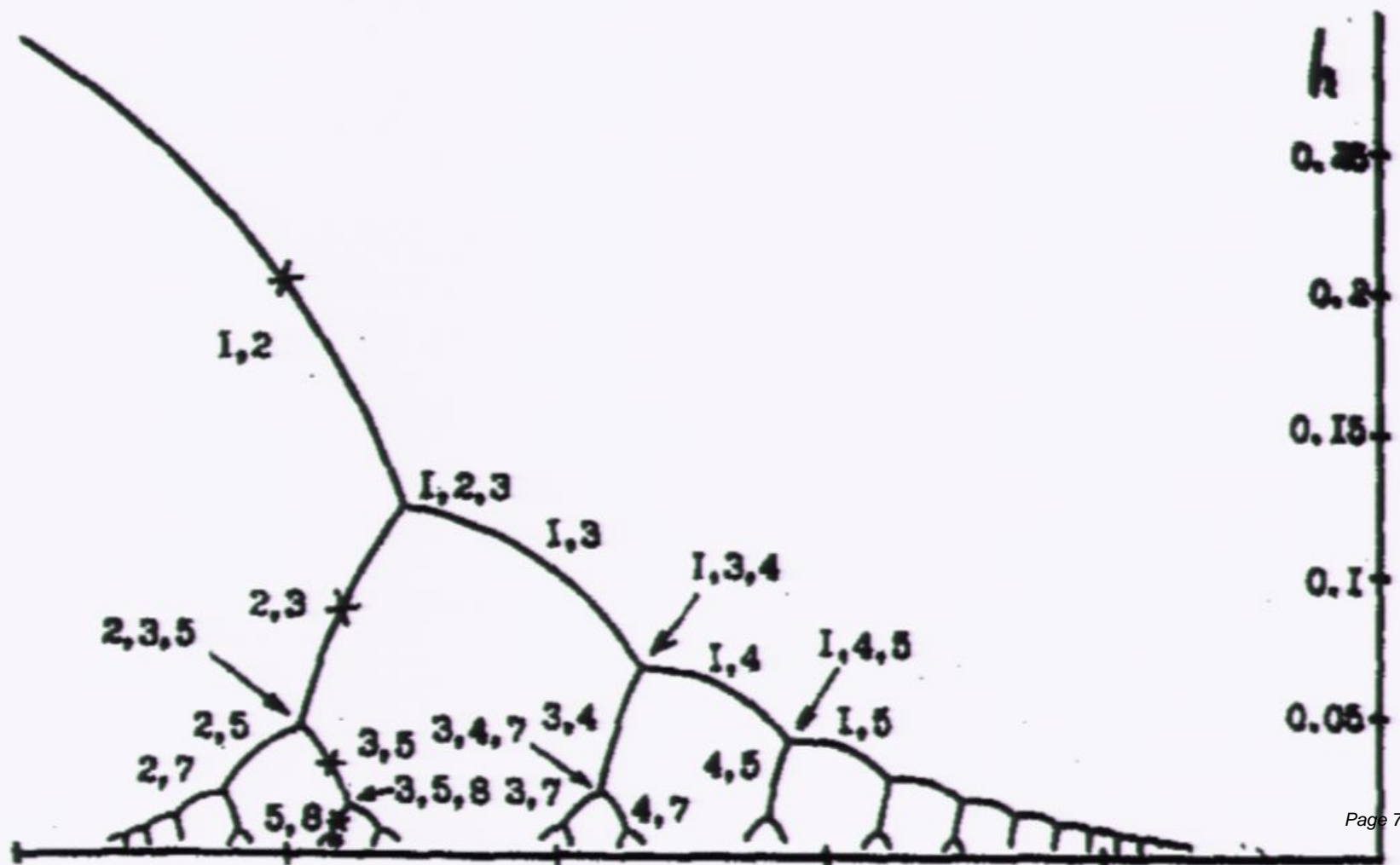




# Cayley tree for lattices



# Cayley tree for lattices



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Outline

Nature Knows Number Theory!

Fibonacci sequence:

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, ...

Connection

Number of LH to RH (or vice versa) spirals is pair of consecutive Fibonacci numbers (n, n+1).

Name: Phyllotaxis

Question: Why does this happen?

Lattice on Cylinder

$A_n = A_m$ ,  $A_n = m$  (mod  $n$ )

Cayley Tree

Cayley tree for lattices

Change lattice

$A_m = (m + n\sqrt{5})/2$ ,  $n \in \mathbb{Z}$

Define energy function:

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For calculations:

$\text{DTA} = \exp(-\beta)$

# Cayley tree for lattices

The diagram shows a Cayley tree structure plotted against an angle  $\alpha$  from  $180^\circ$  to  $360^\circ$ . The vertical axis is labeled  $h$  and ranges from 0.05 to 0.25. The tree branches out from the horizontal axis, with nodes labeled with sets of integers:  $1,2$ ,  $1,2,3$ ,  $1,3$ ,  $1,3,4$ ,  $1,4$ ,  $1,4,5$ ,  $1,5$ ,  $2,3,5$ ,  $2,3$ ,  $2,5$ ,  $2,7$ ,  $3,5$ ,  $3,4,7$ ,  $3,4$ ,  $3,5,8$ ,  $3,7$ ,  $4,7$ ,  $4,5$ ,  $5,8$ . Some nodes are marked with an asterisk (\*).

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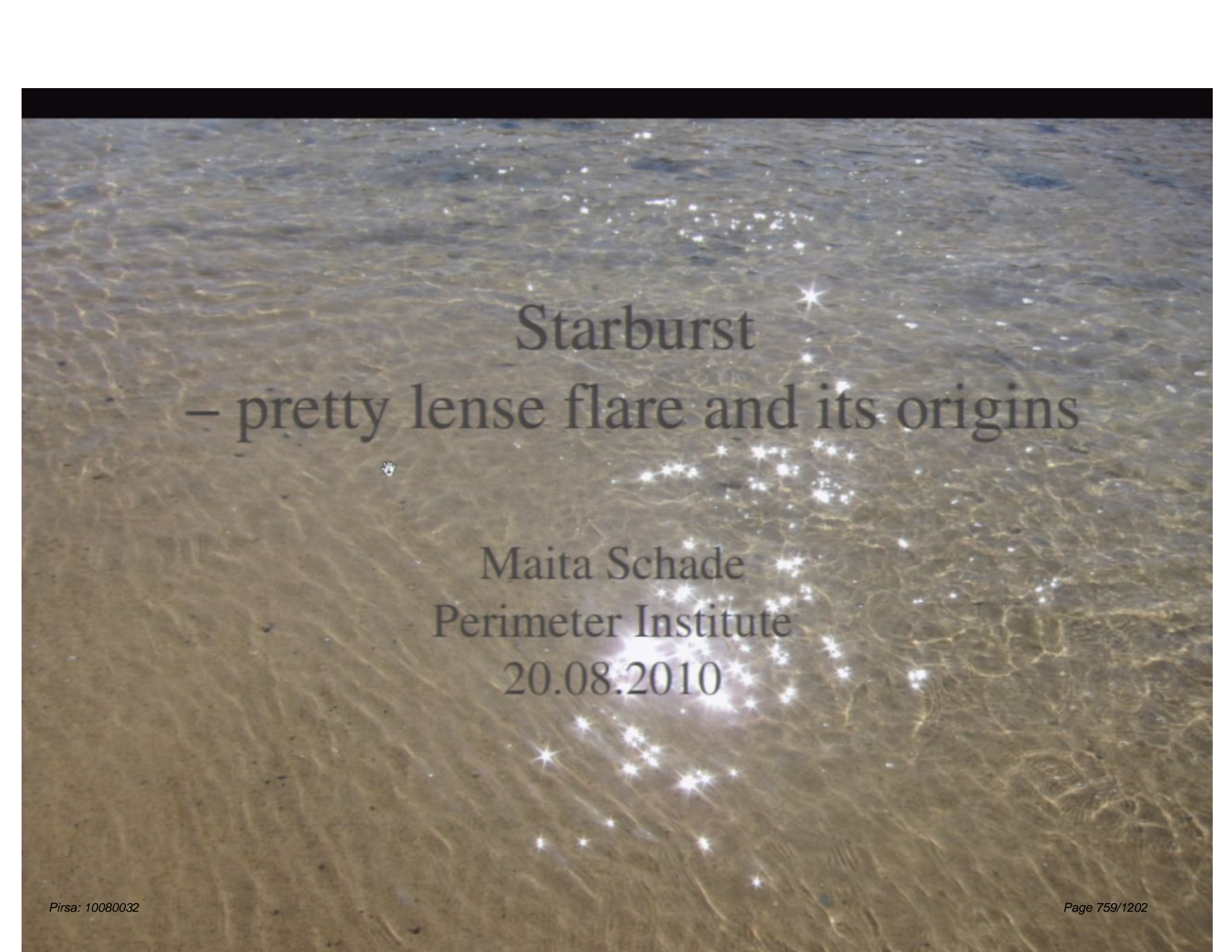
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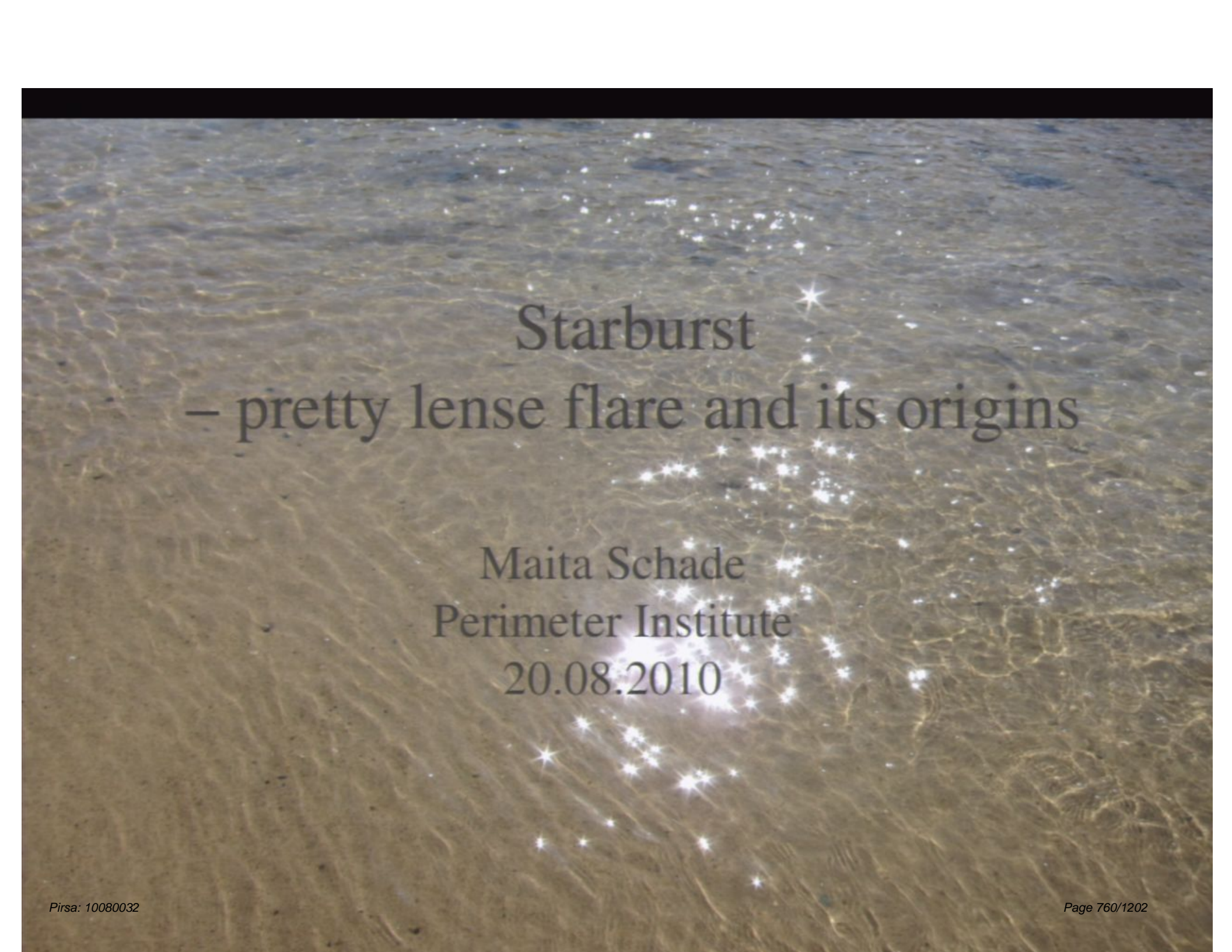


# Starburst

– pretty lense flare and its origins

Maita Schade  
Perimeter Institute  
20.08.2010





# Starburst

– pretty lense flare and its origins

Maita Schade  
Perimeter Institute  
20.08.2010



# Outline

- Odd effects in my photos
- Zoom lens optics and lens flares
- Tracking down the points of my stars – Fraunhofer diffraction in polygonal apertures
- Other ways to achieve this effect
- What I learned from this project

# What I found my camera could do



# What I found my camera could do

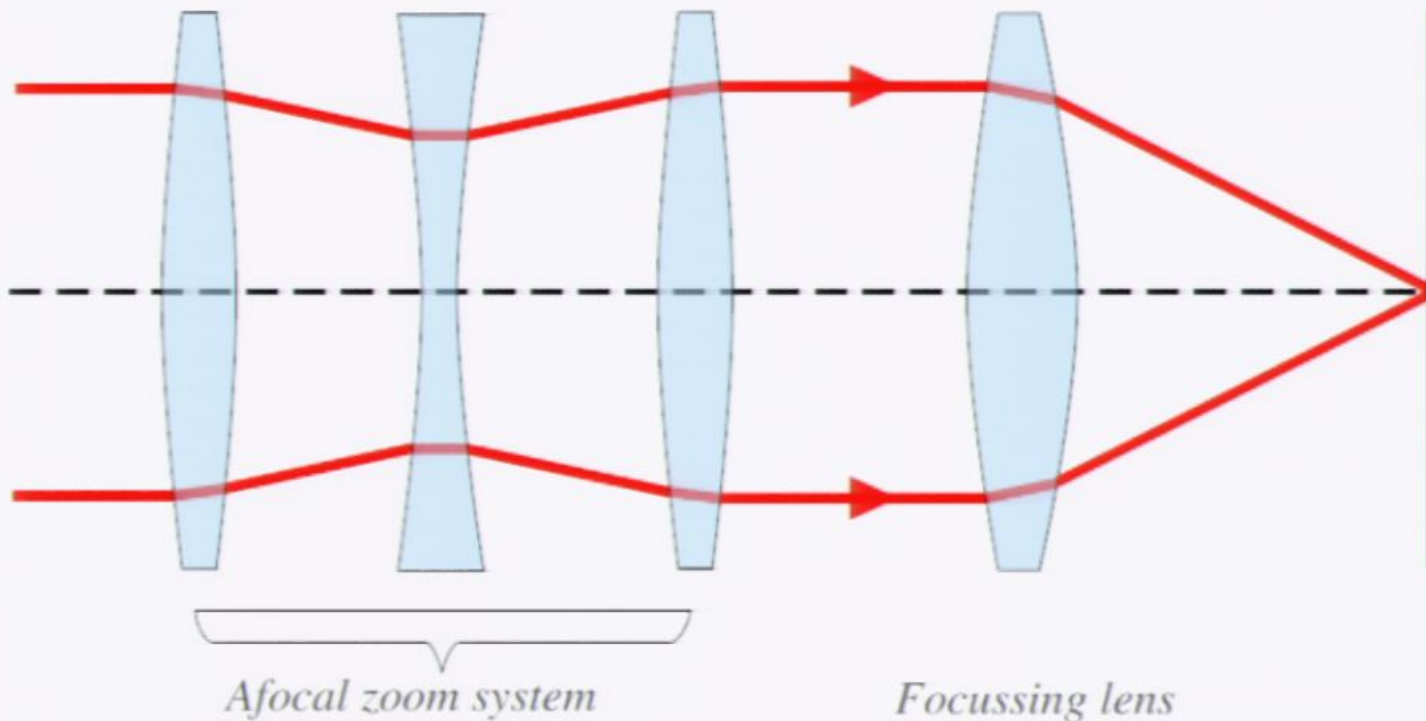




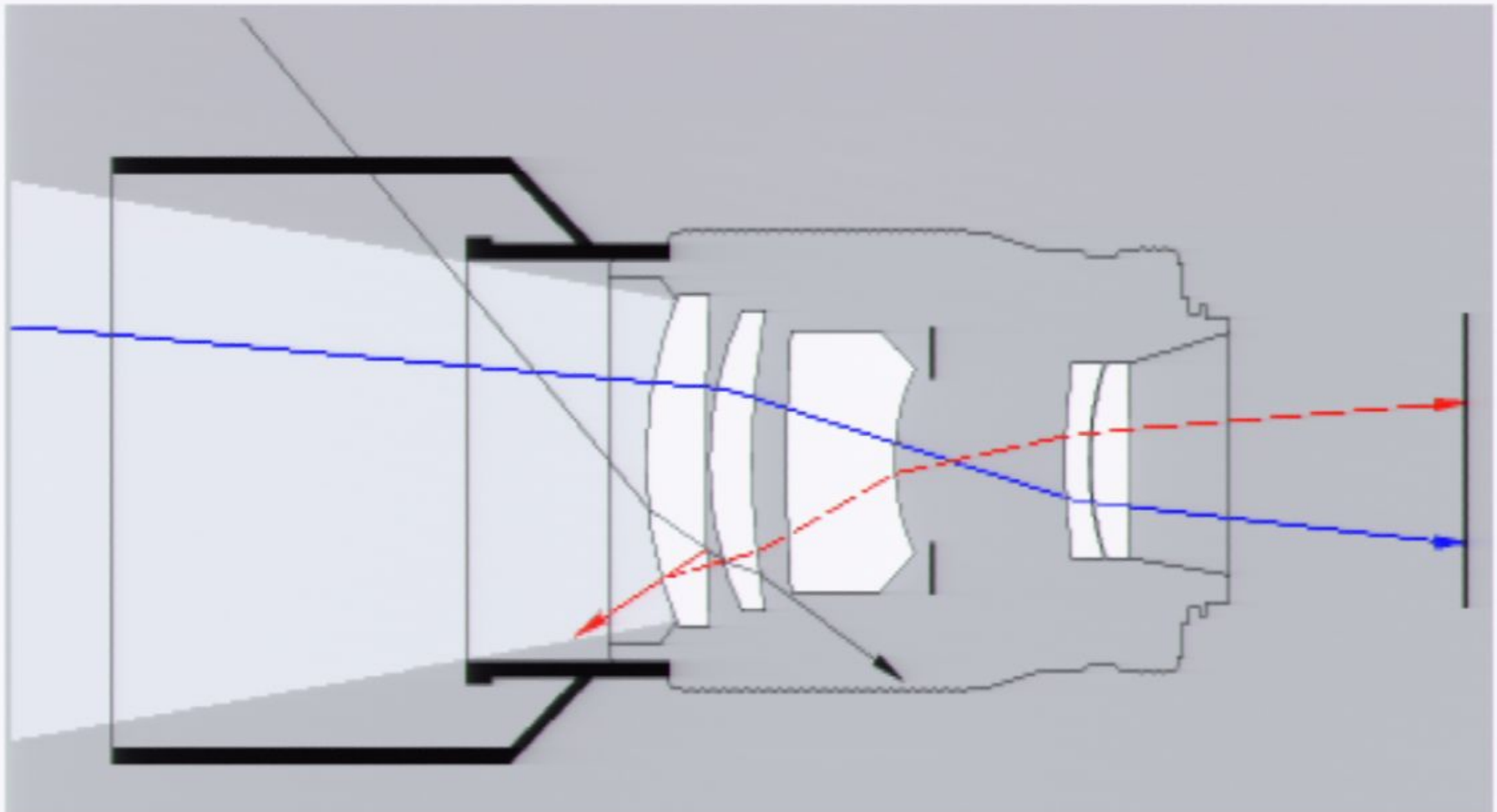
# A closer look



# Zoom lens

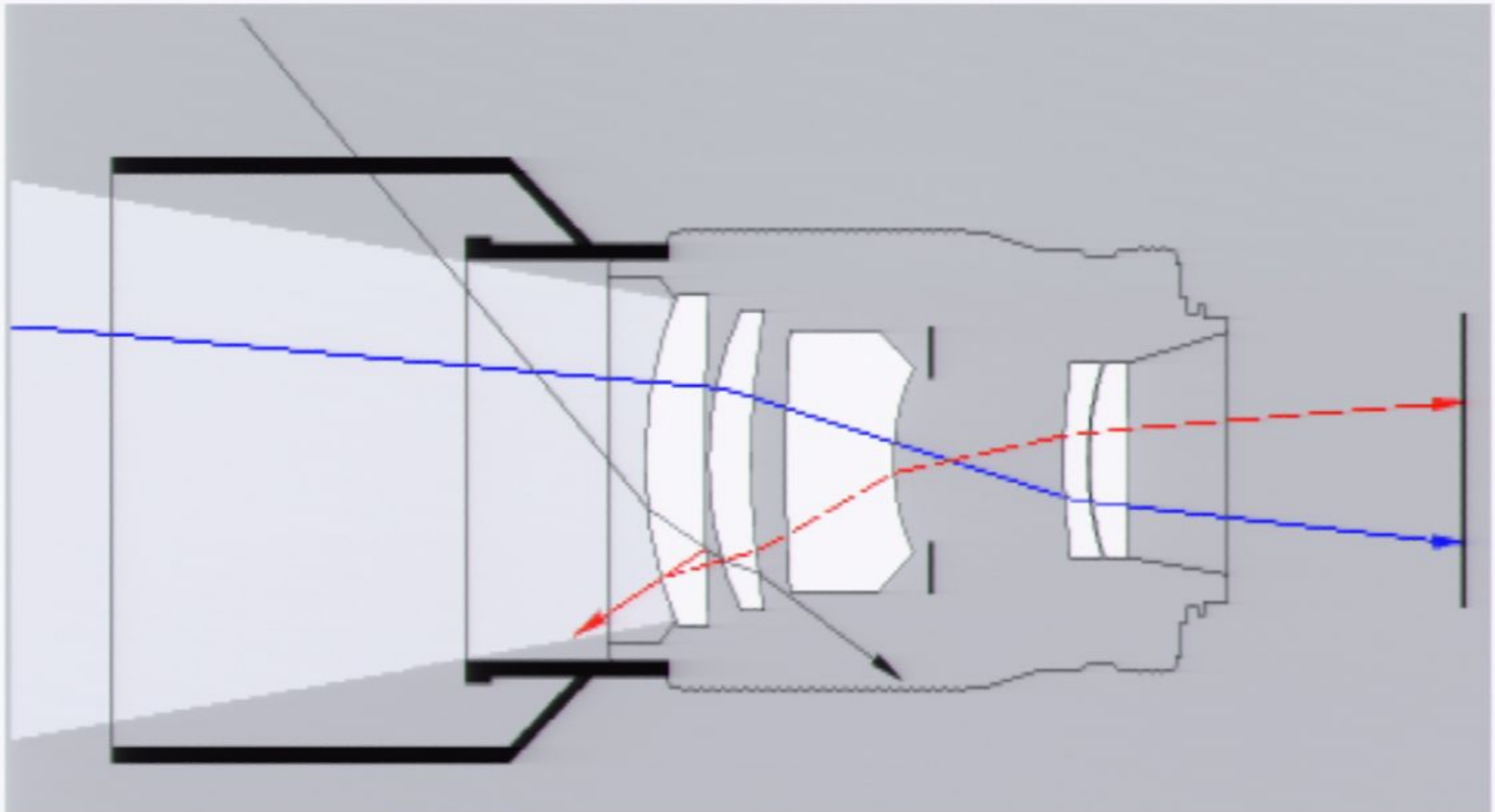


# Lens flare





# Lens flare



# Lens flare



But this is not what we were looking for!

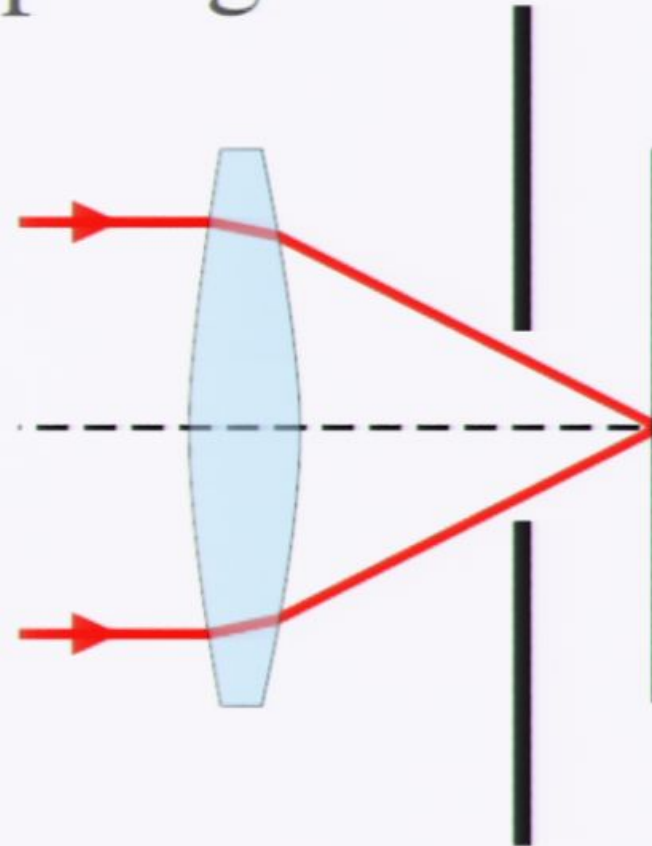
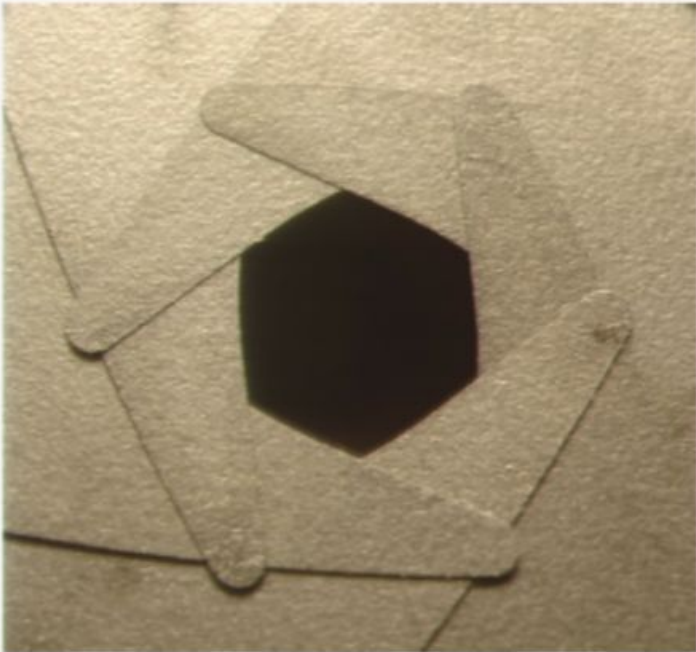
- Our flares are right on bright objects.
- They are *anisotropic*, with six spikes.

Another clue:

- The star shapes are always in the same orientation relative to the camera *given* the same aperture settings.



# Camera diaphragm

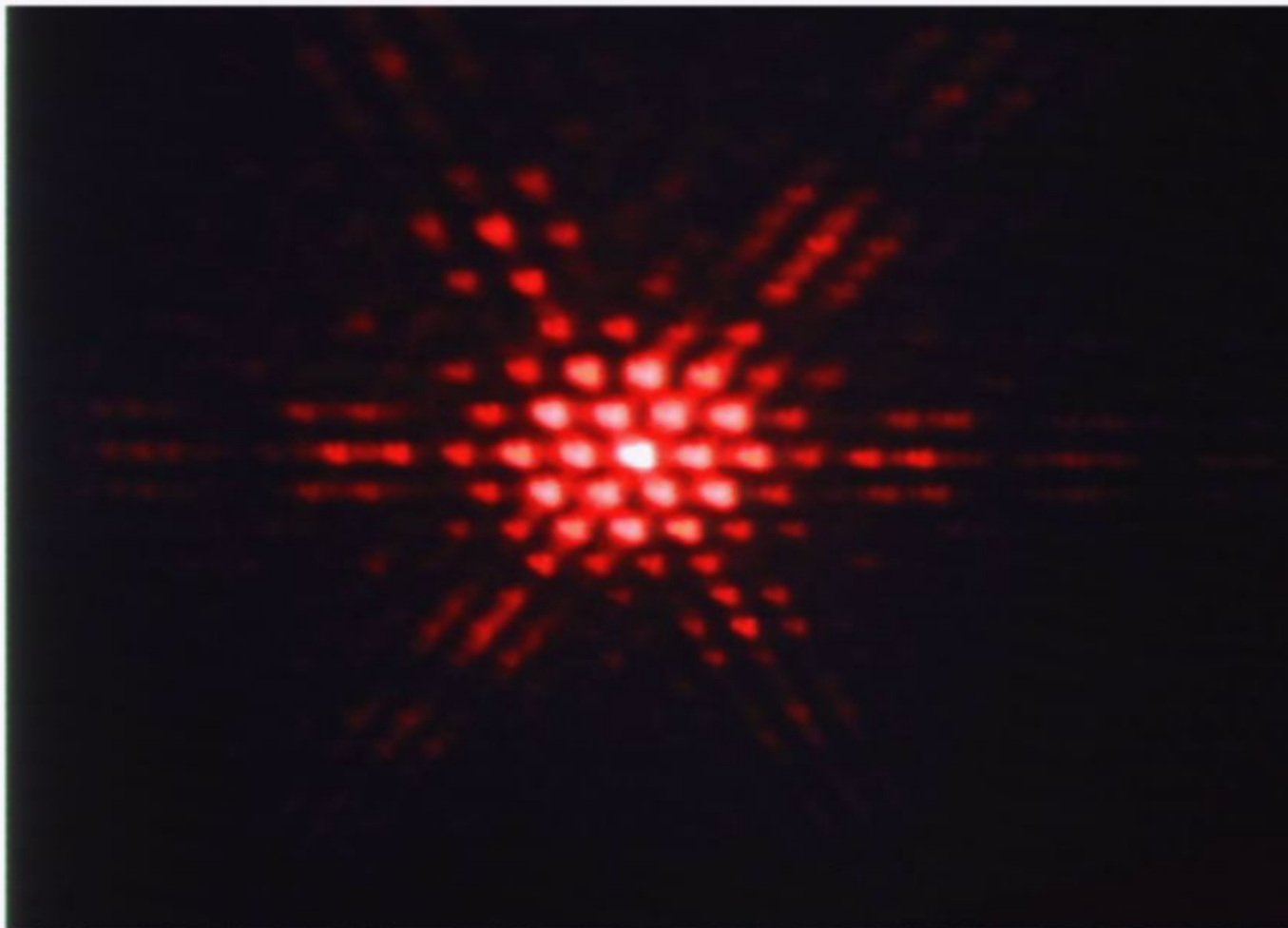


Large aperture  
~cm



Small aperture  
~mm

# Hexagonal apertures



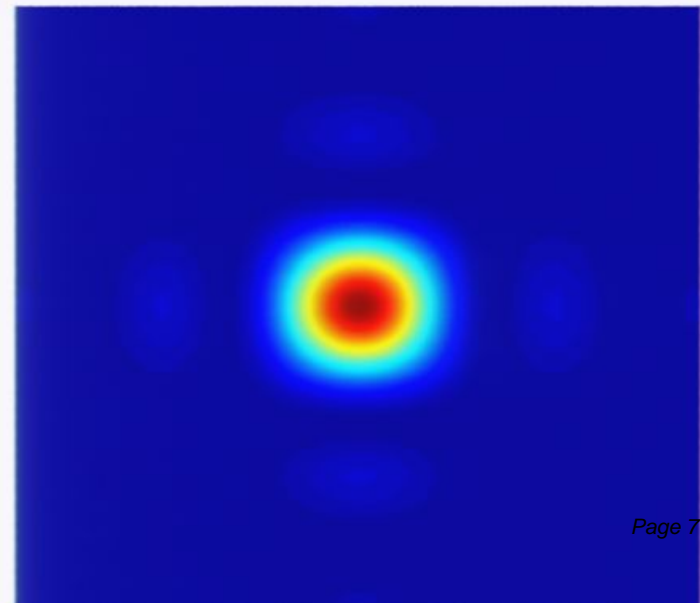
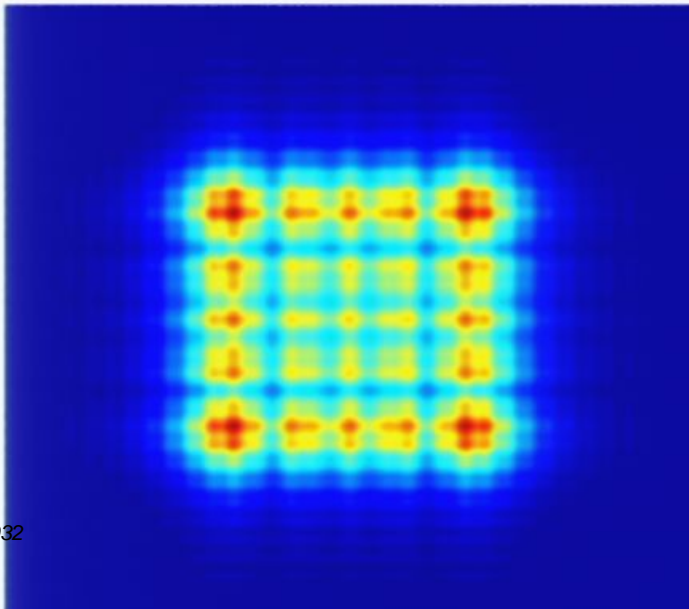
# Hexagonal apertures





# What is going on?

- Fraunhofer or Fresnel diffraction?
- Flares out from actual image point: can happen only in far field – Fraunhofer regime (does this make sense?  $F = \frac{a^2}{L\lambda} \ll 1$  ?)



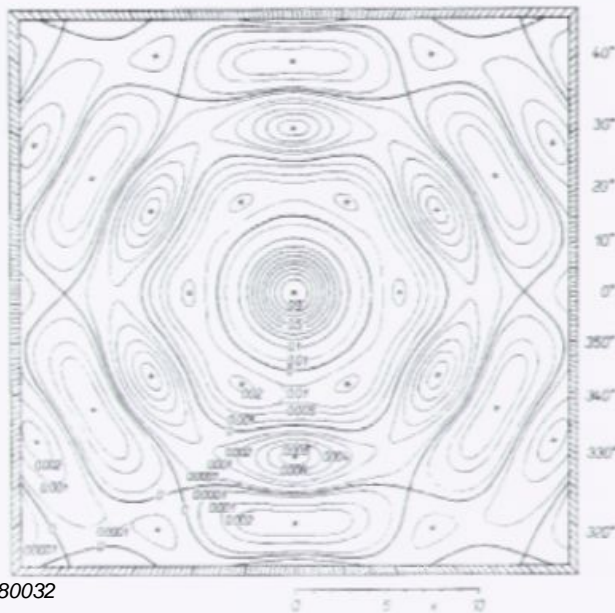
# Fraunhofer diffraction at polygonal apertures

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J. Komrska

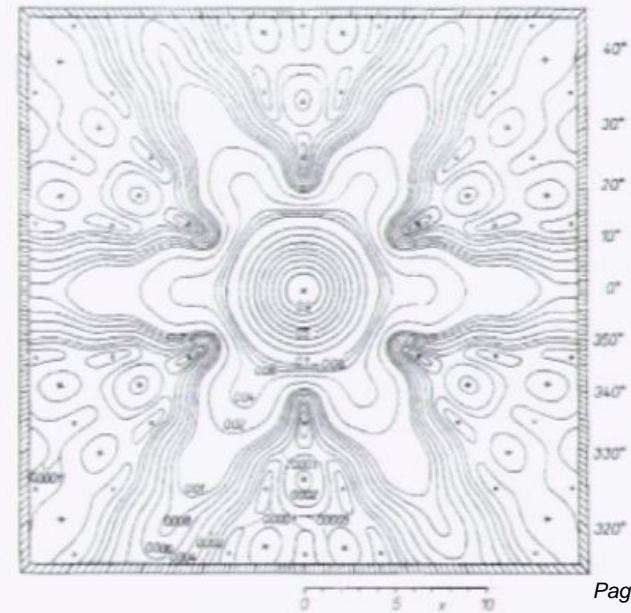
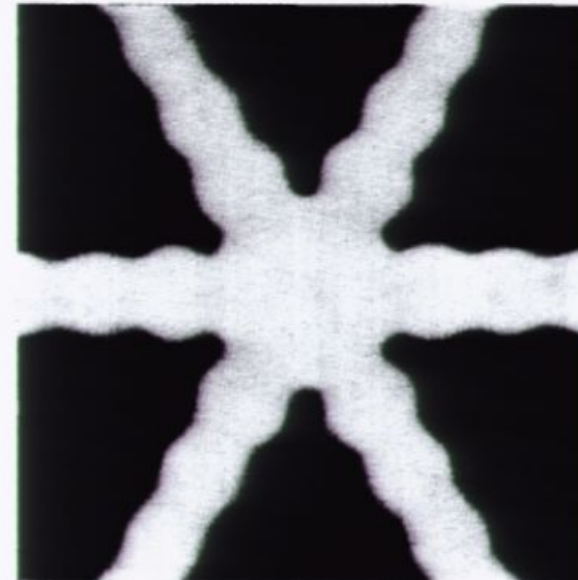
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

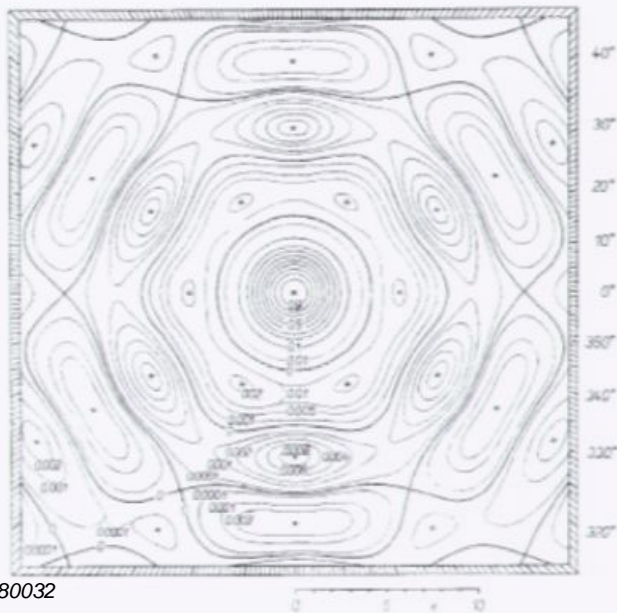
# Fraunhofer diffraction at polygonal apertures

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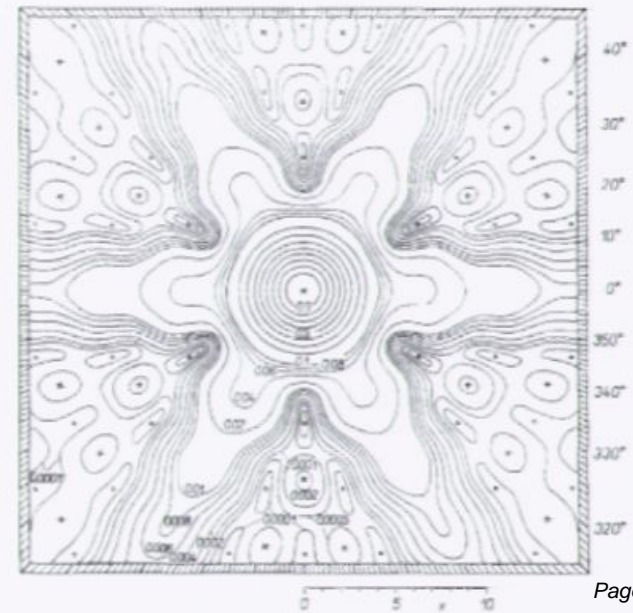
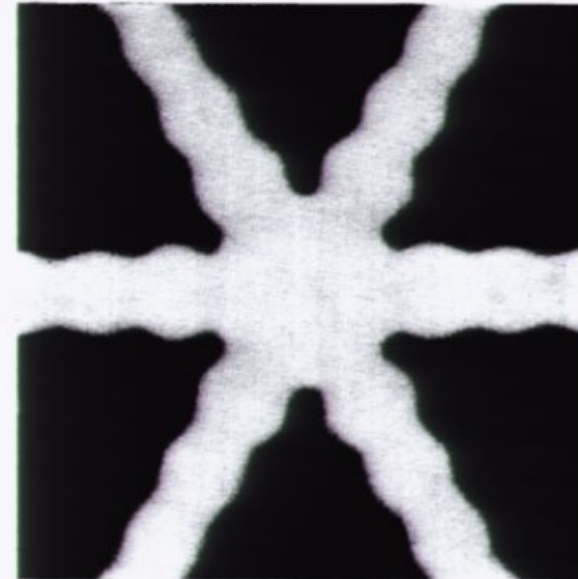
Fraunhofer diffraction at regular polygons

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Pirsa: 10080032

Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



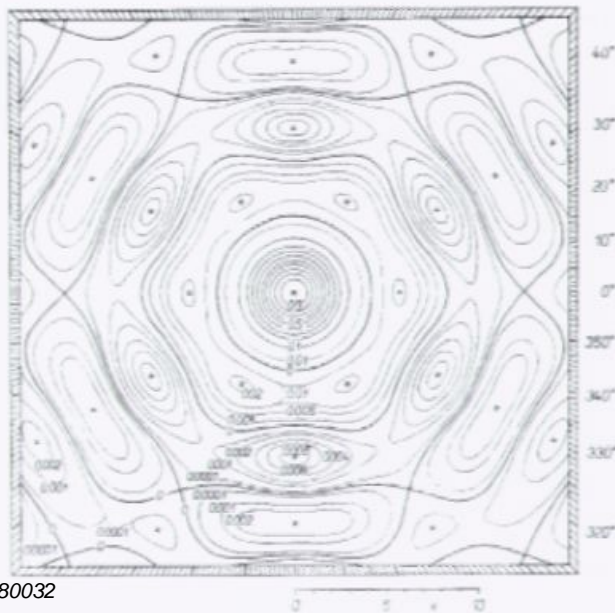
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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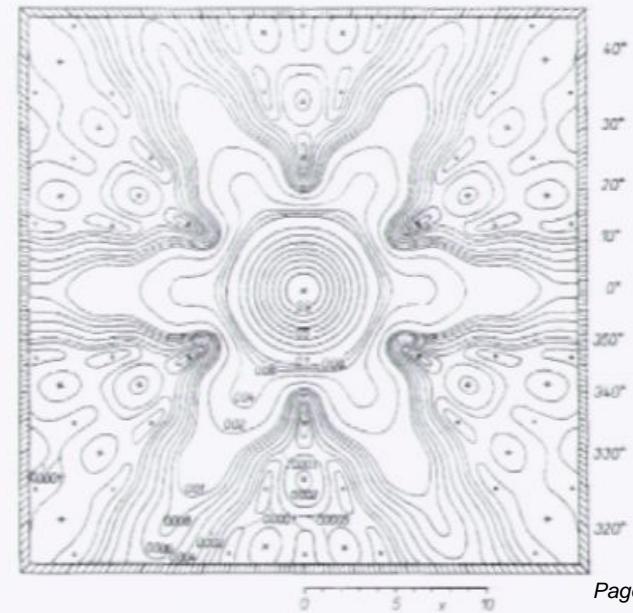
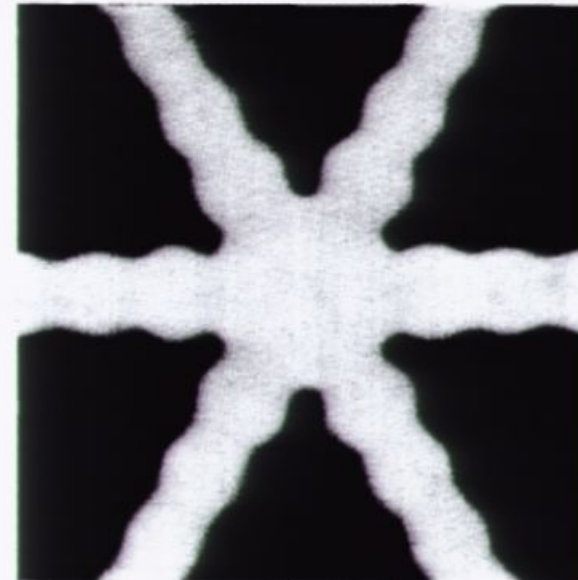


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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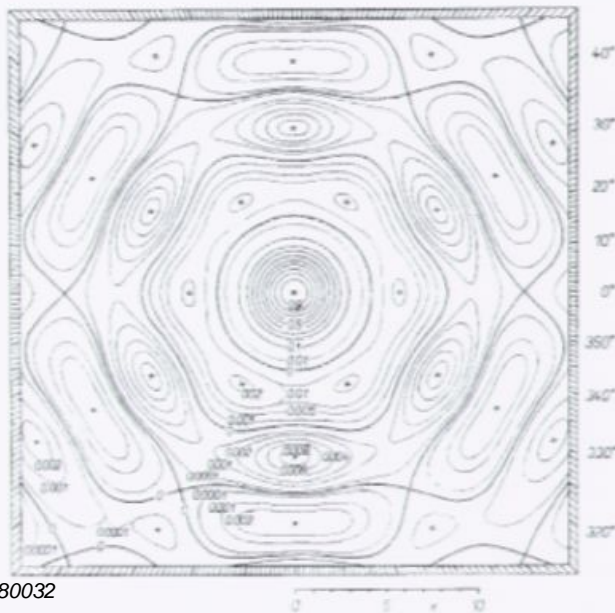
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

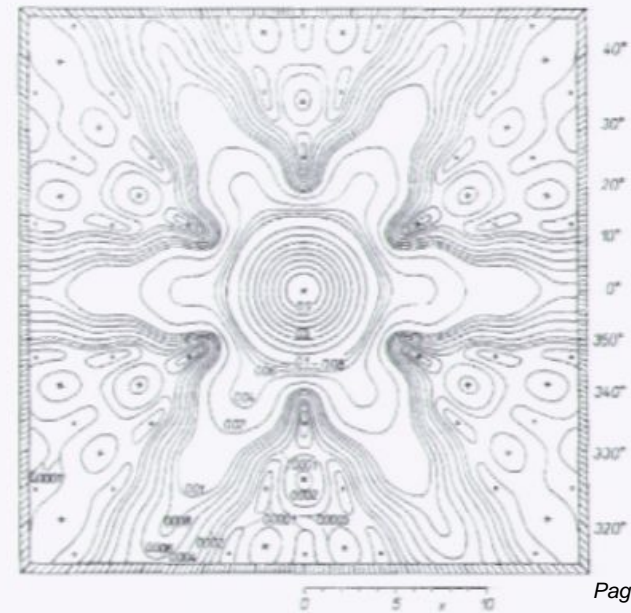
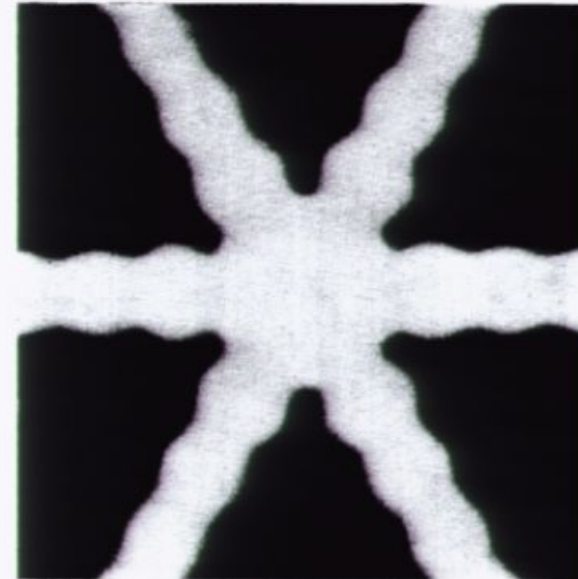


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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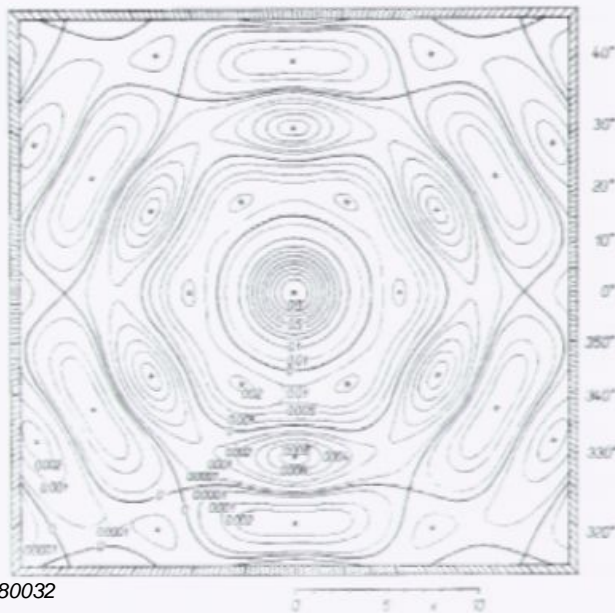
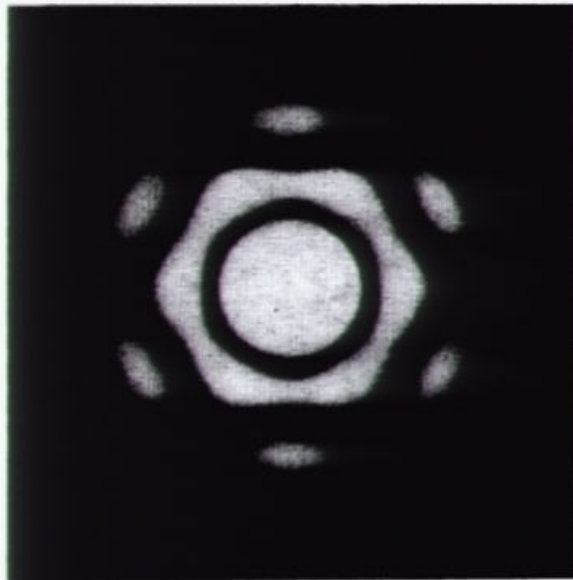
# Fraunhofer diffraction at polygonal apertures

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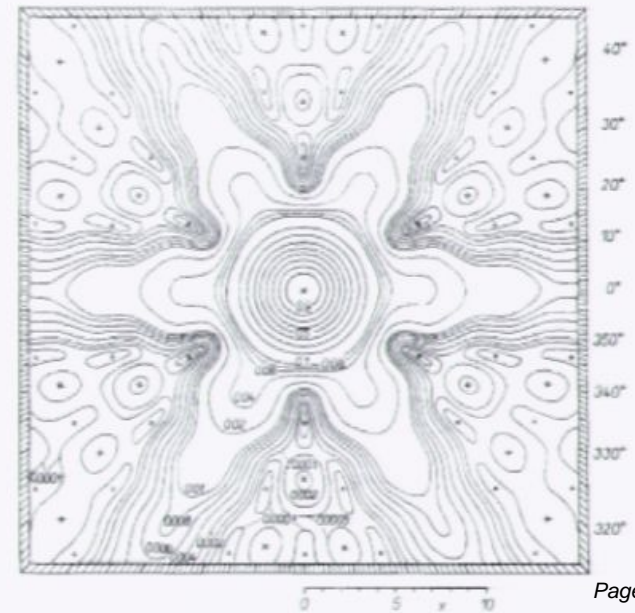
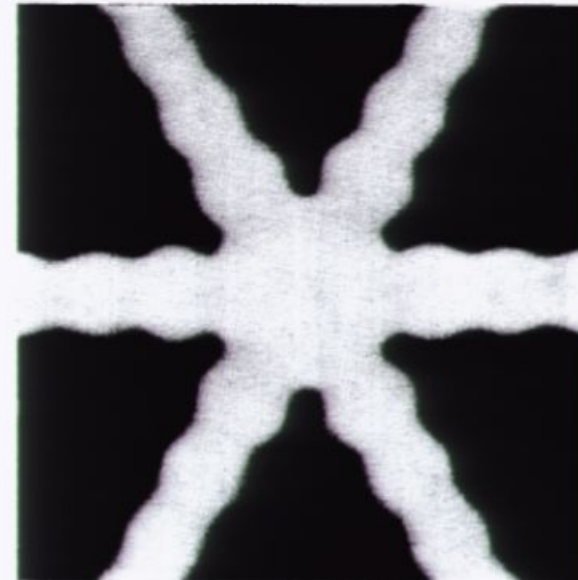
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



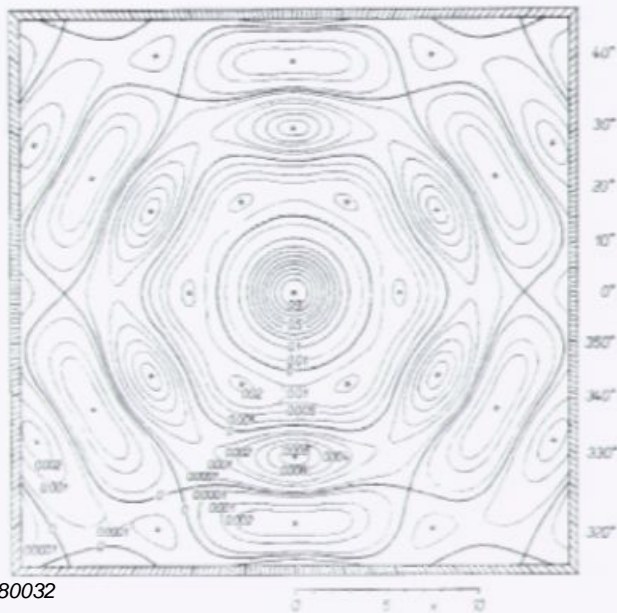
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

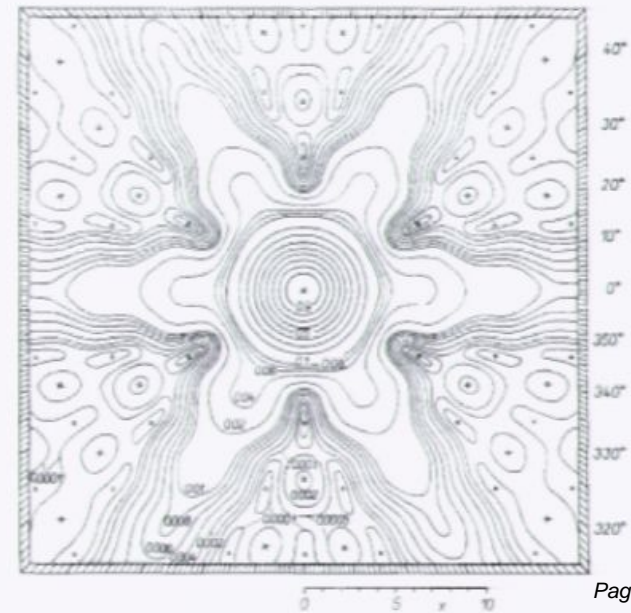
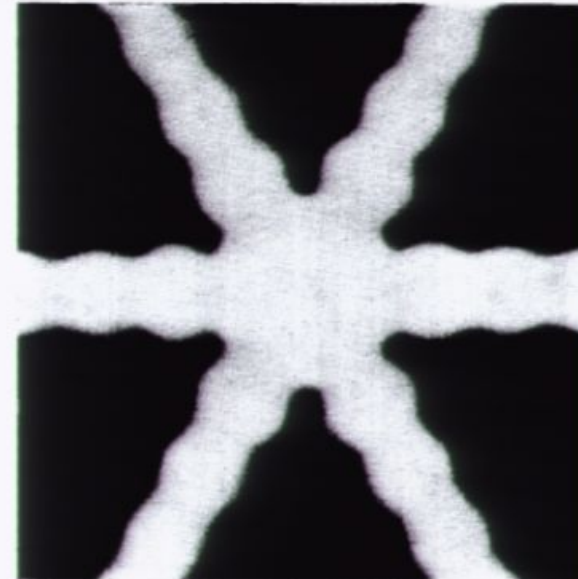


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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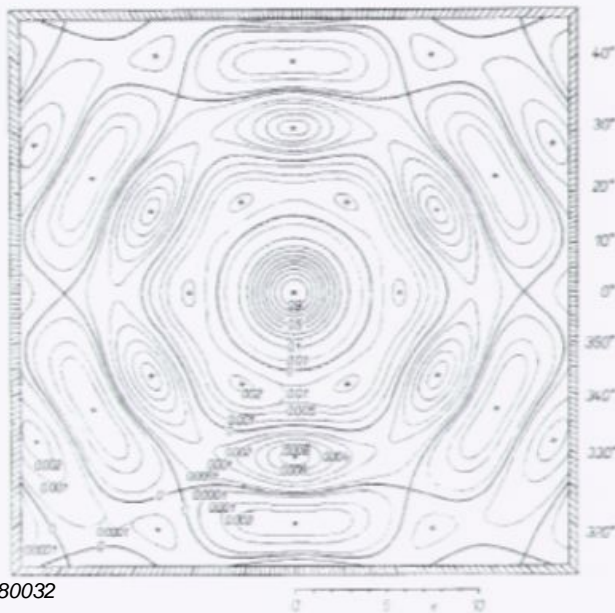
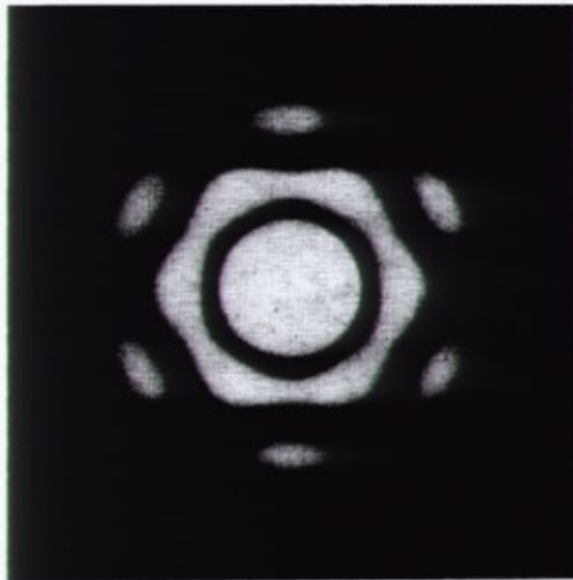
# Fraunhofer diffraction at polygonal apertures

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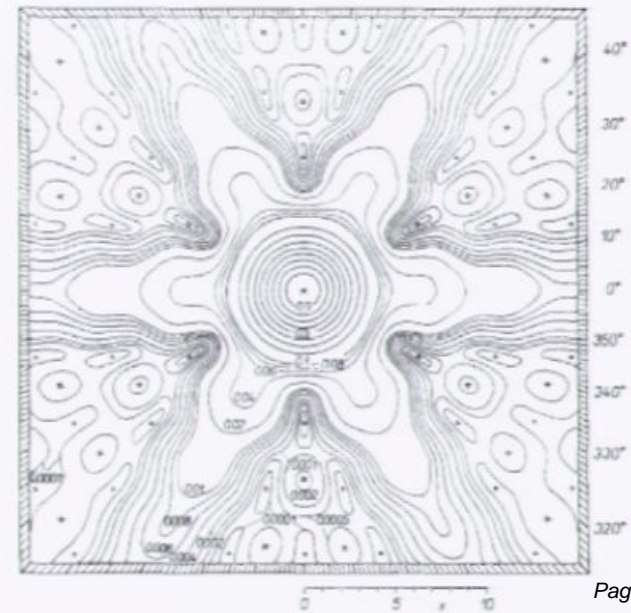
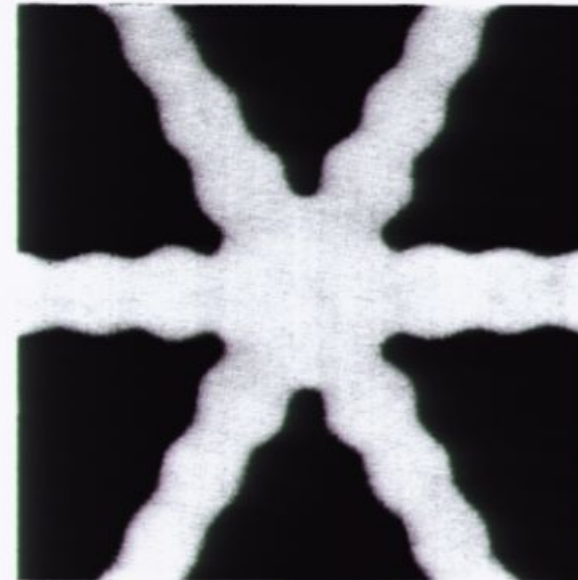
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

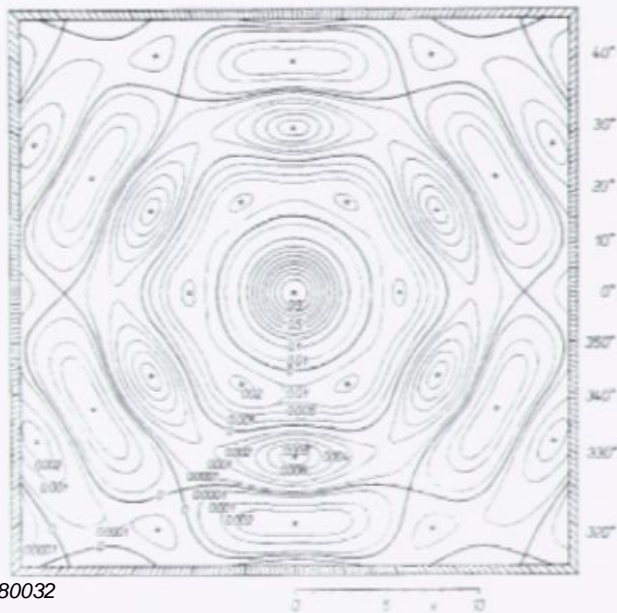
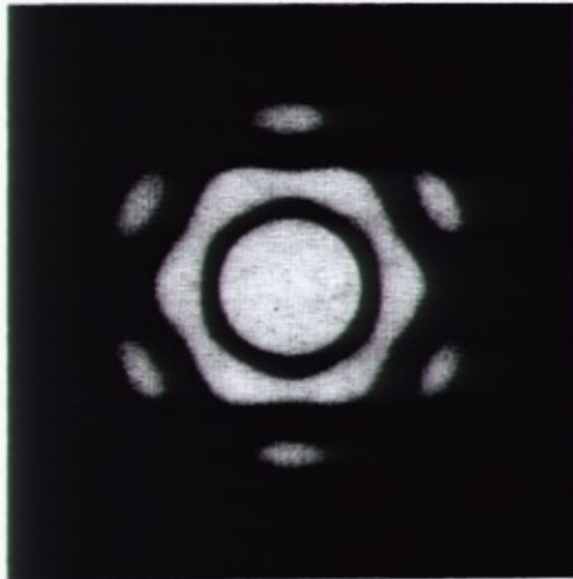
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

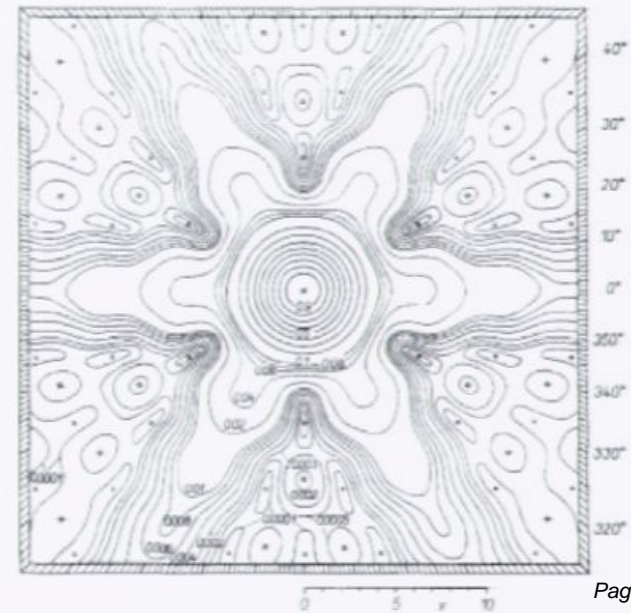
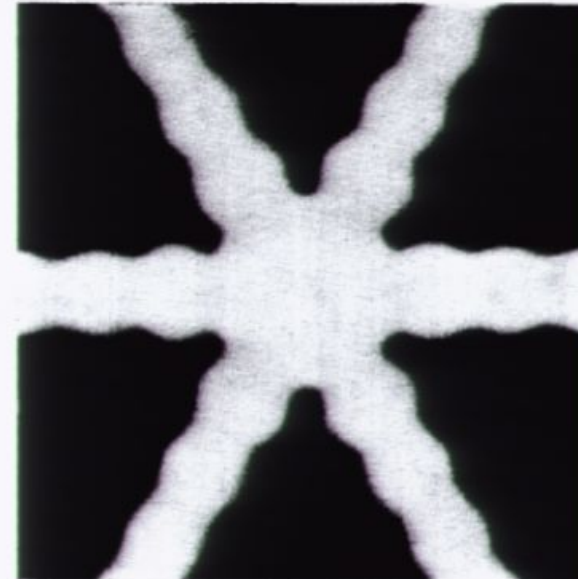


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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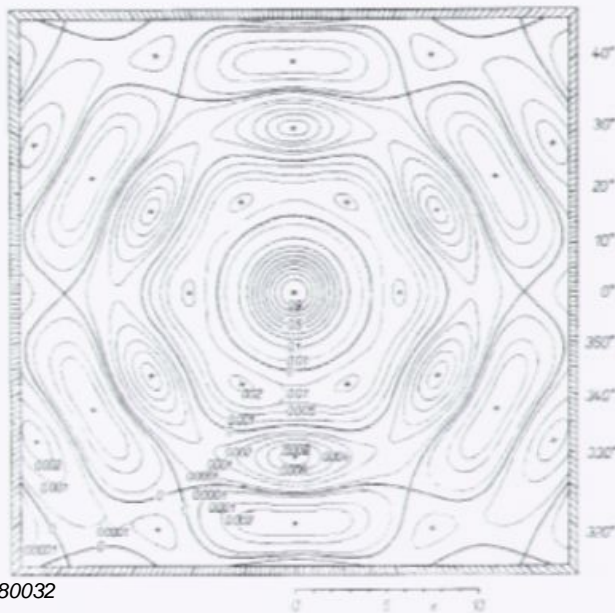
# Fraunhofer diffraction at polygonal apertures

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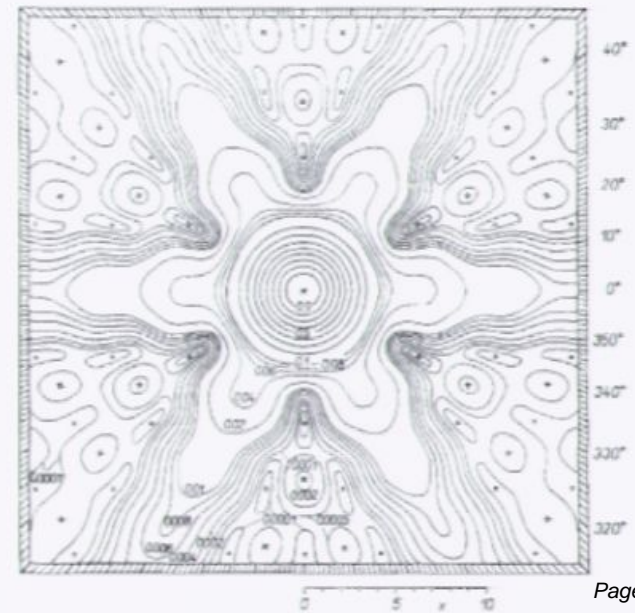
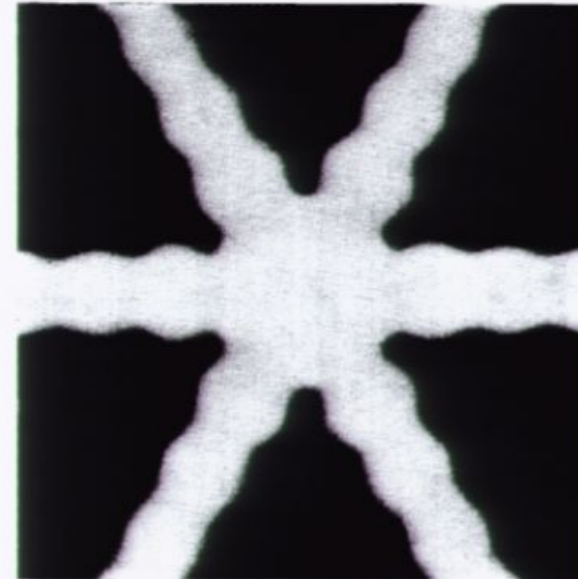
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

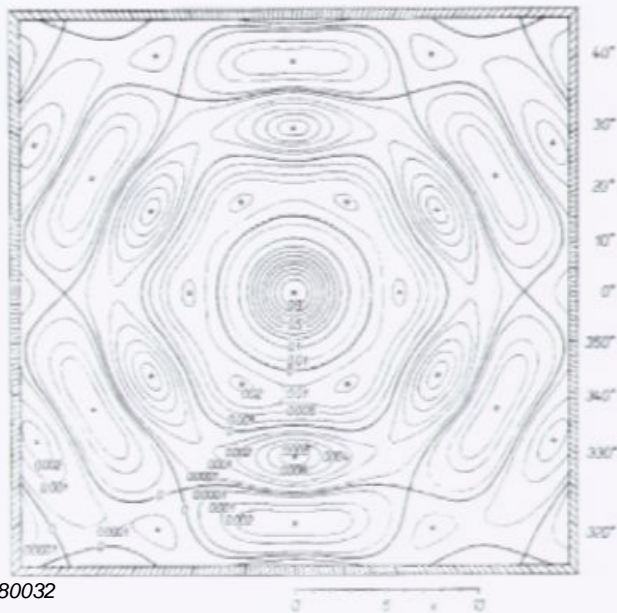
# Fraunhofer diffraction at polygonal apertures

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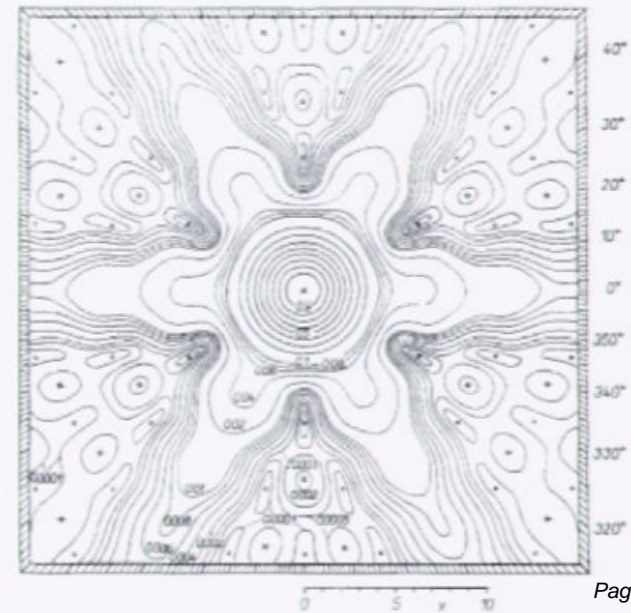
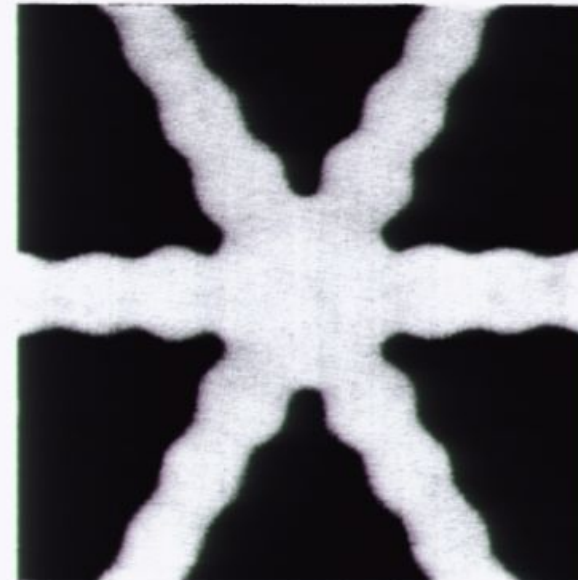
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



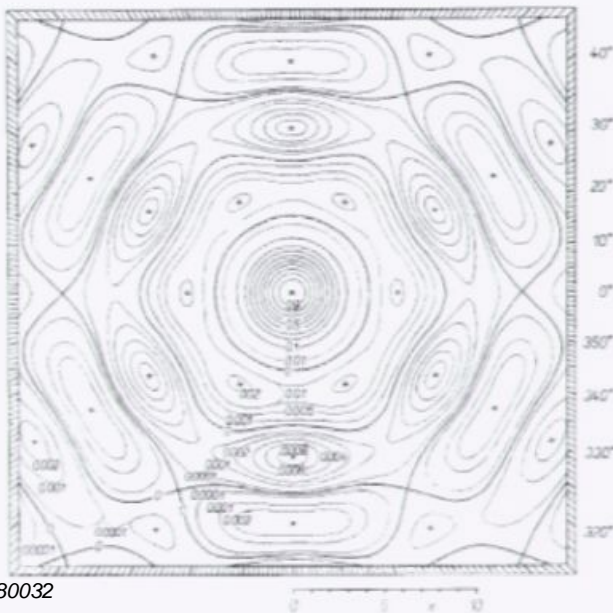
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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

# Fraunhofer diffraction at polygonal apertures

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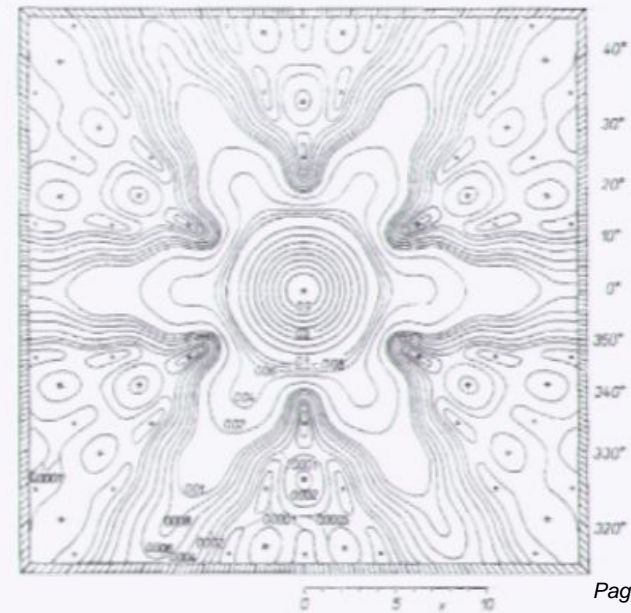
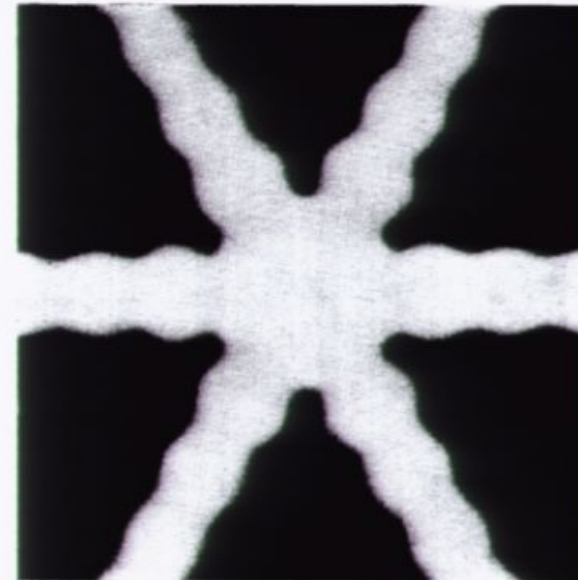


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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

Fraunhofer diffraction at regular polygons

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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



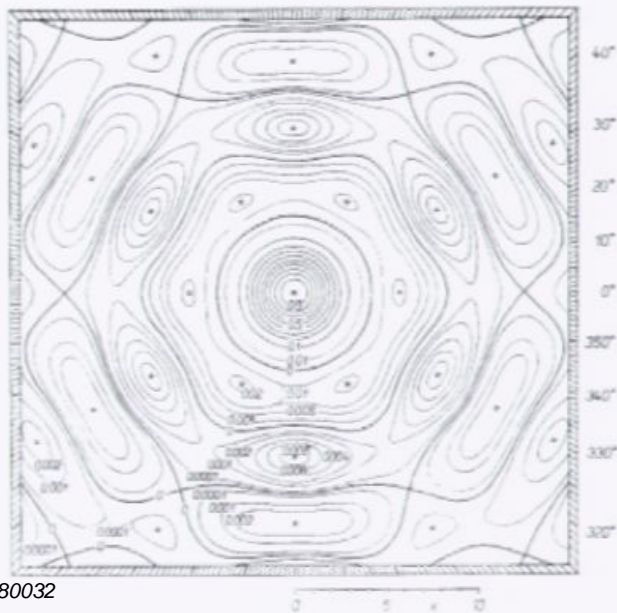
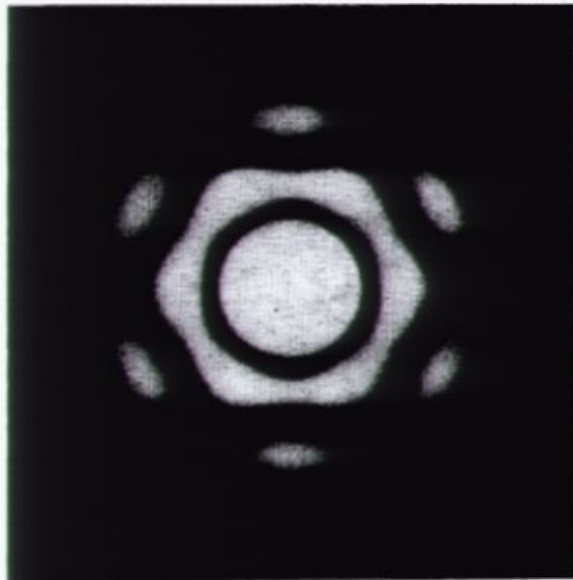
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

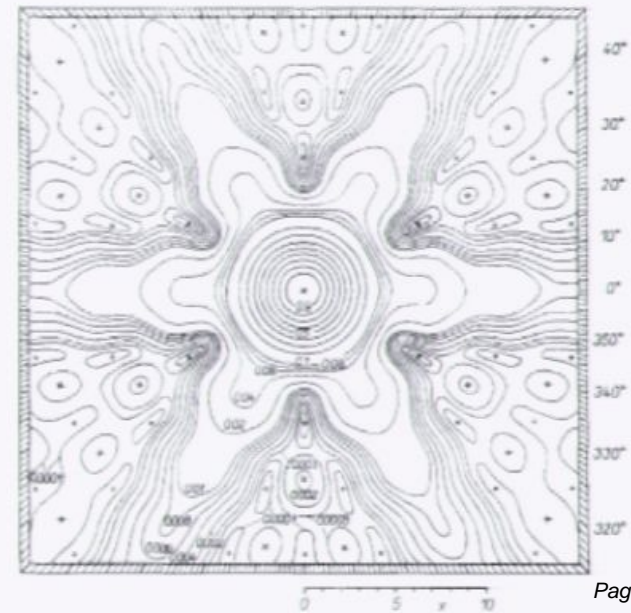
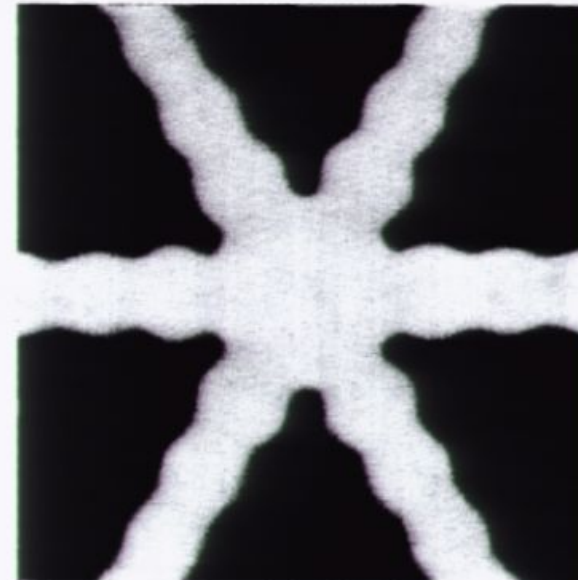


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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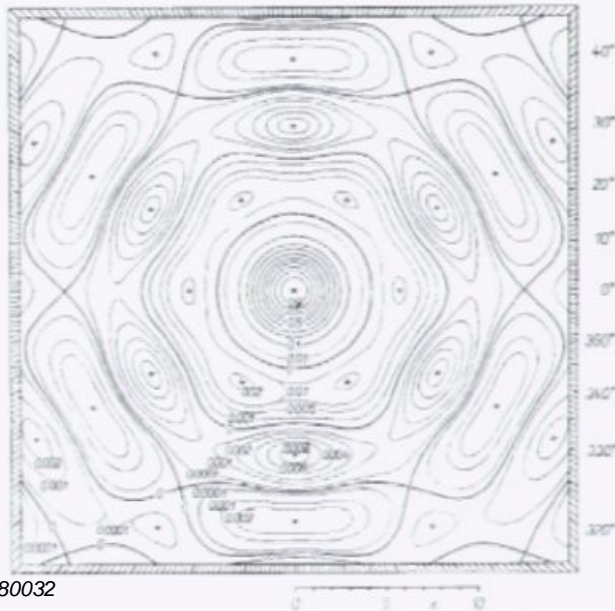
# Fraunhofer diffraction at polygonal apertures

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J. Komrška

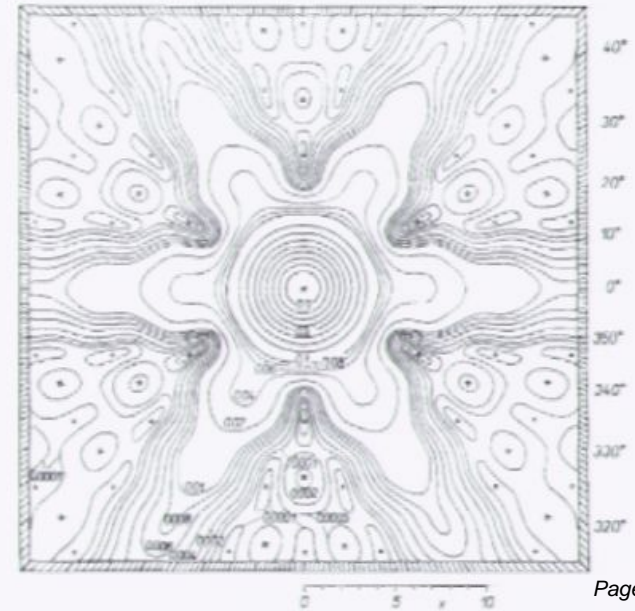
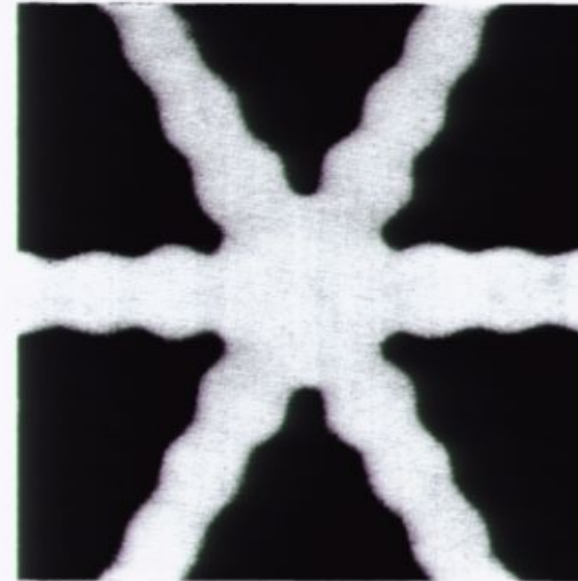
Fraunhofer diffraction at regular polygons

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Pirsa: 10080032

Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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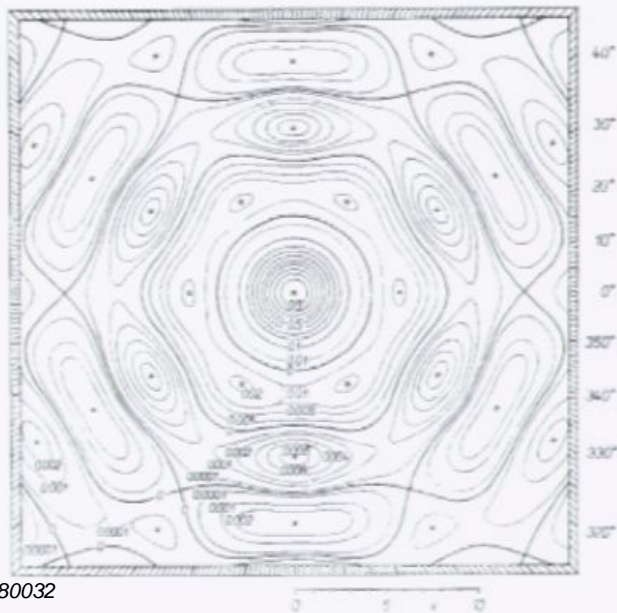
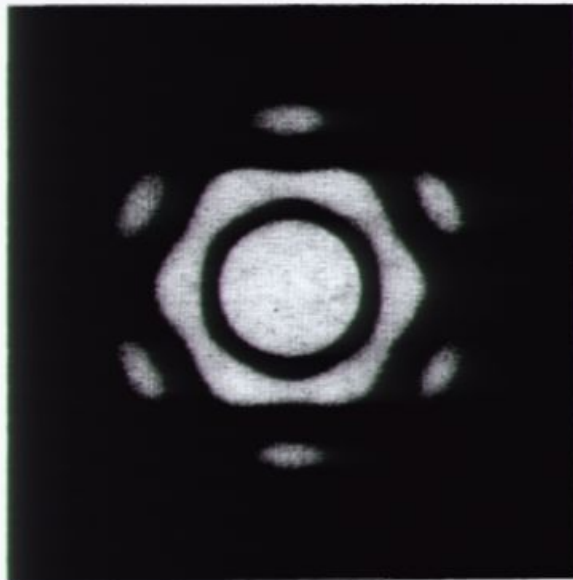
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J. Komrská

Fraunhofer diffraction at regular polygons

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Pirsa: 10080032

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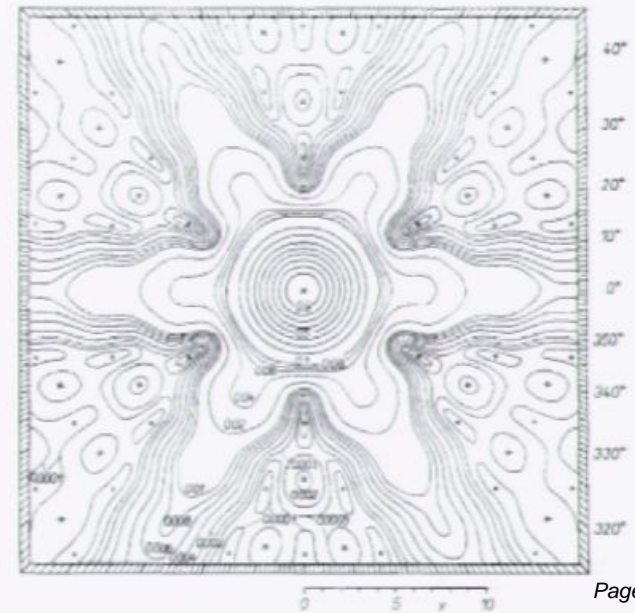
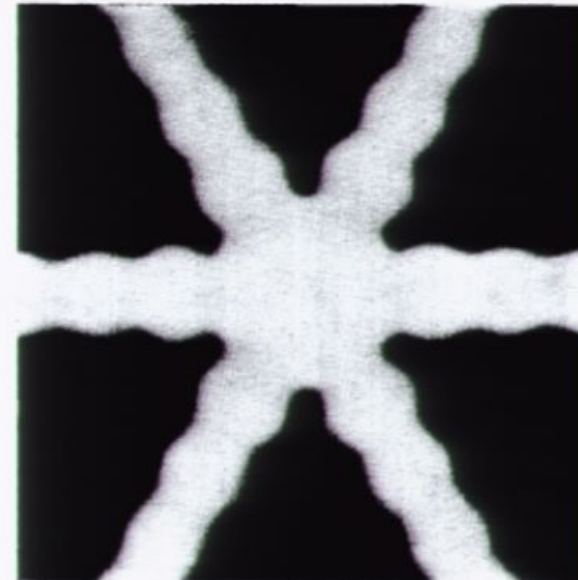


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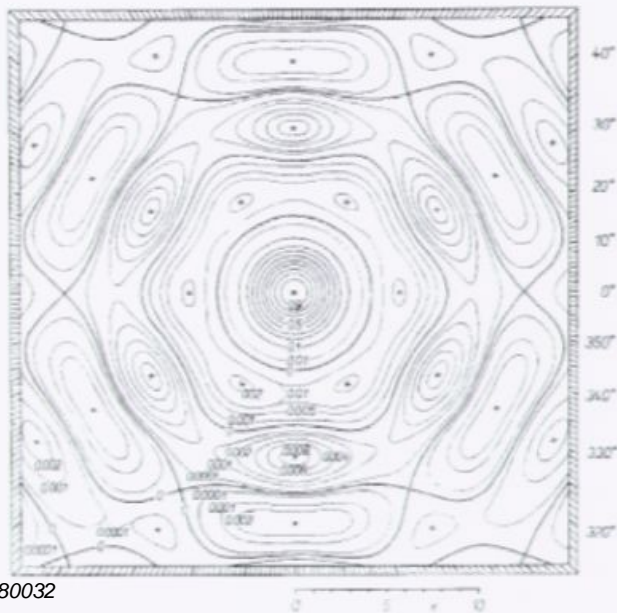
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# Fraunhofer diffraction at polygonal apertures

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J. Komrha

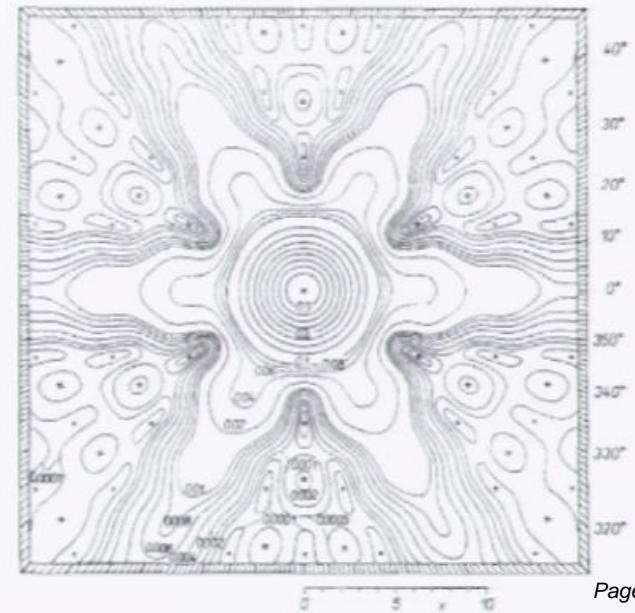
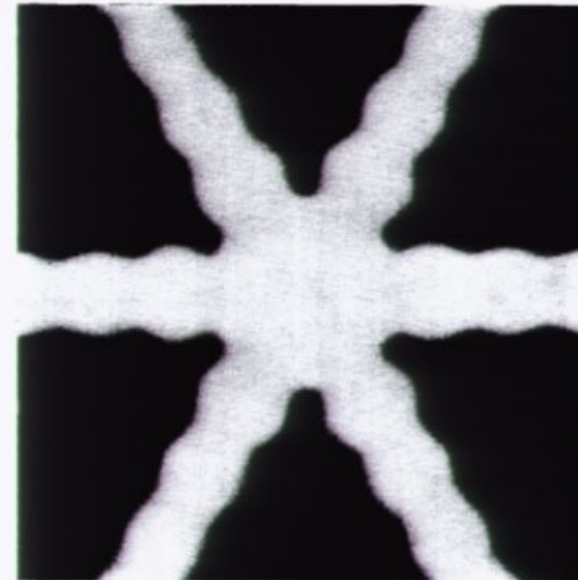


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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

Fraunhofer diffraction at regular polygons

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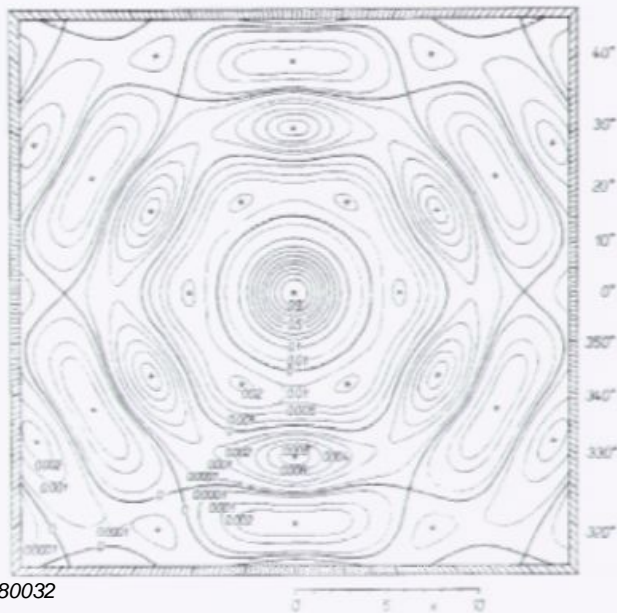
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J. Komrská

Fraunhofer diffraction at regular polygons

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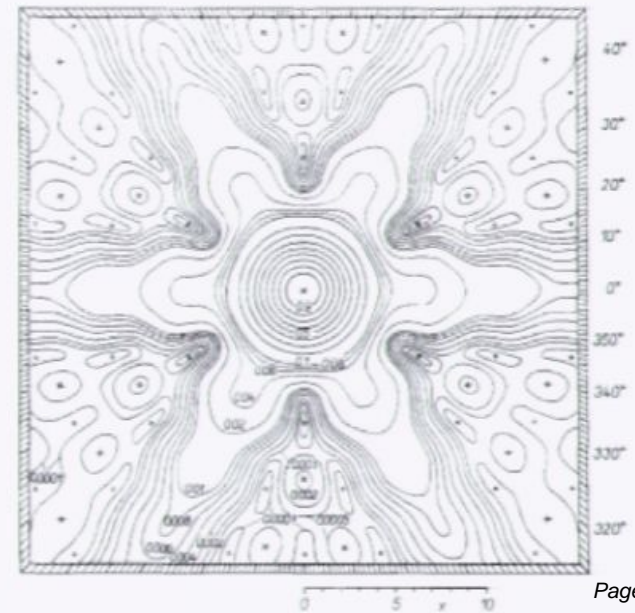
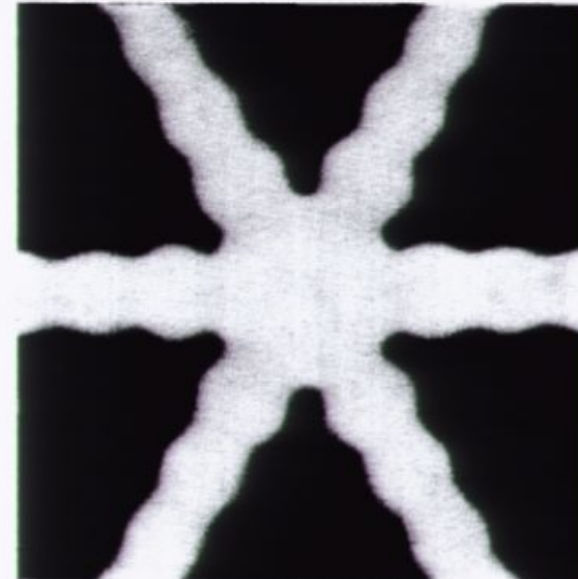


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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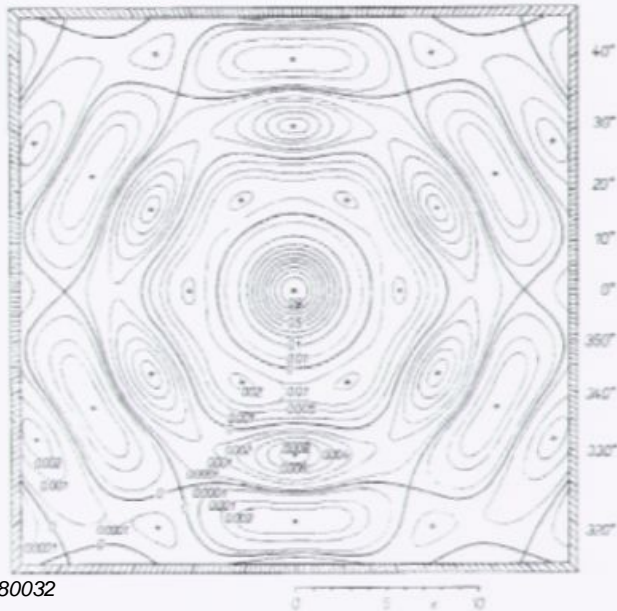
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J. Komrška

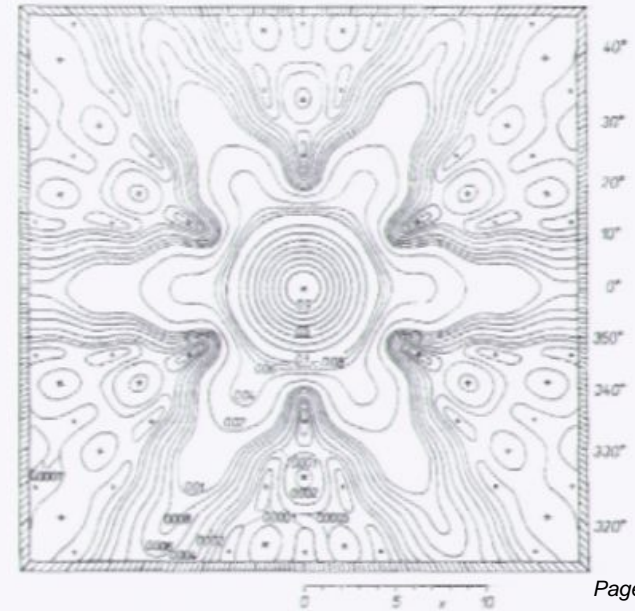
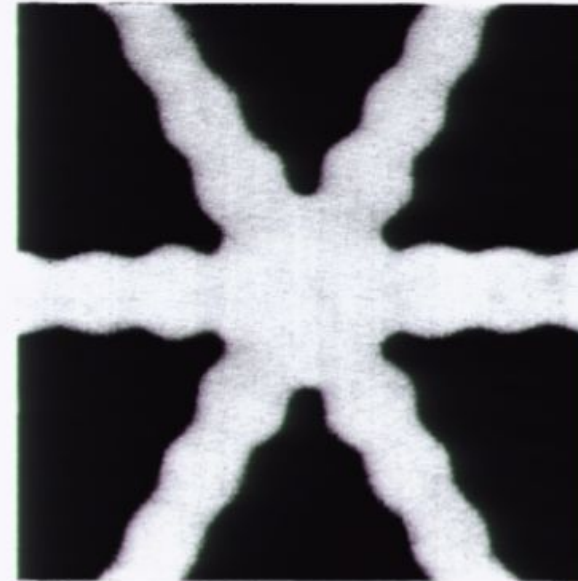
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



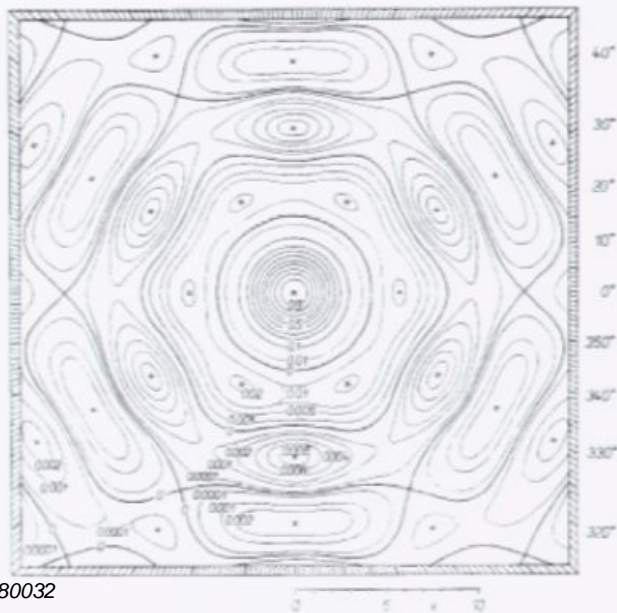
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Fraunhofer diffraction at regular polygons

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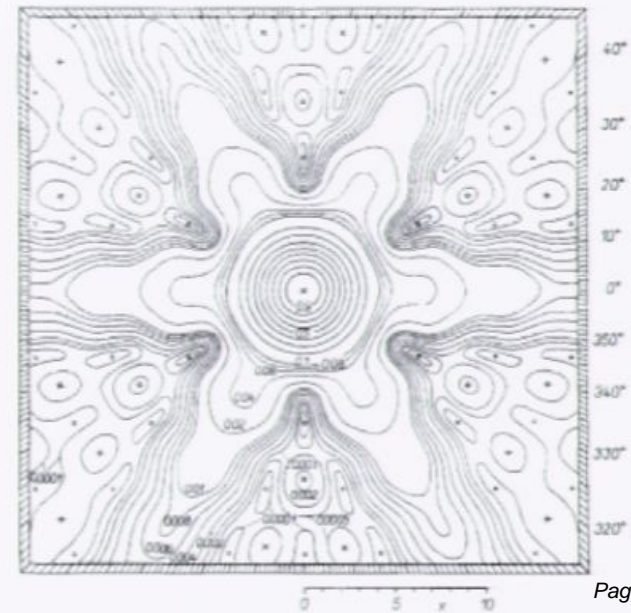
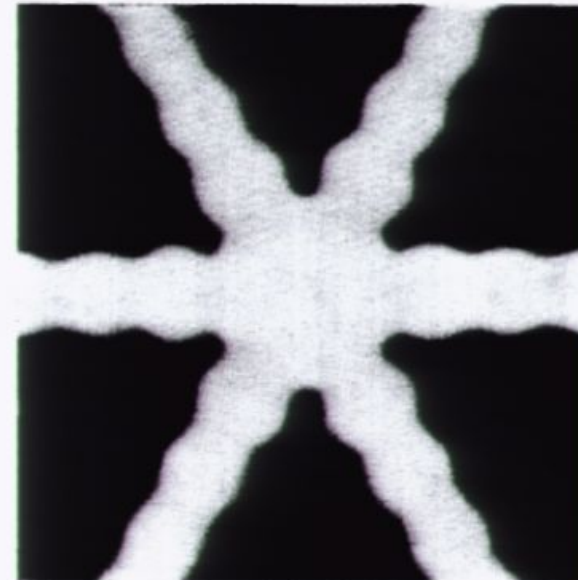


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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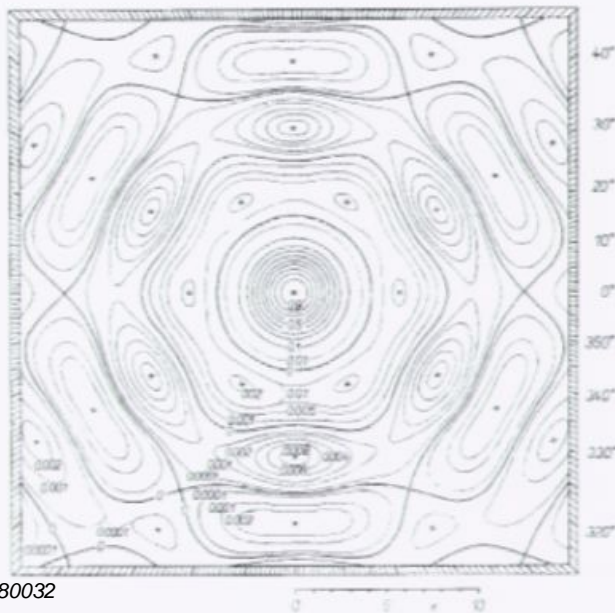
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J. Komrha

Fraunhofer diffraction at regular polygons

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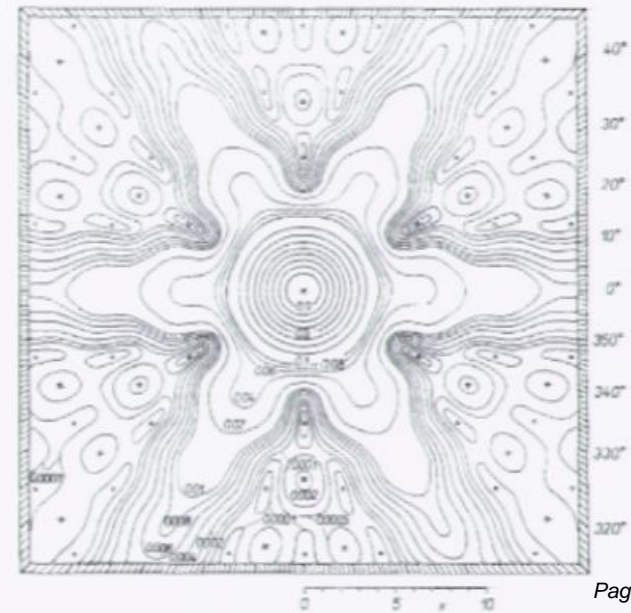
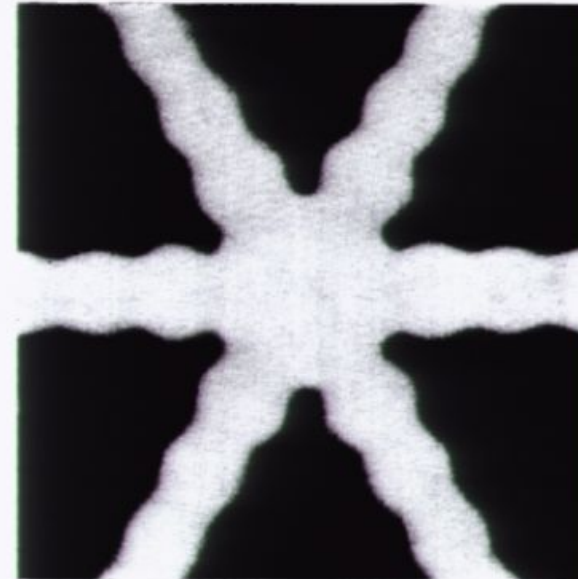


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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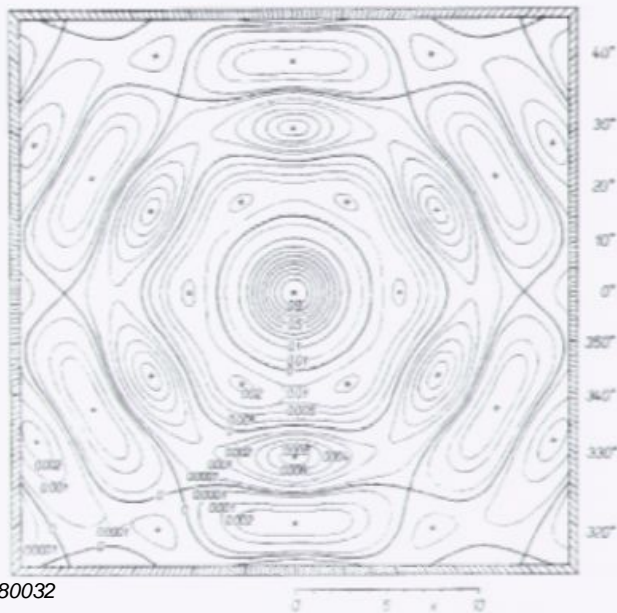
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Fraunhofer diffraction at regular polygons

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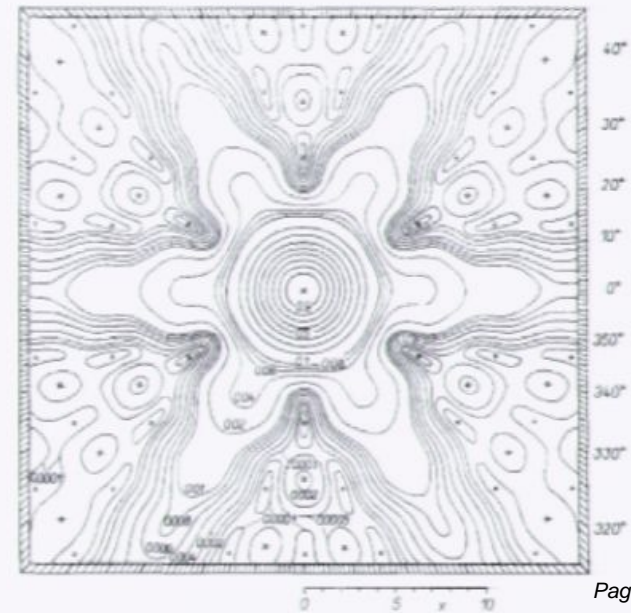
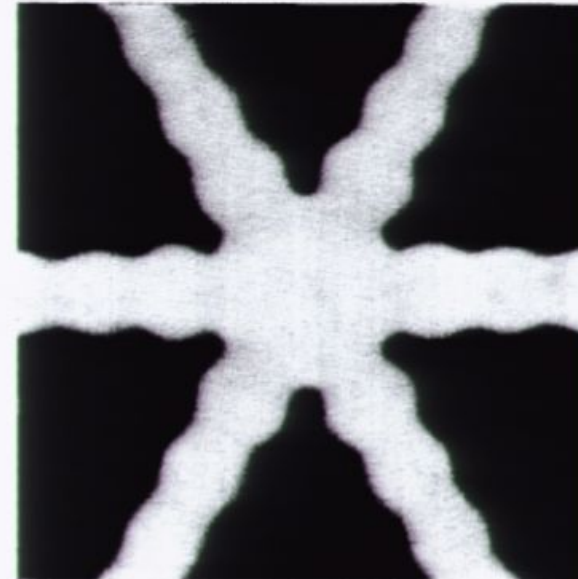


Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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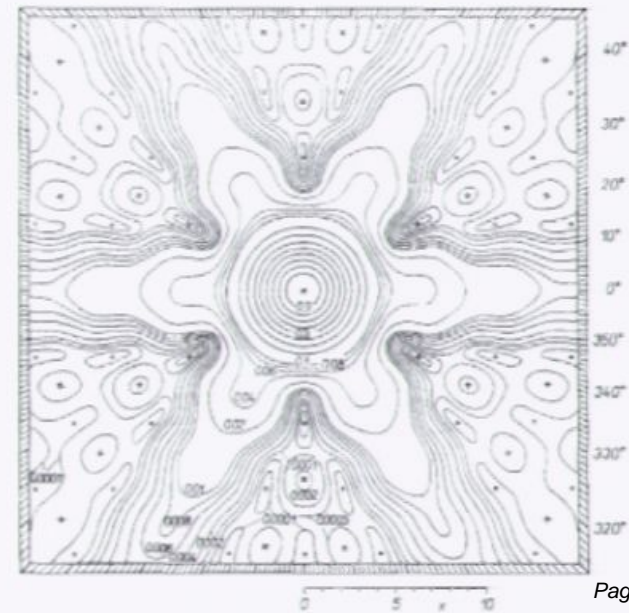
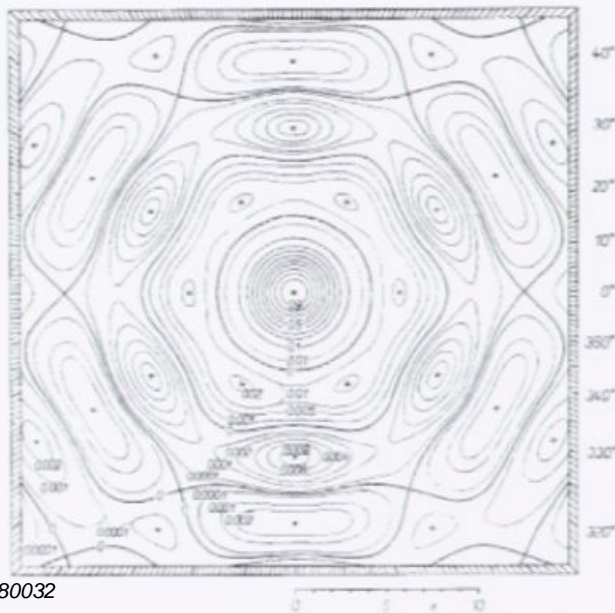
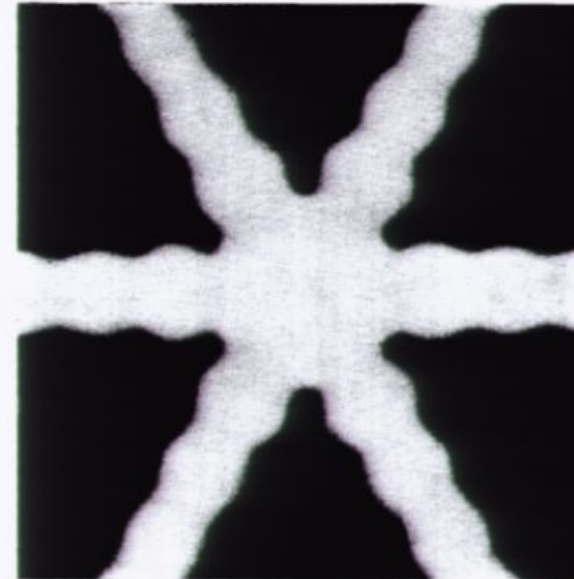
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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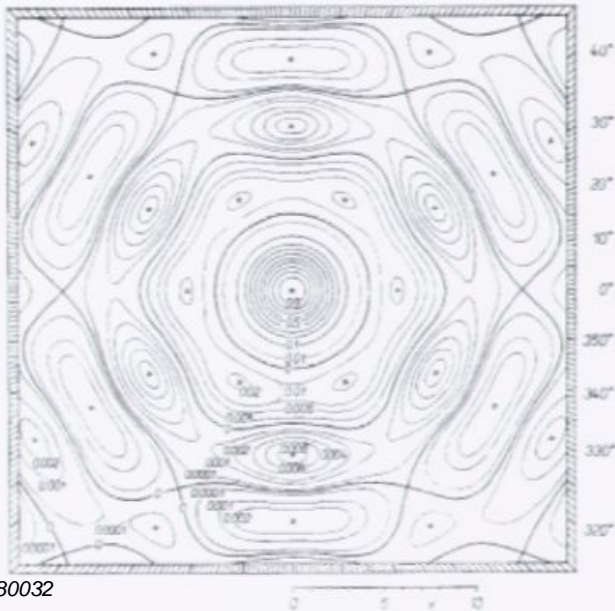
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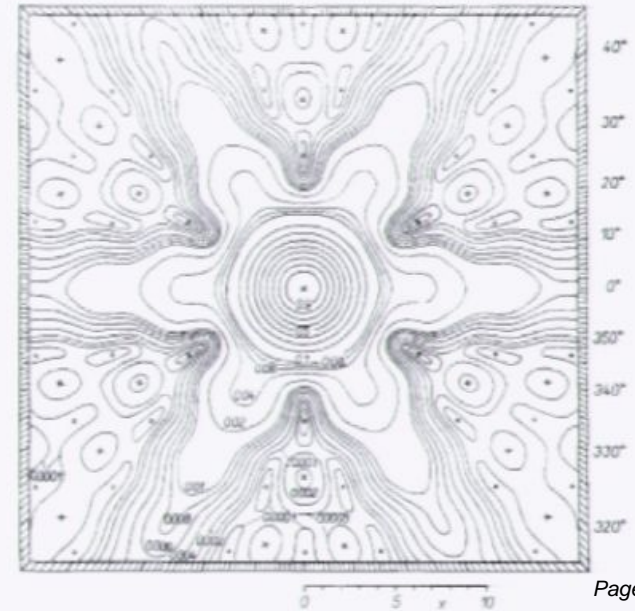
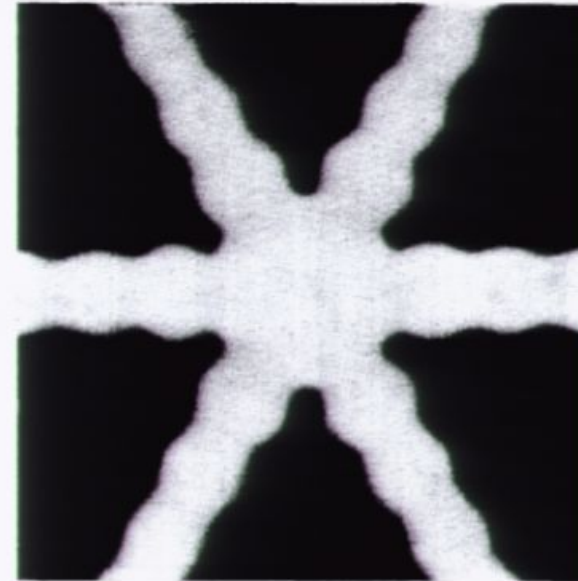
Fraunhofer diffraction at regular polygons

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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



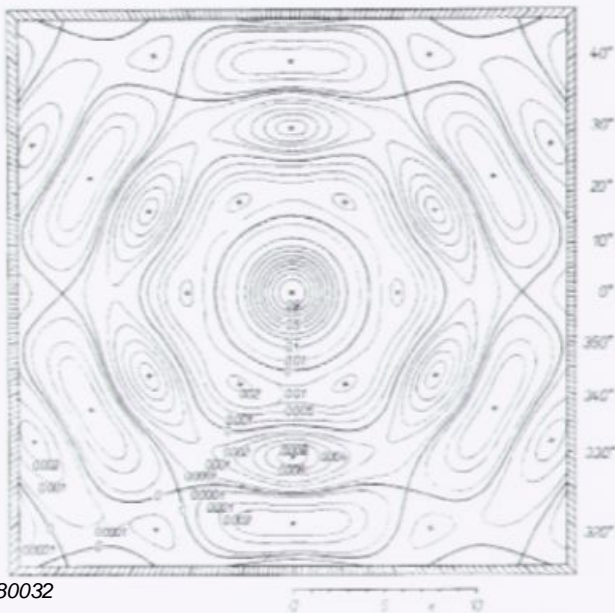
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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

# Fraunhofer diffraction at polygonal apertures

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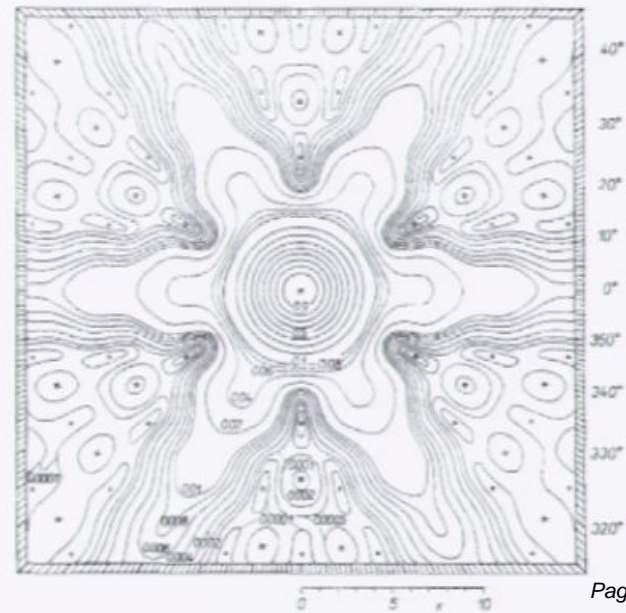
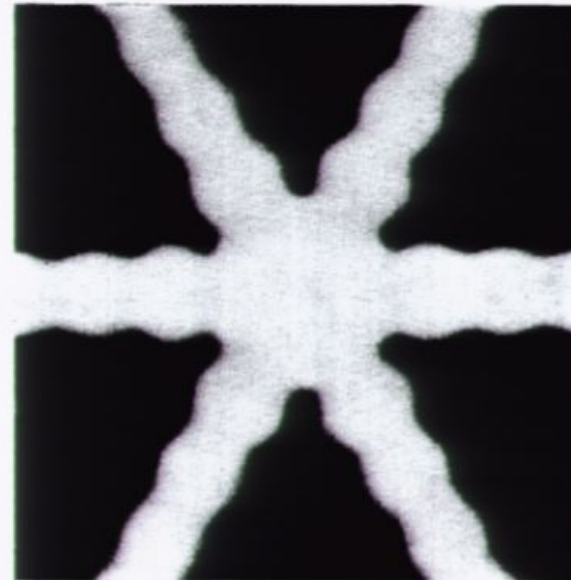


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Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



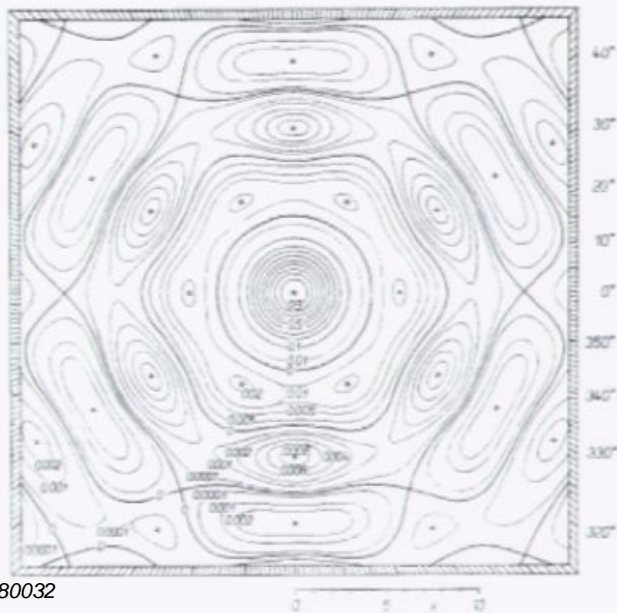
# Fraunhofer diffraction at polygonal apertures

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Fraunhofer diffraction at regular polygons

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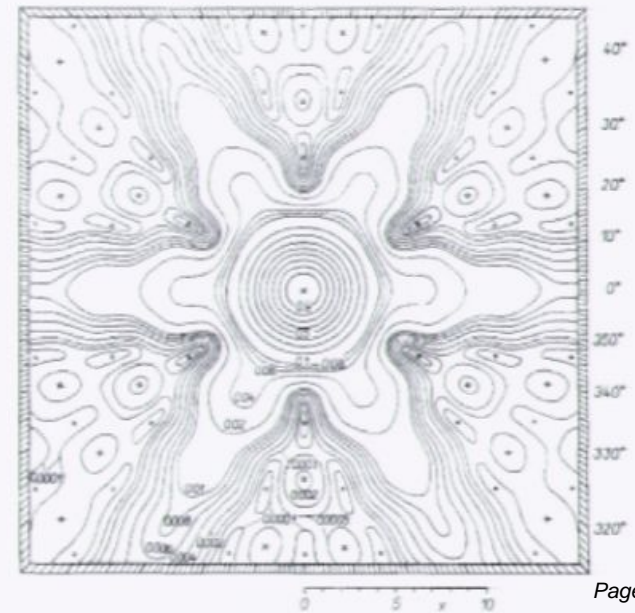
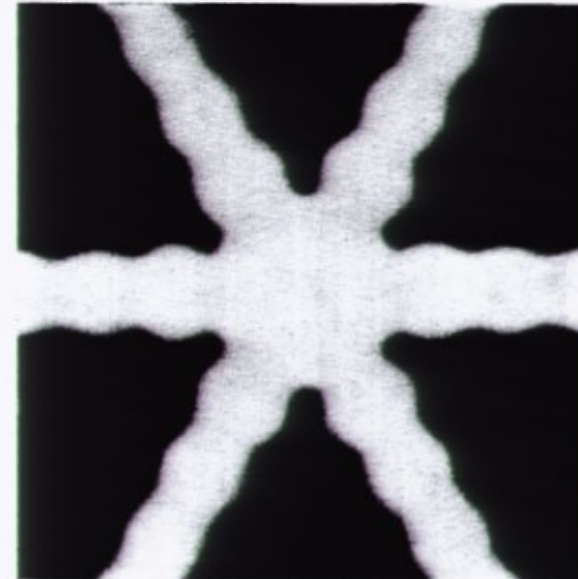


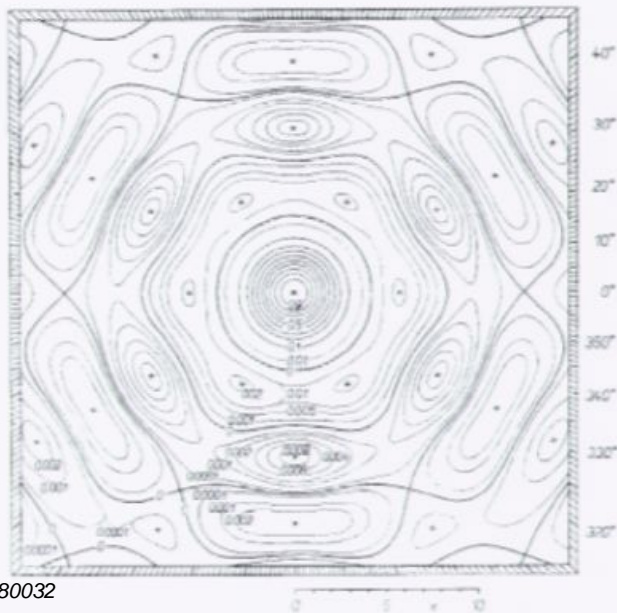
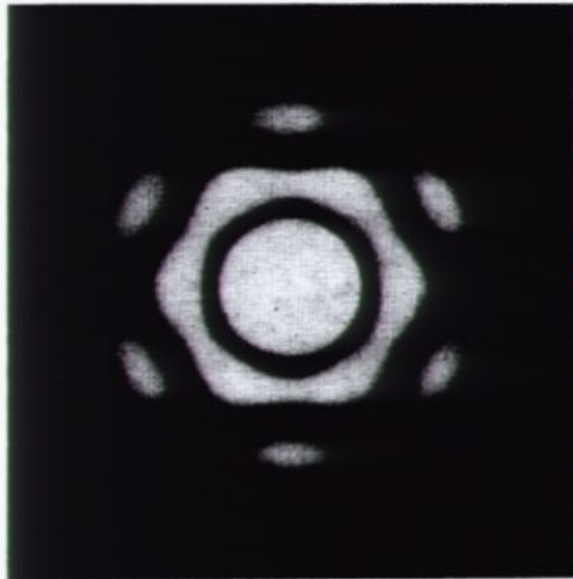
Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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# Fraunhofer diffraction at polygonal apertures

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J. Komrka

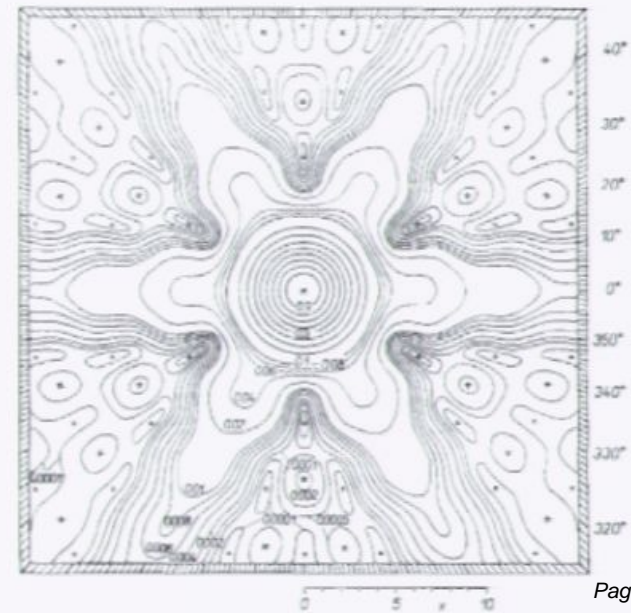
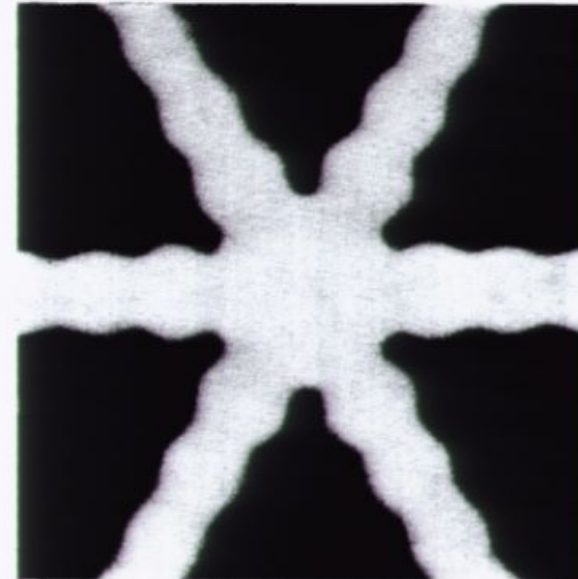


Pirsa: 10080032

Figure 8. Fraunhofer diffraction pattern of a hexagonal aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

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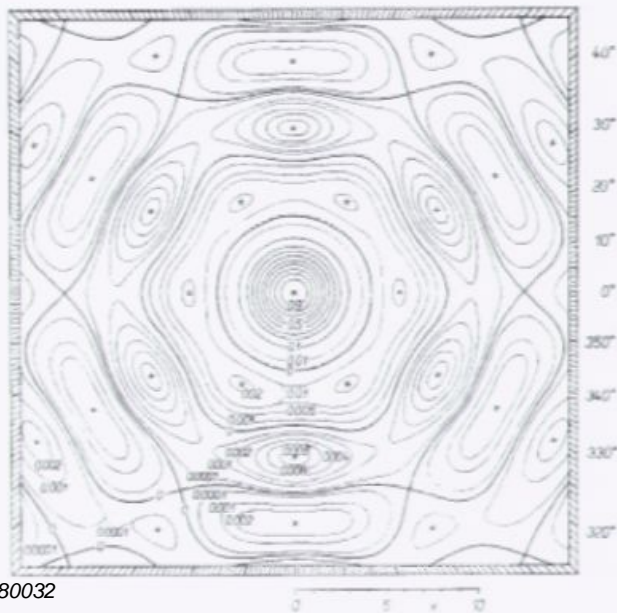
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Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .

# Fraunhofer diffraction at polygonal apertures

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J. Komrka

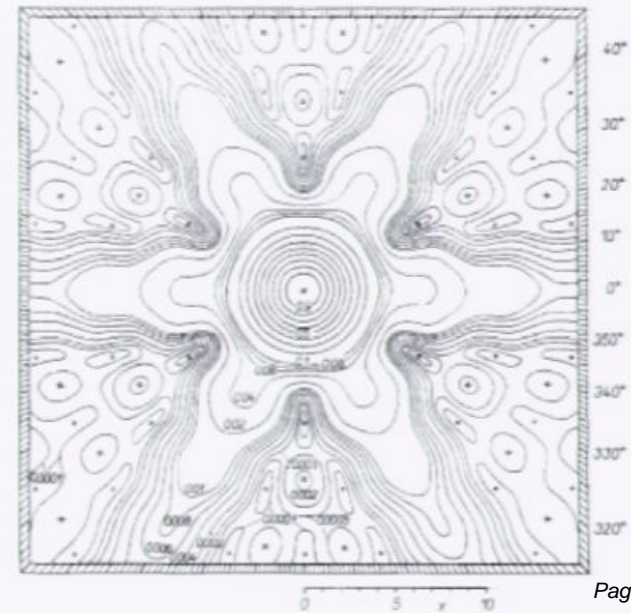
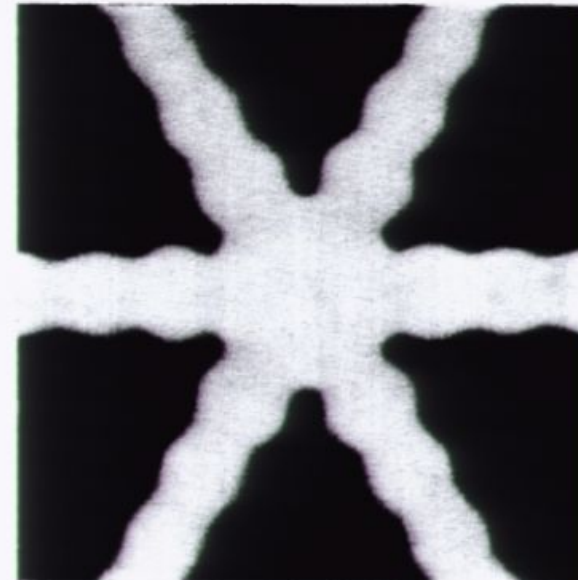


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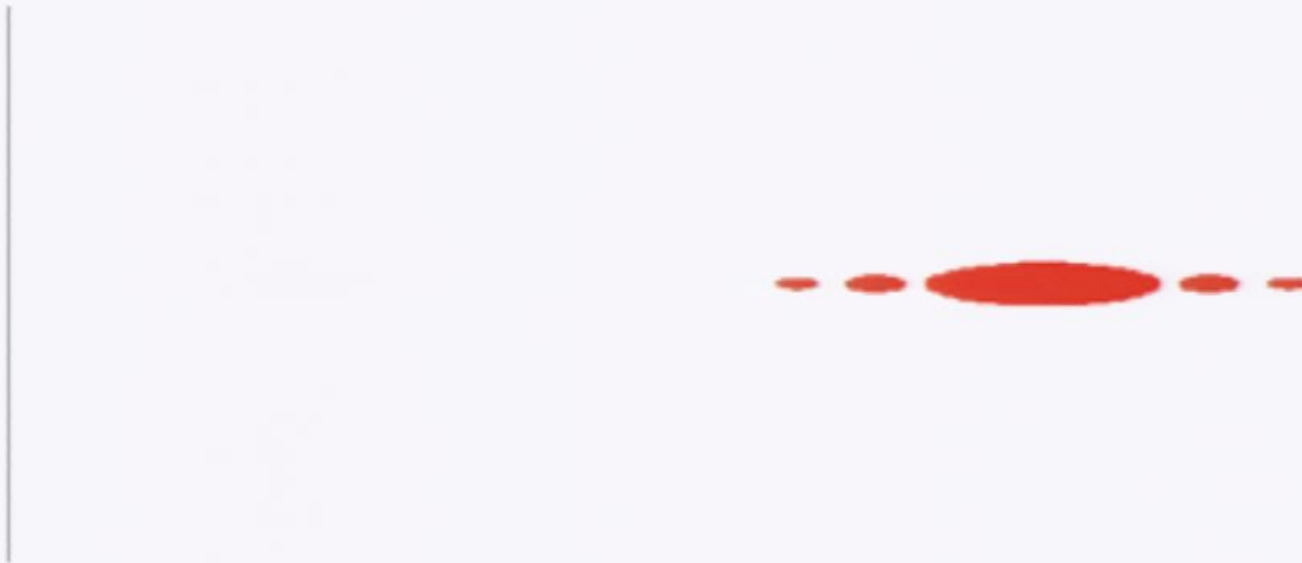
Figure 3. Fraunhofer diffraction pattern of a triangular aperture compared with calculated intensity distribution  $I(x, y)/I_0$ .



# Star filters



# Star filters



# Star filters





# Star filters



# Combination effects



# Conclusion

- Internal reflections can lead to other odd, “ghost” images in the final picture.
- The non-circular nature of camera apertures can cause interesting diffraction effects, such as starburst.
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# **Spacetime - on your Bookshelf**

**James Reid**

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# Motivation

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- **To highlight the duality of Mathematical and Physical intuition**
- **To show that analogies in nature can lead us to the correct Mathematics**

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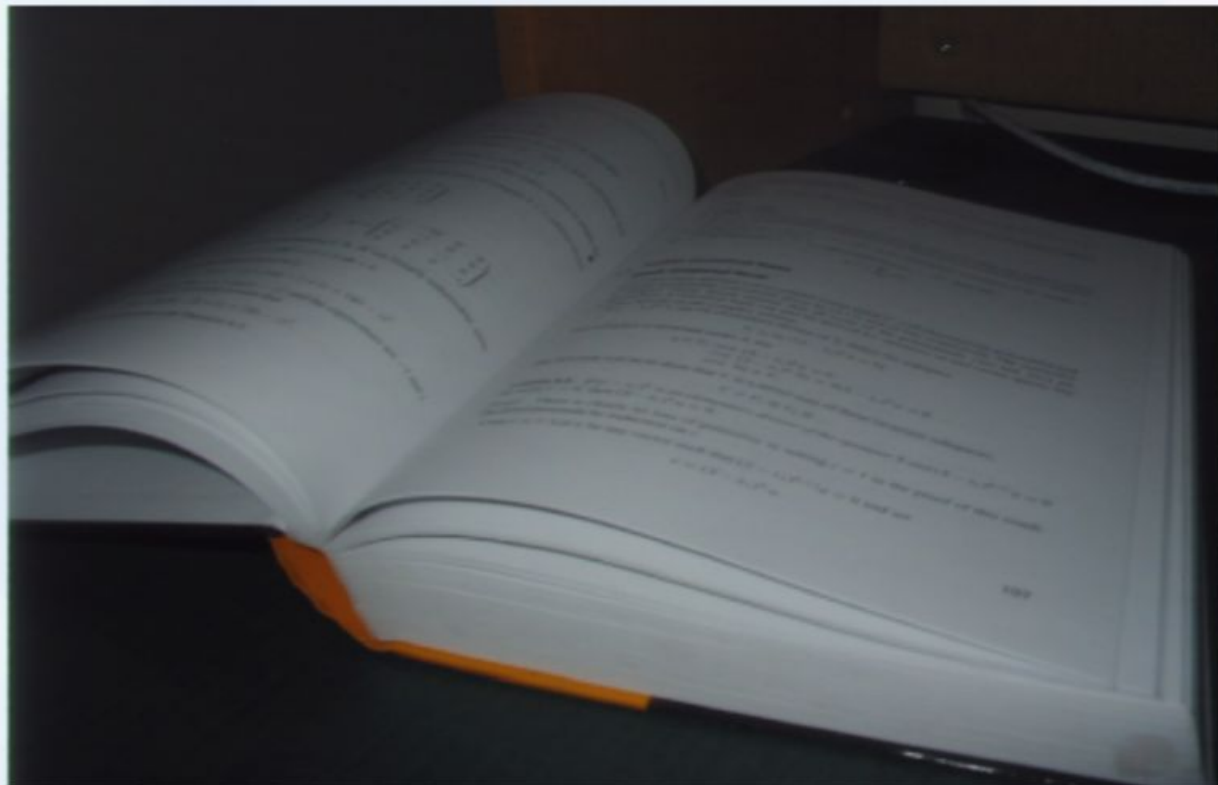
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# A 2-dimensional spacetime

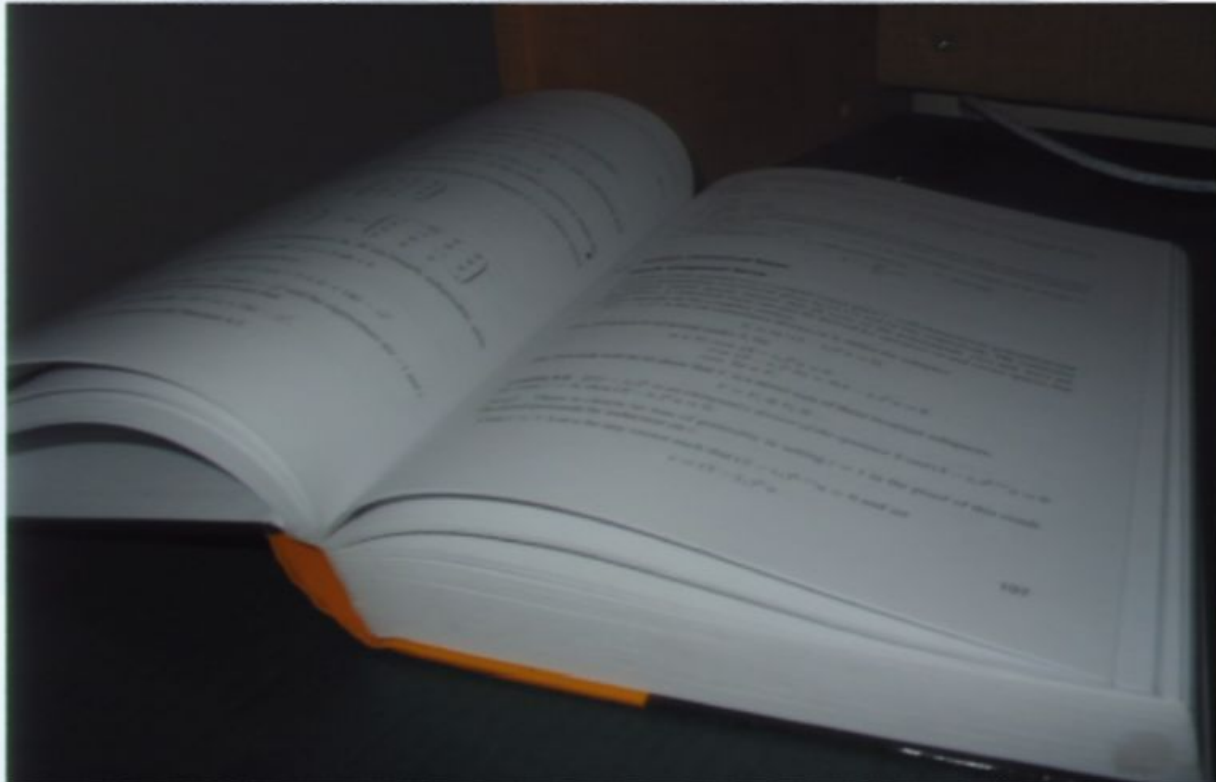
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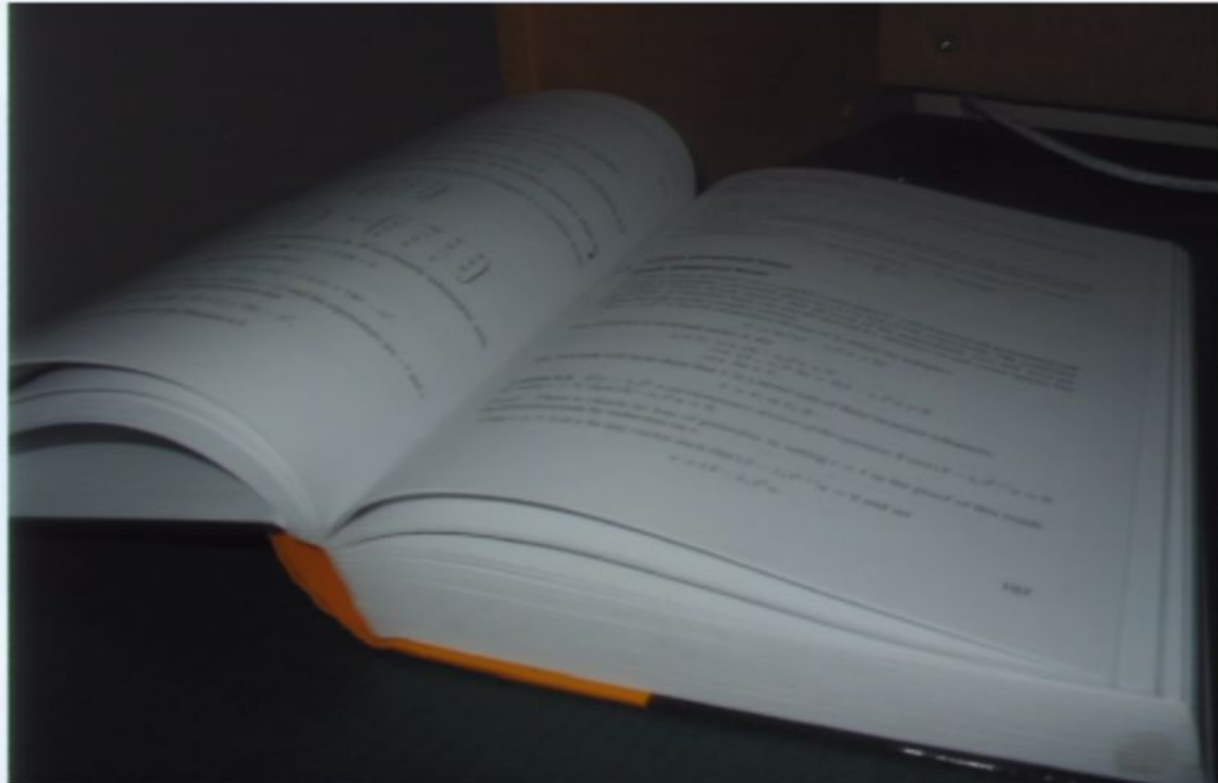
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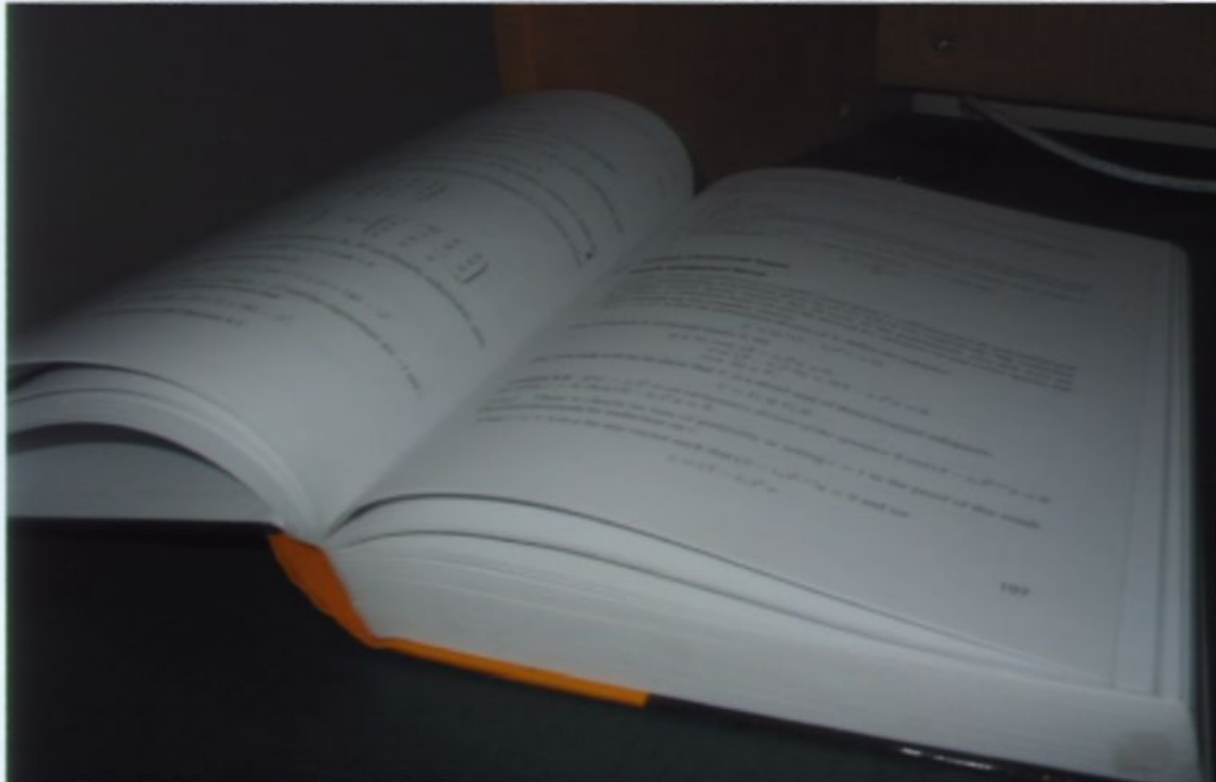
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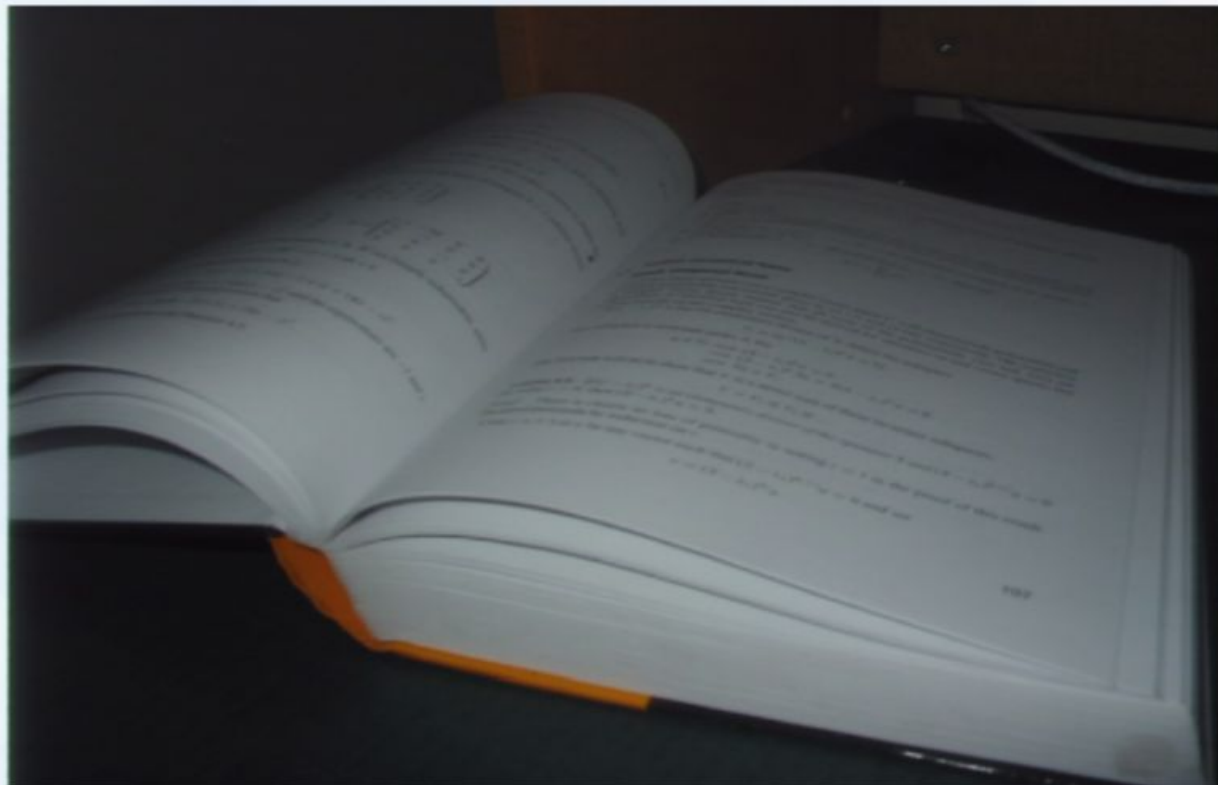
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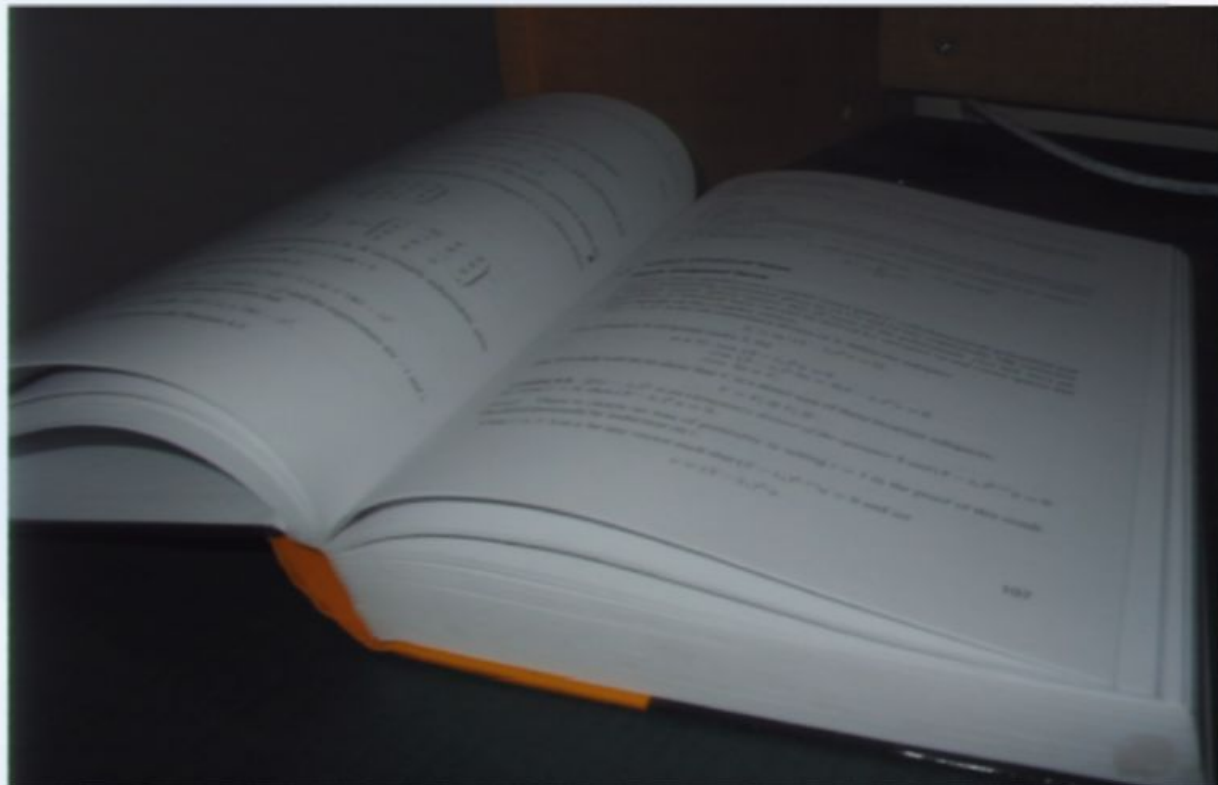
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# A 2-dimensional spacetime

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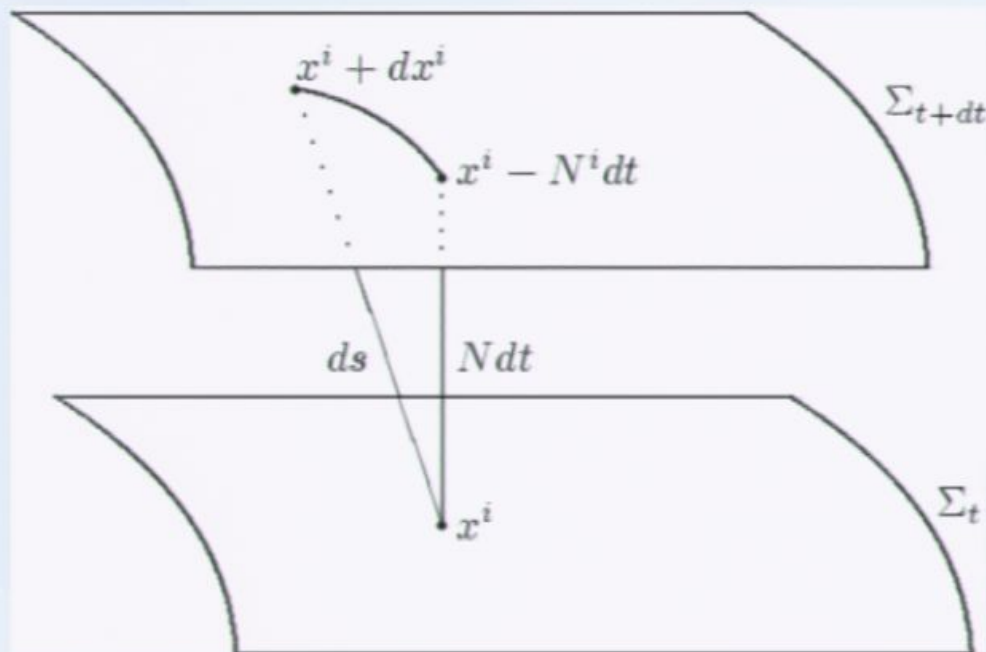


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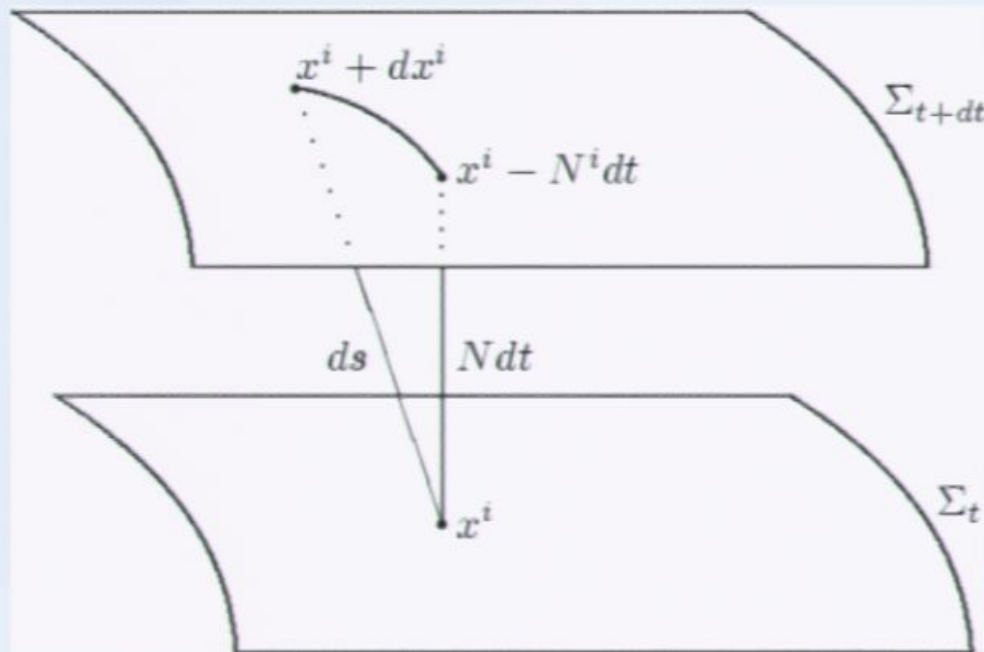
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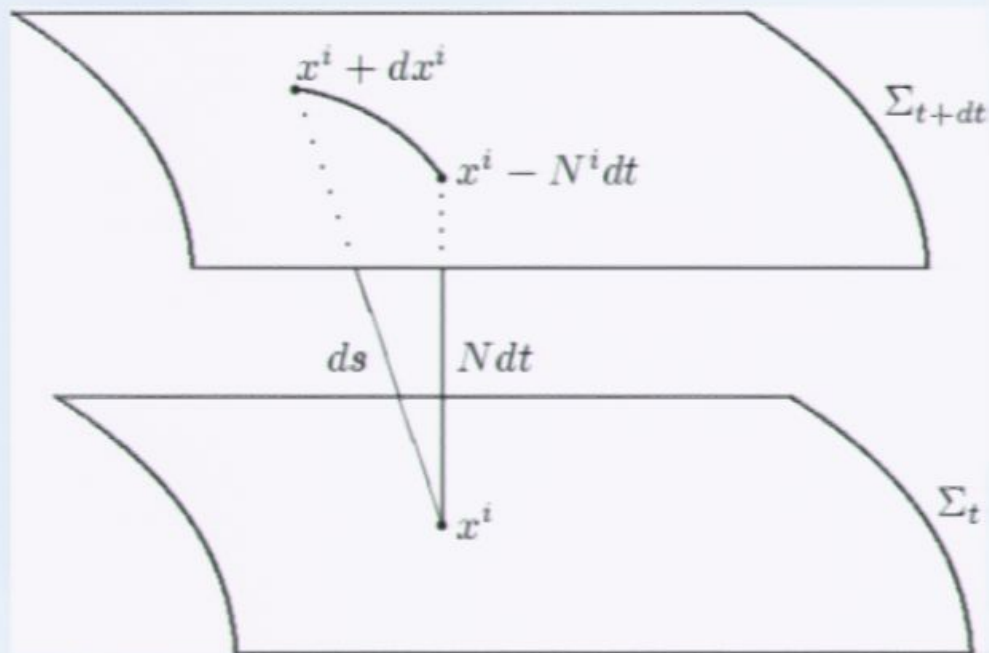
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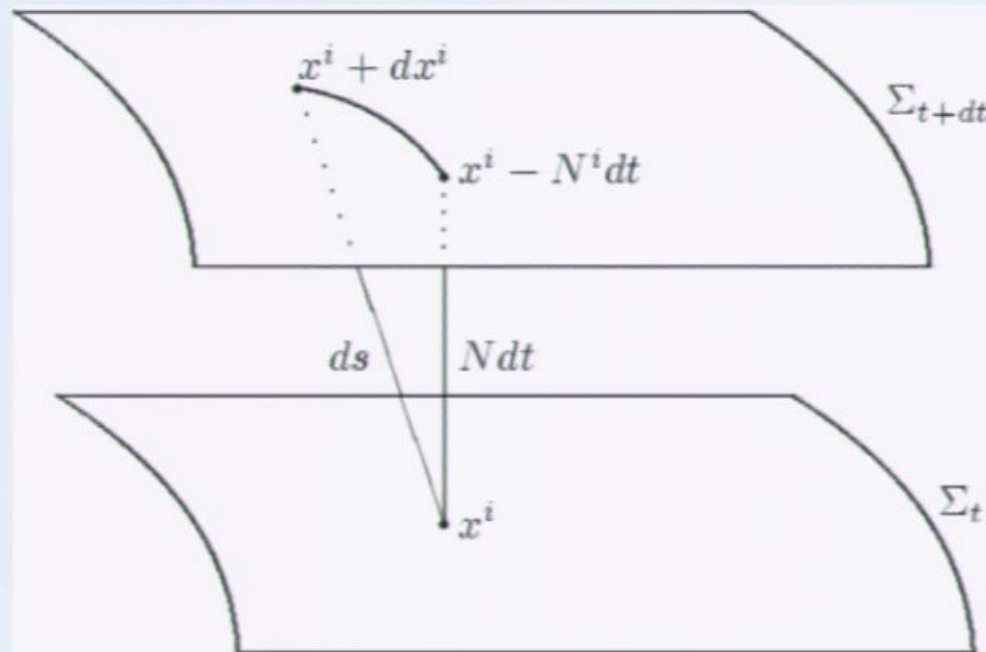




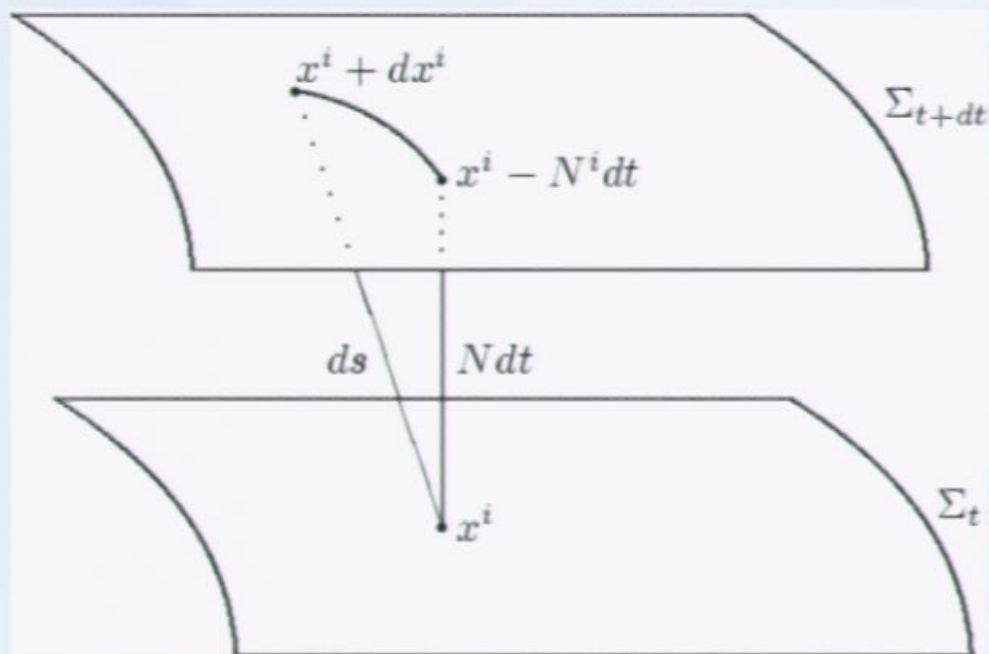
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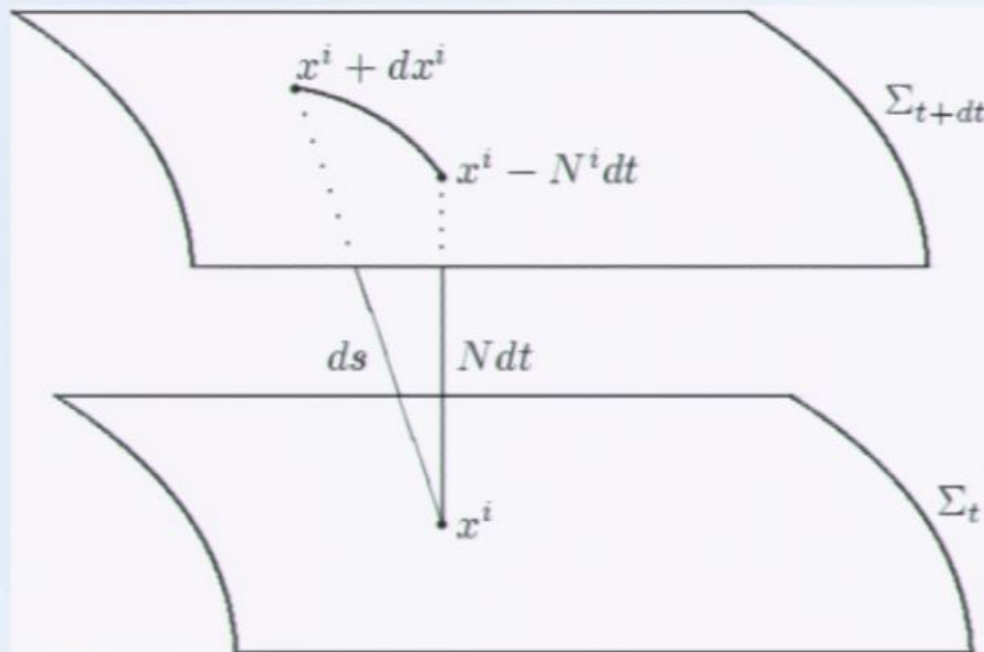


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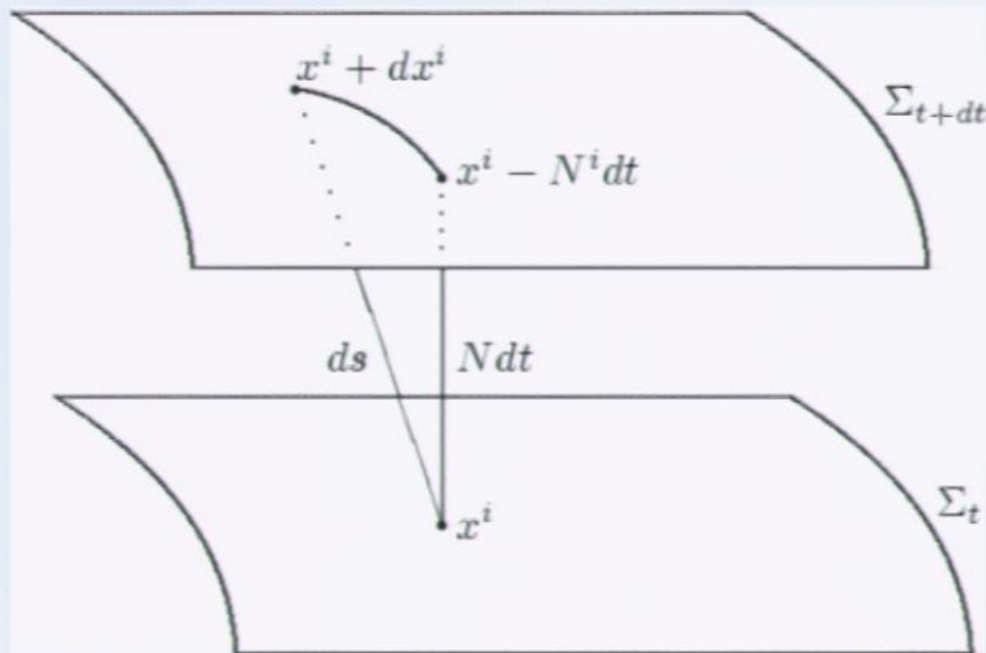




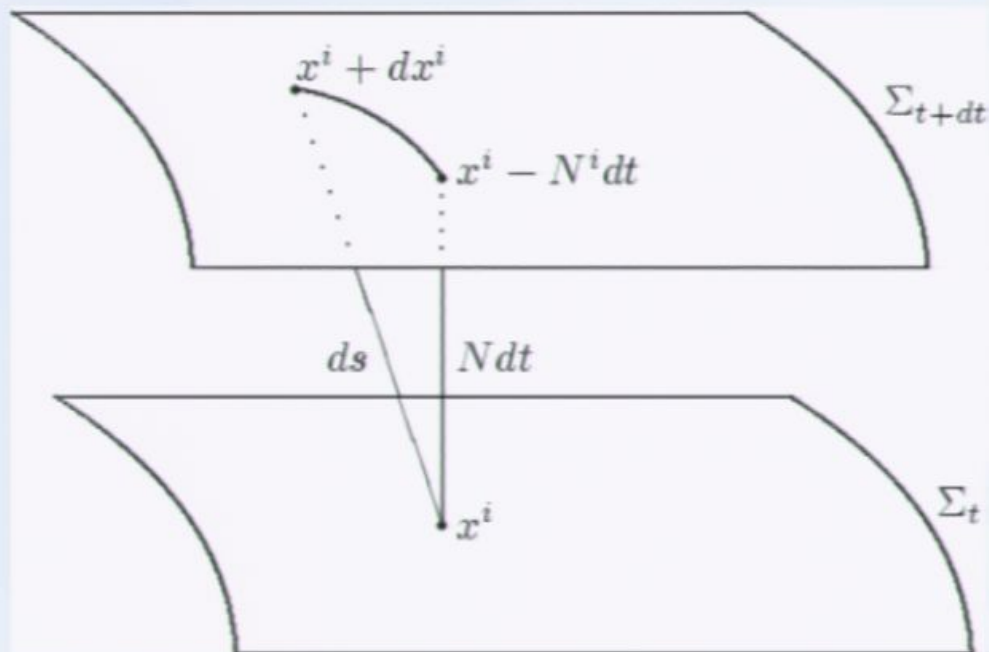
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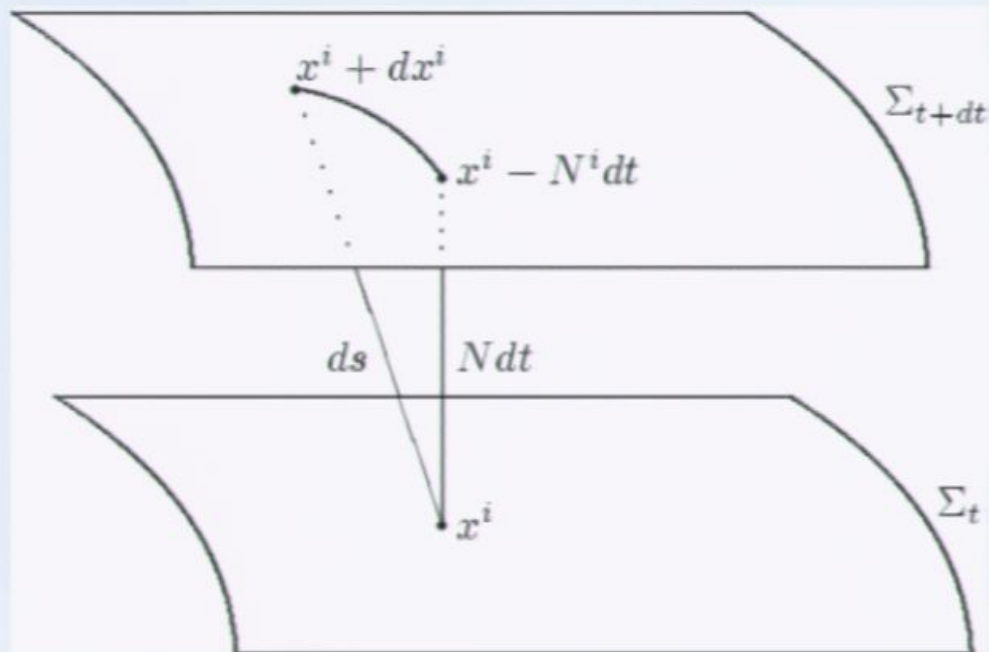


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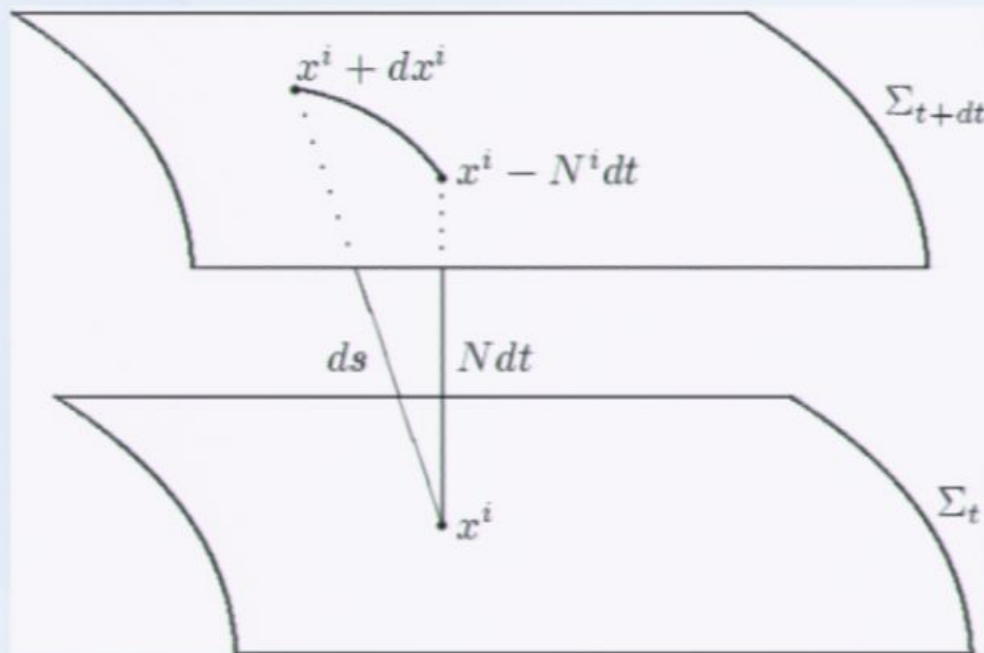


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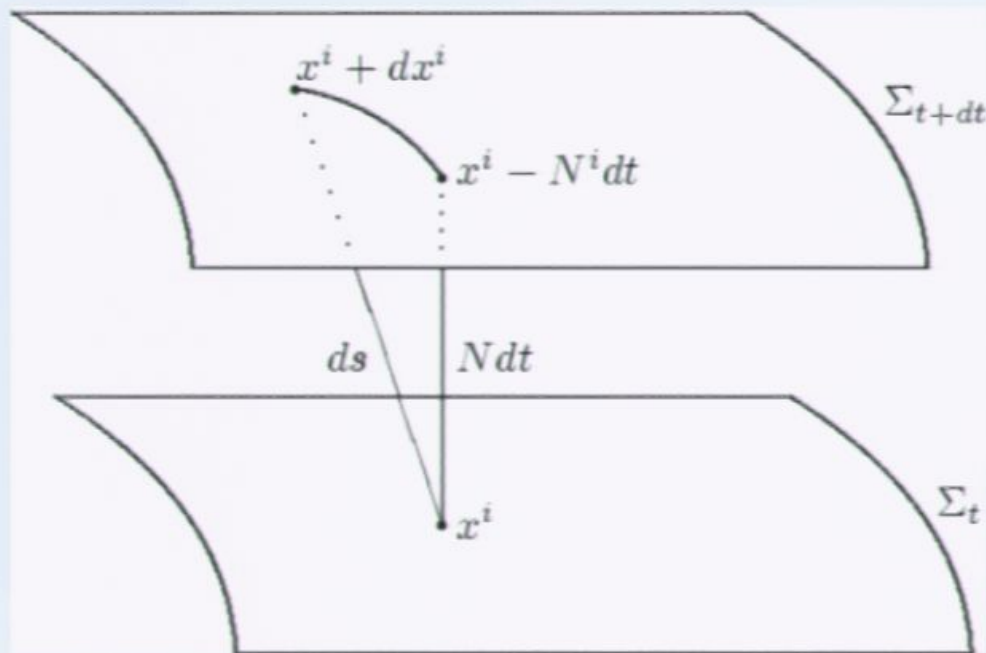


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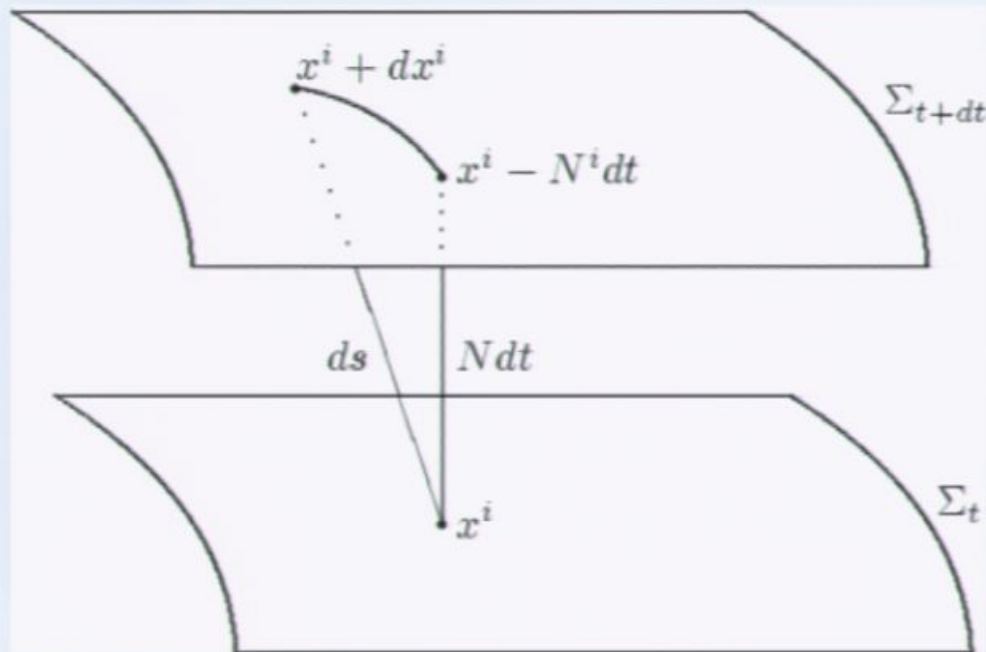


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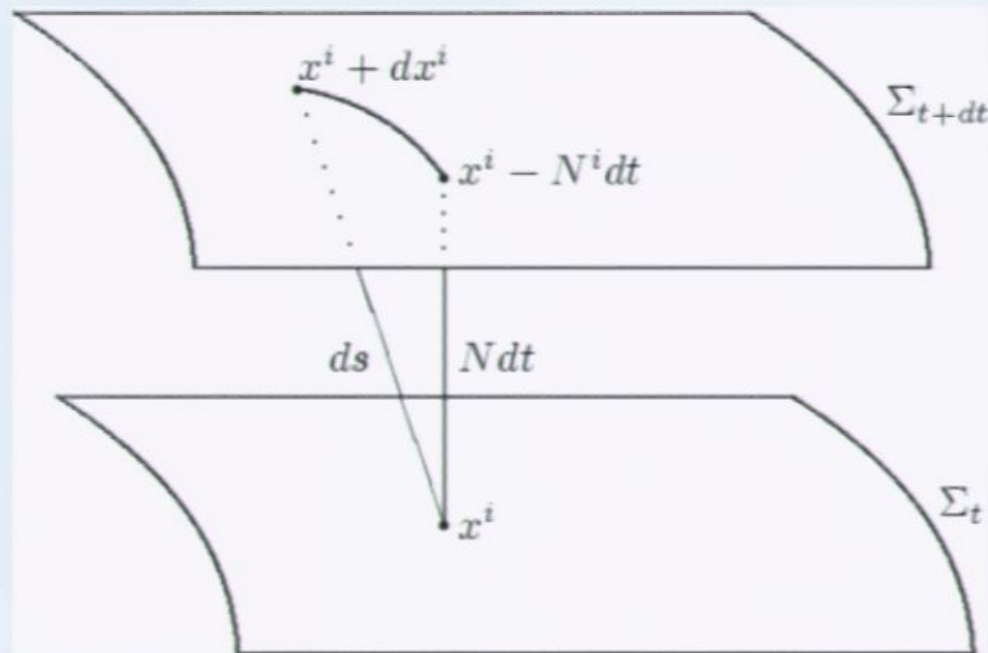




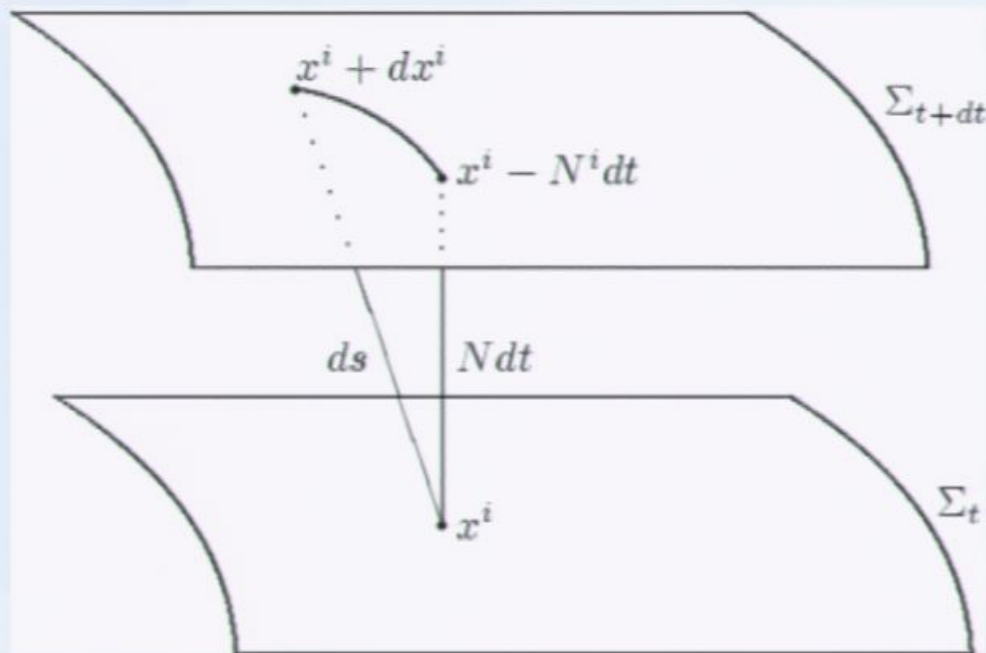
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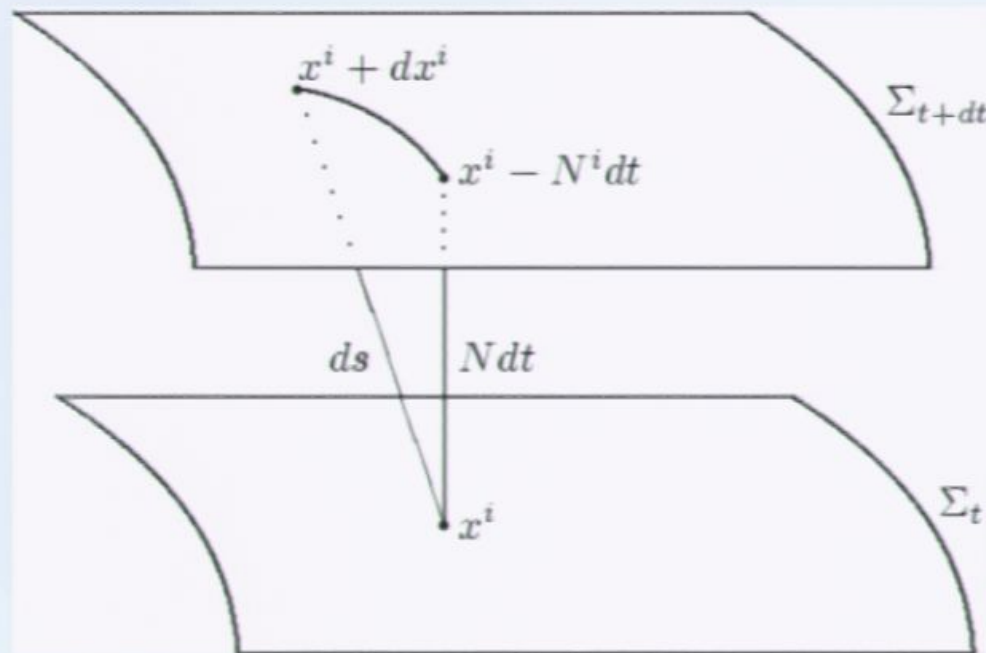


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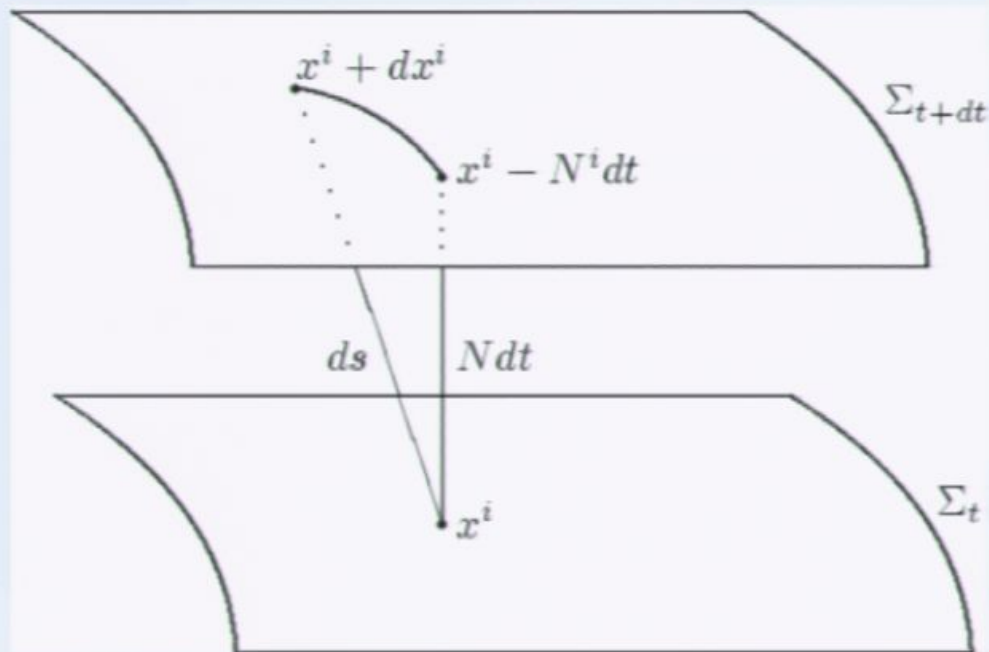




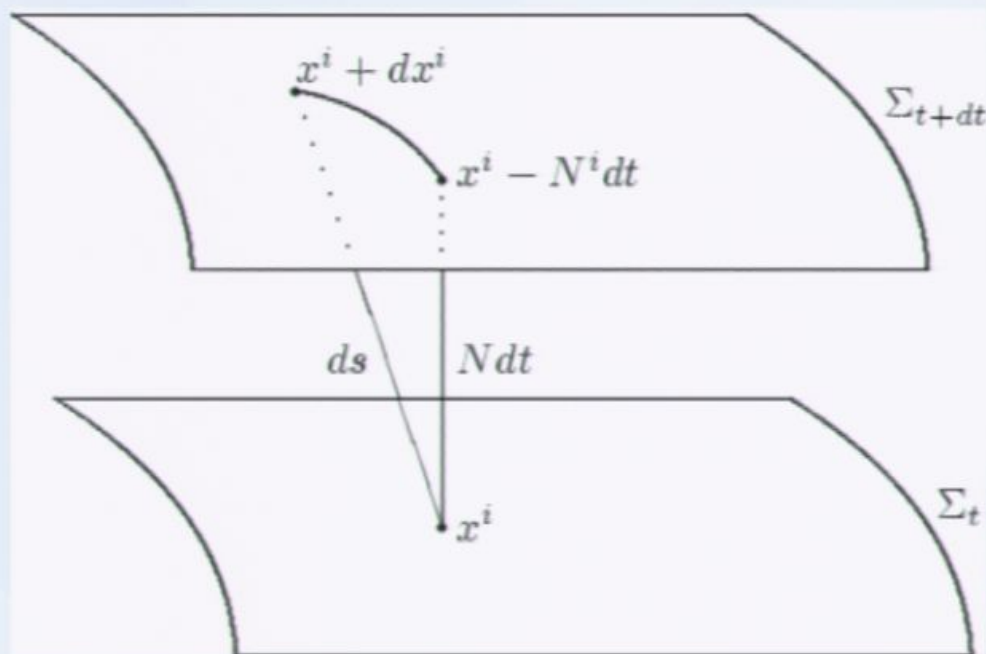
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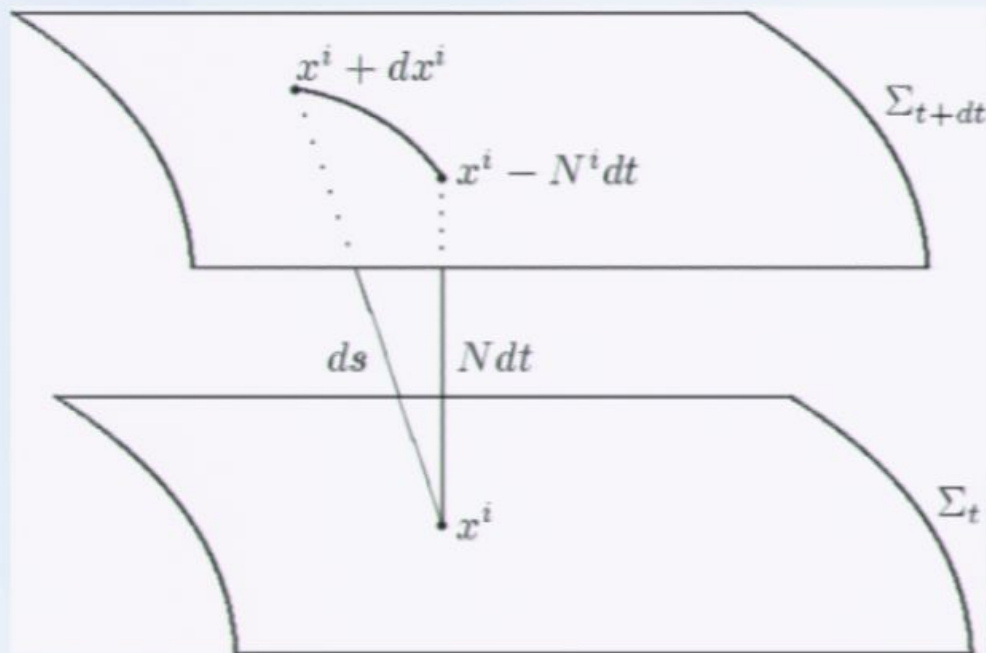


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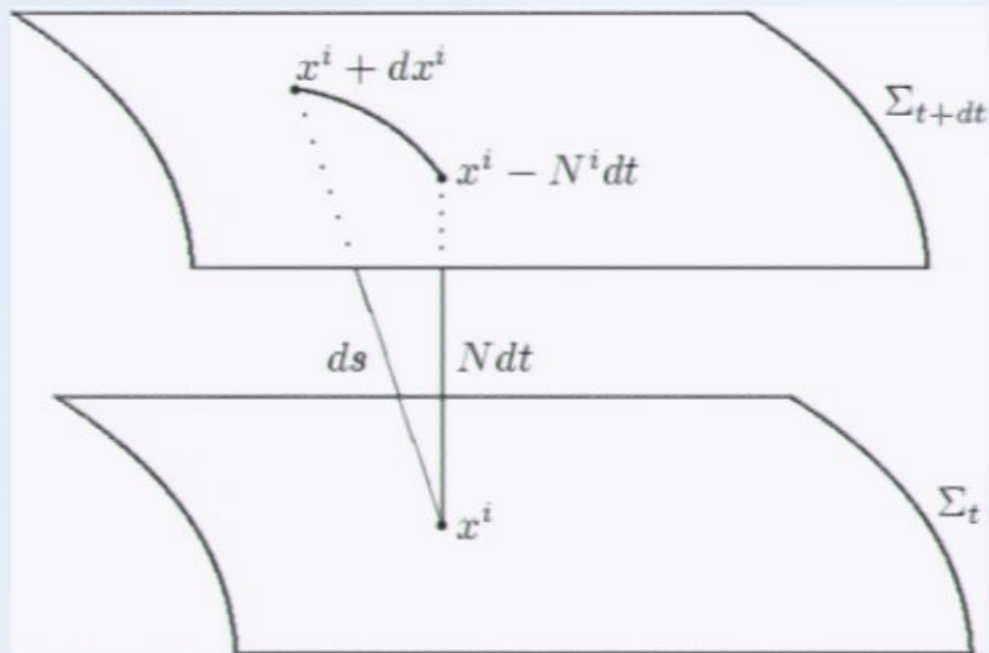




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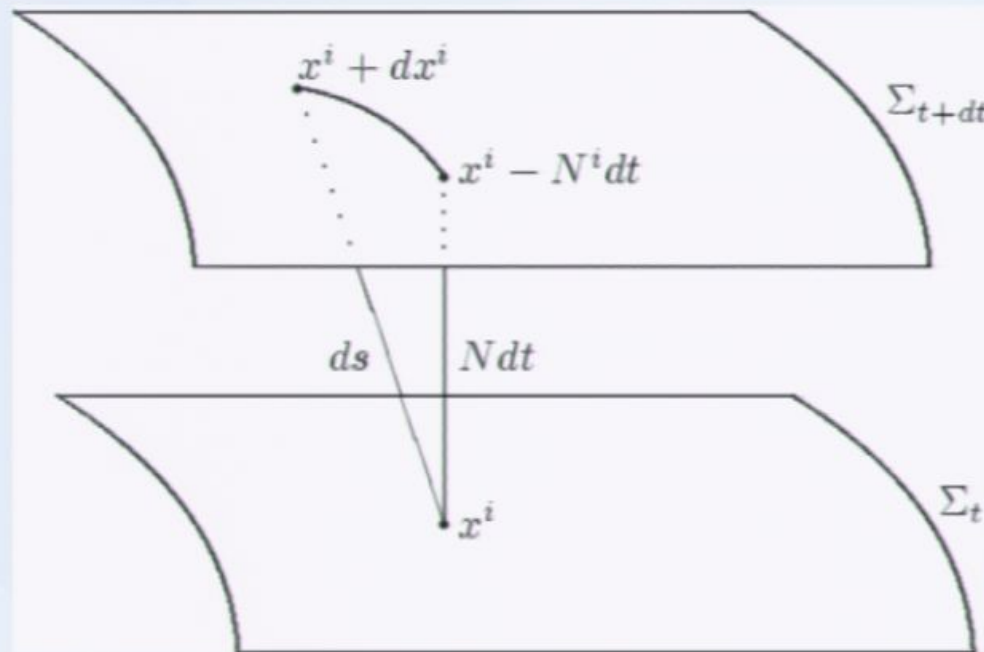


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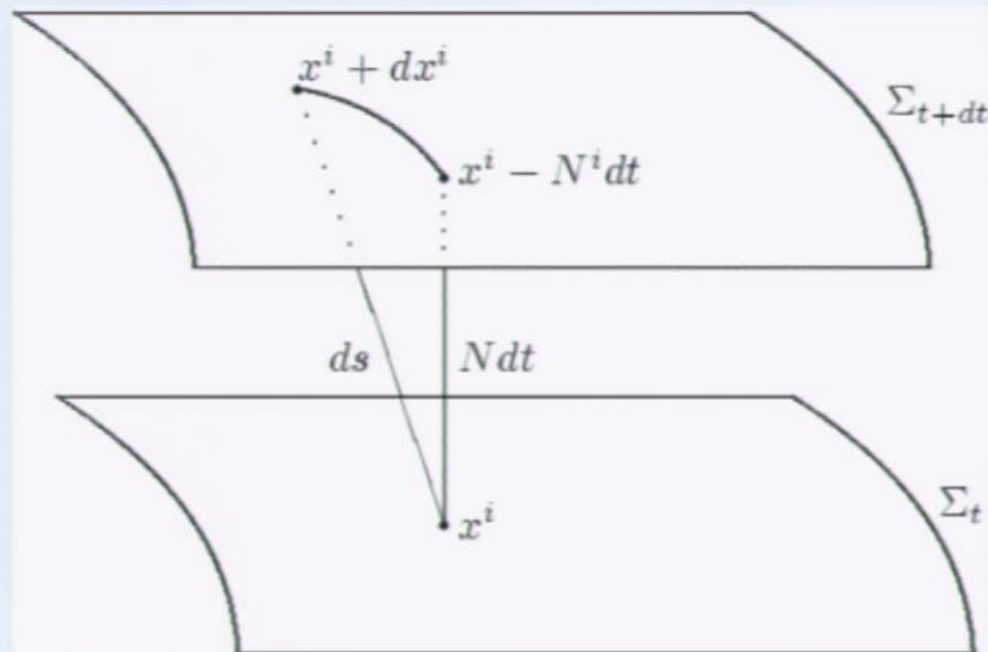
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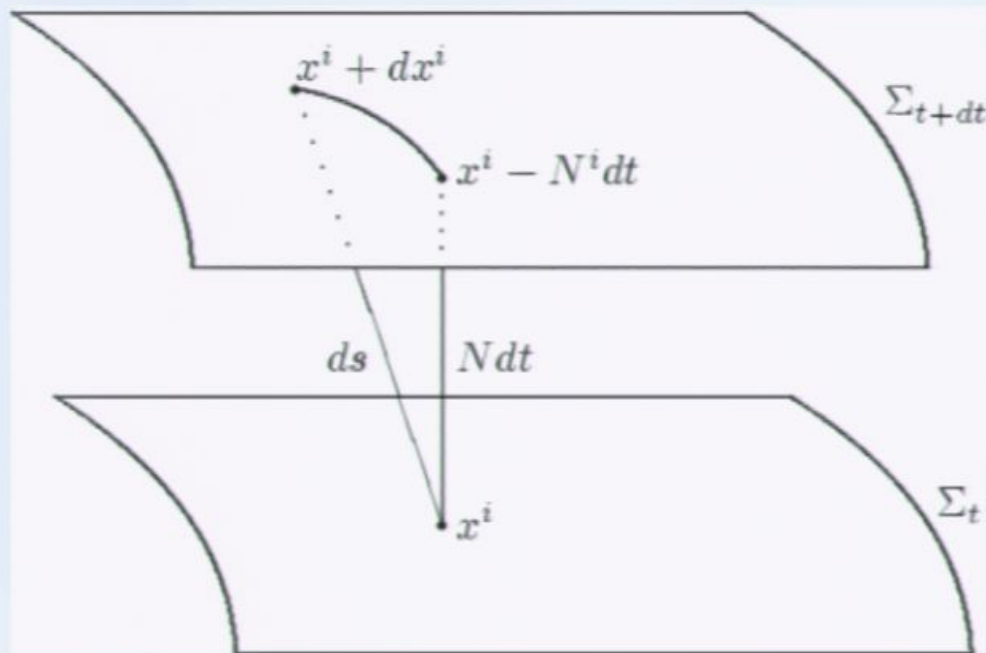


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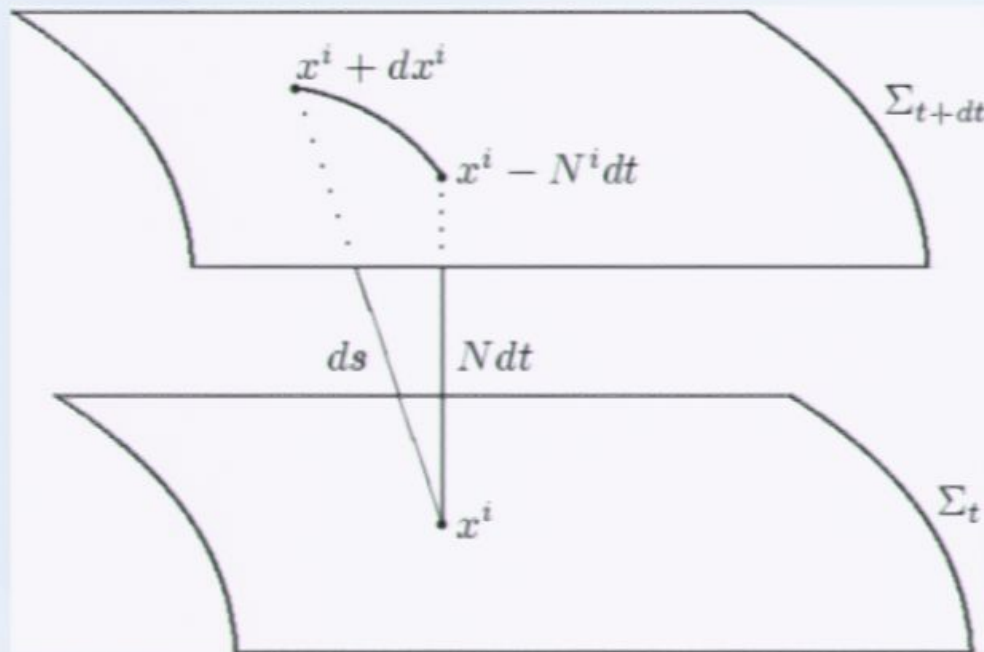
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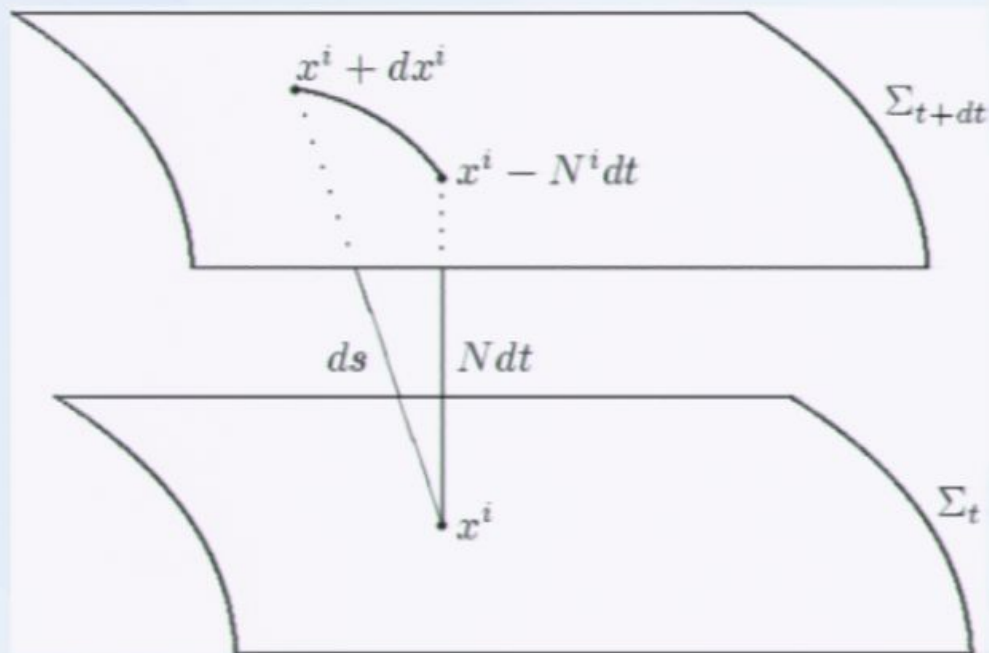


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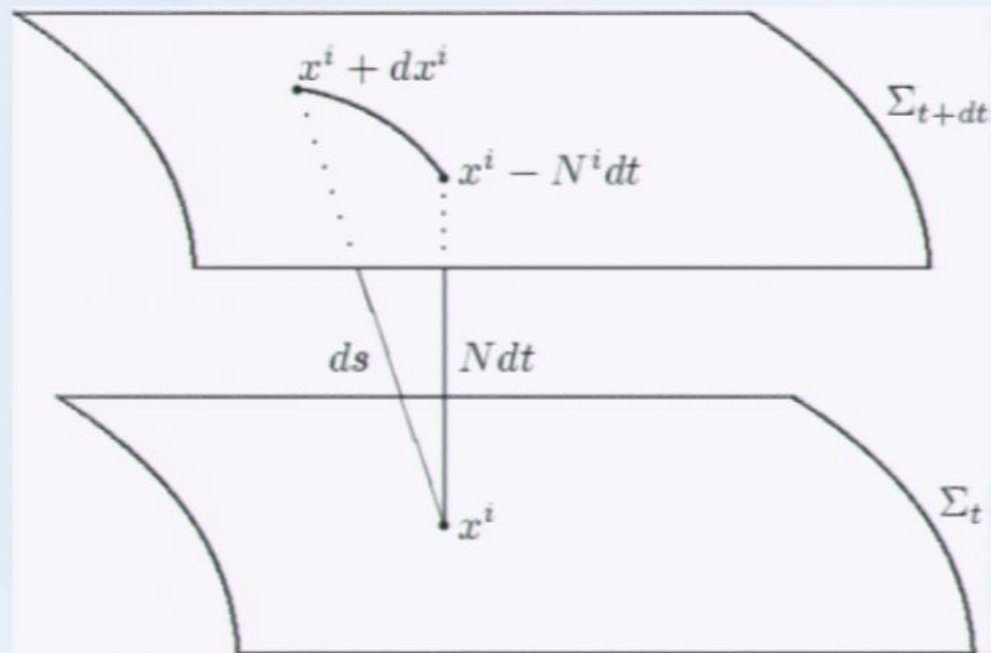




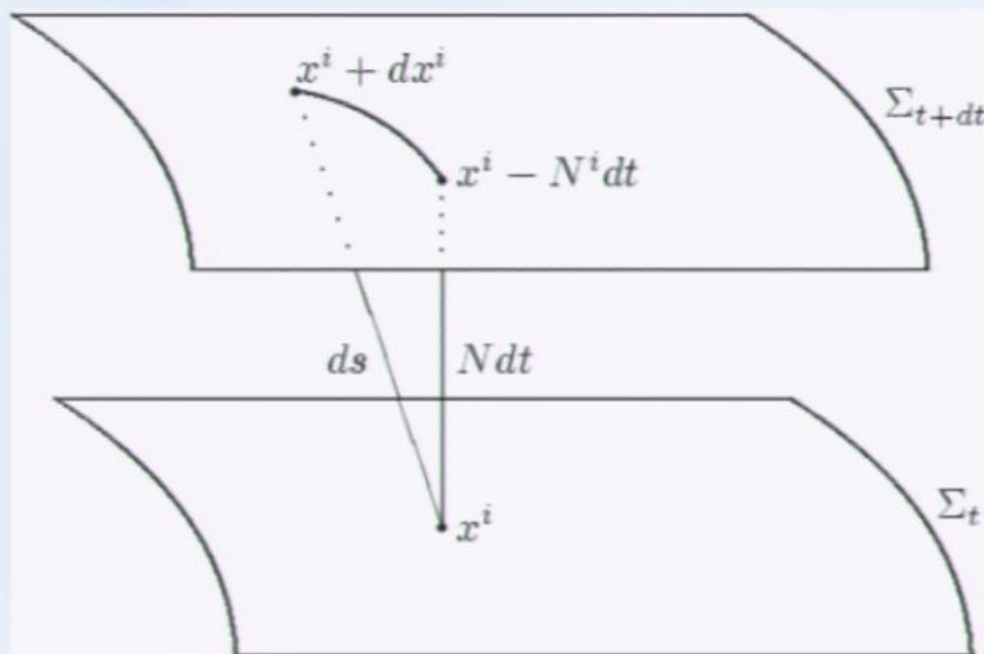
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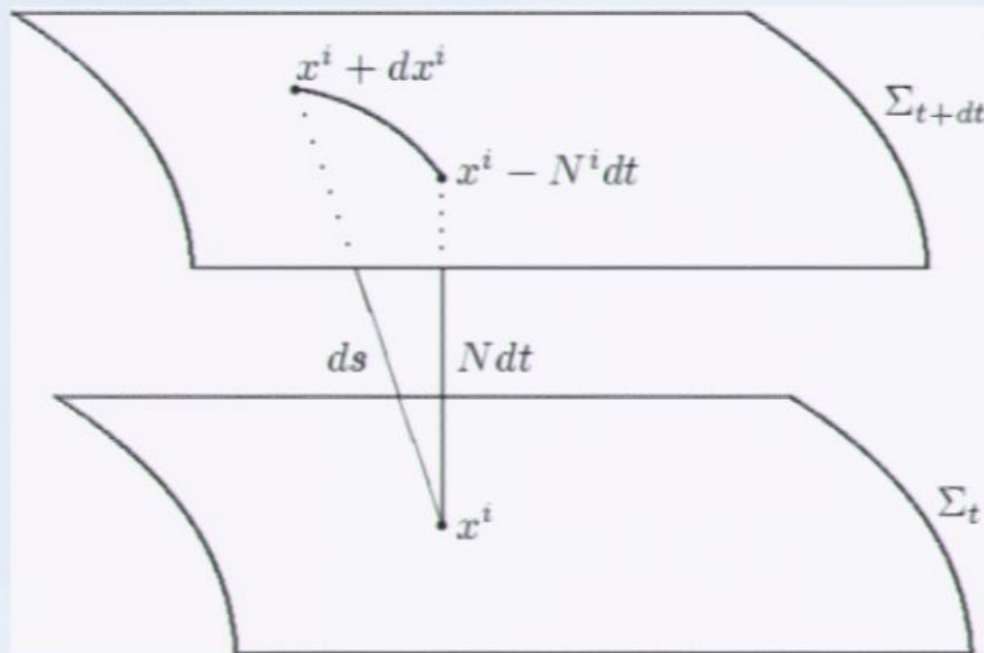


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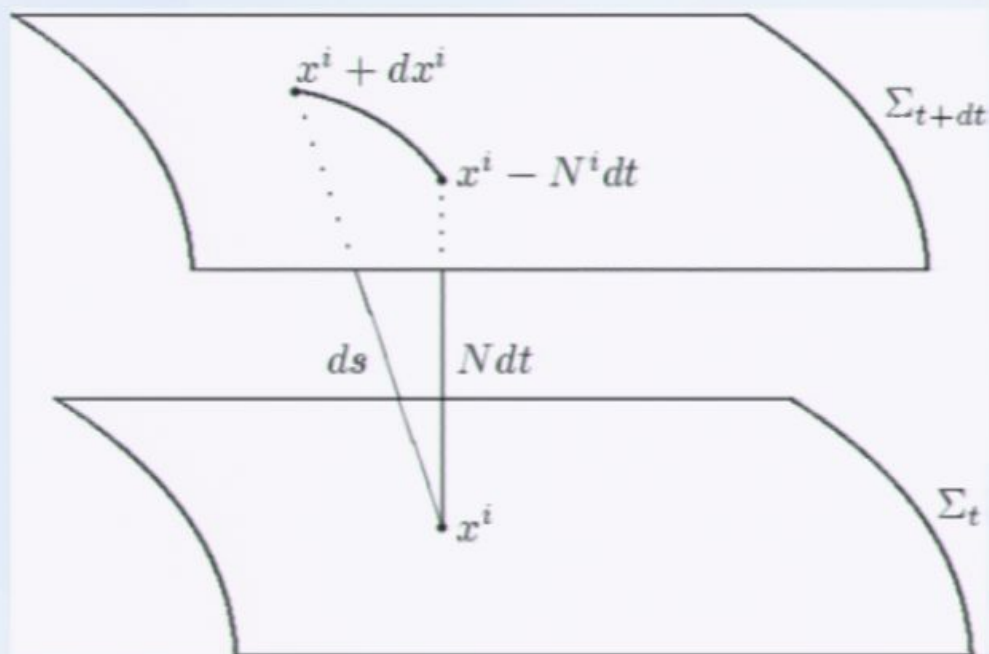




# Let's evolve the system in time!

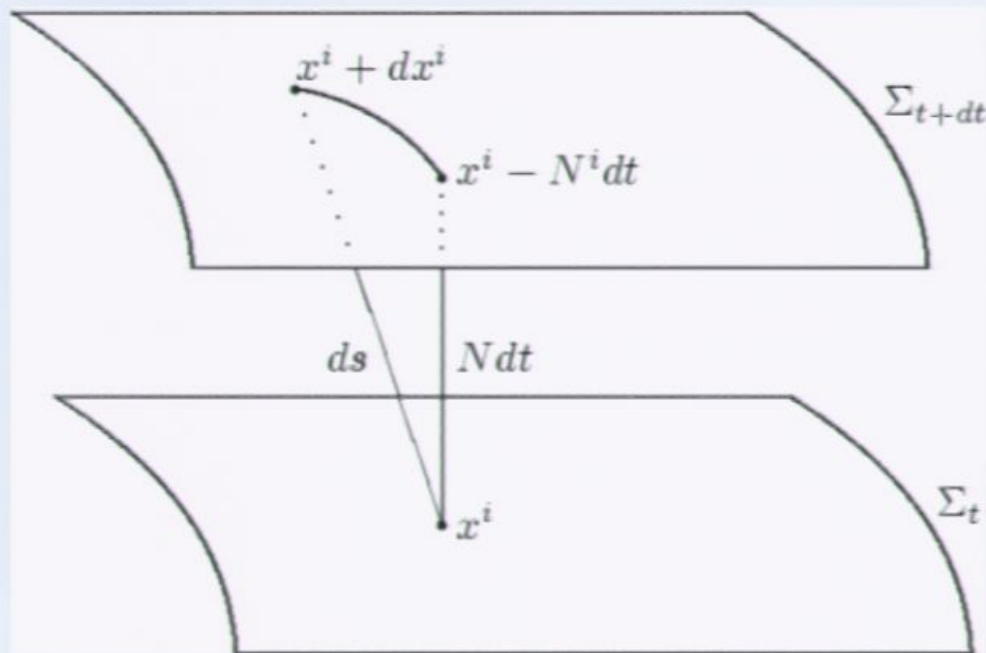


# Let's evolve the system in time!



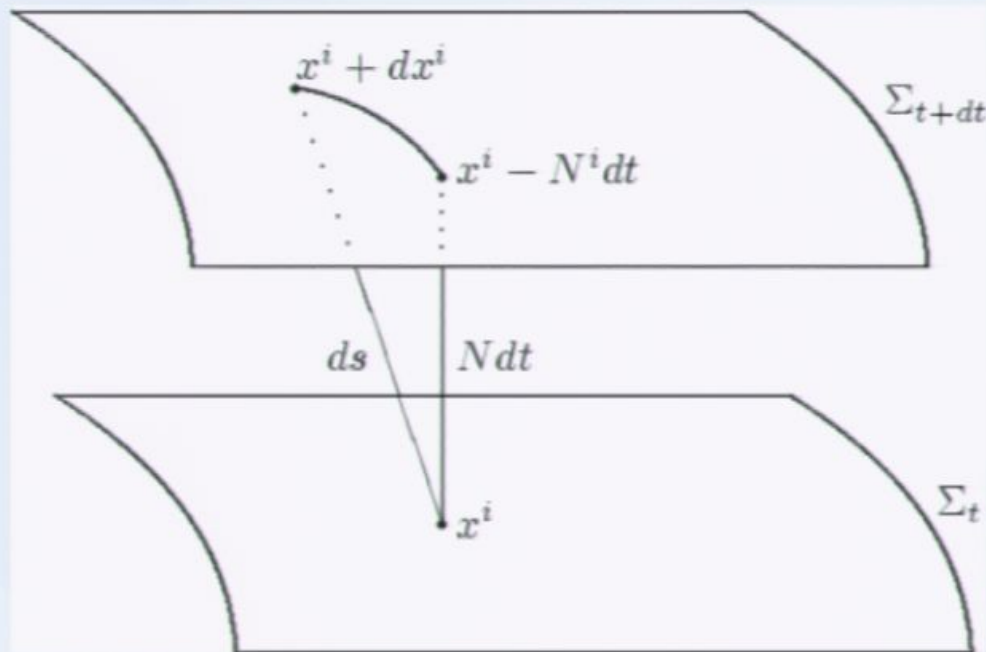
# Let's evolve the system in time!

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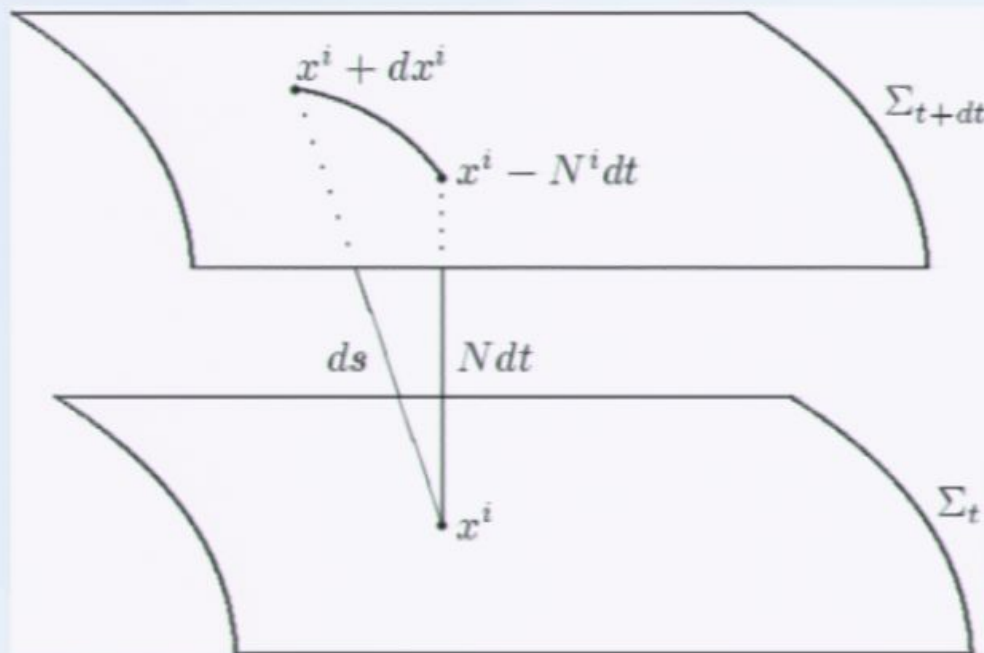




# Let's evolve the system in time!

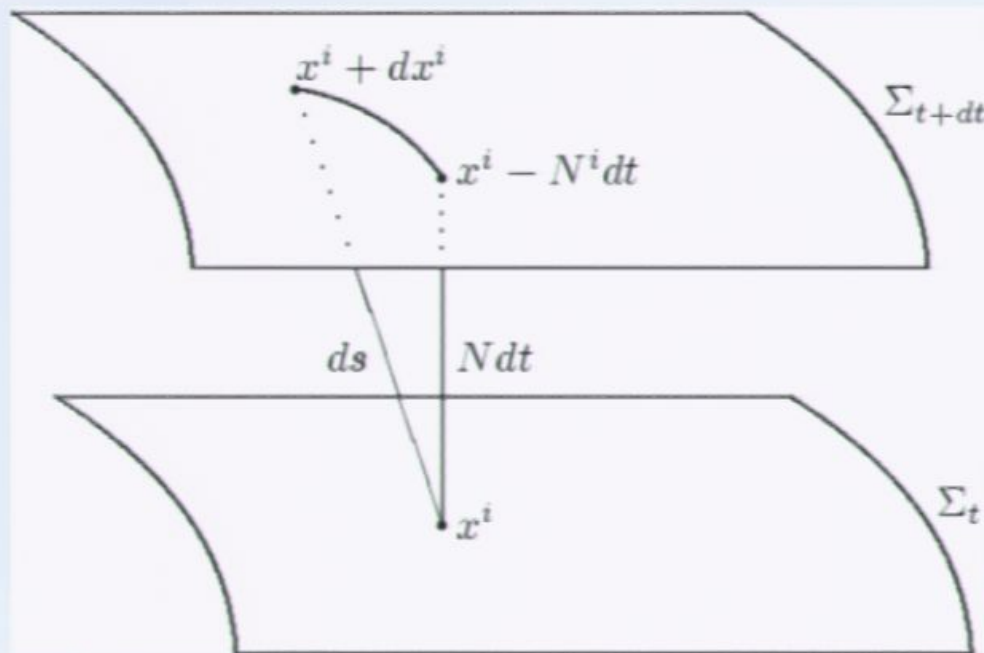


# Let's evolve the system in time!

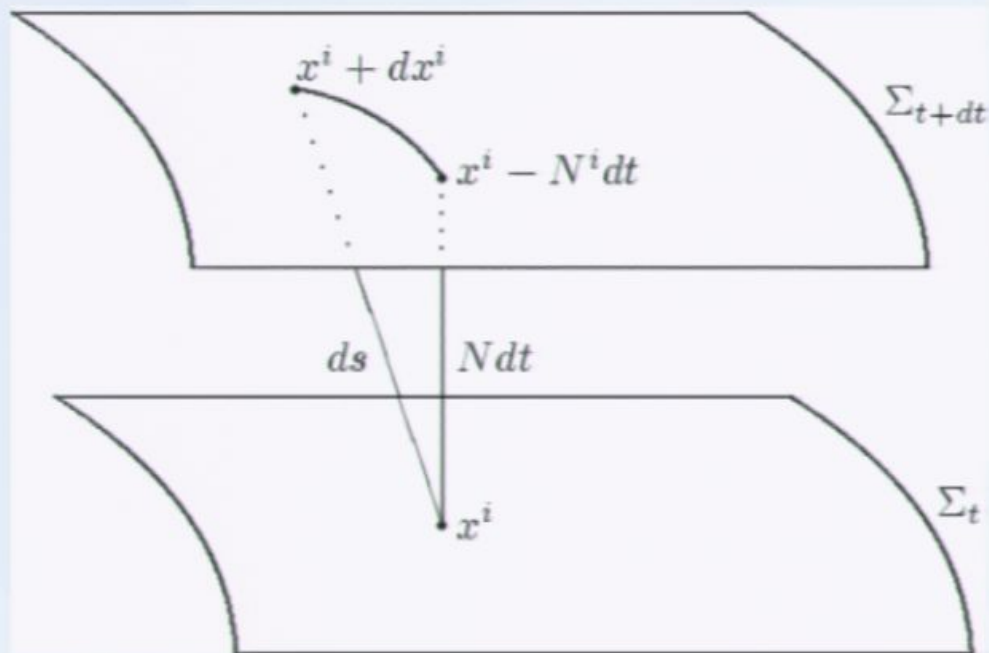


# Let's evolve the system in time!

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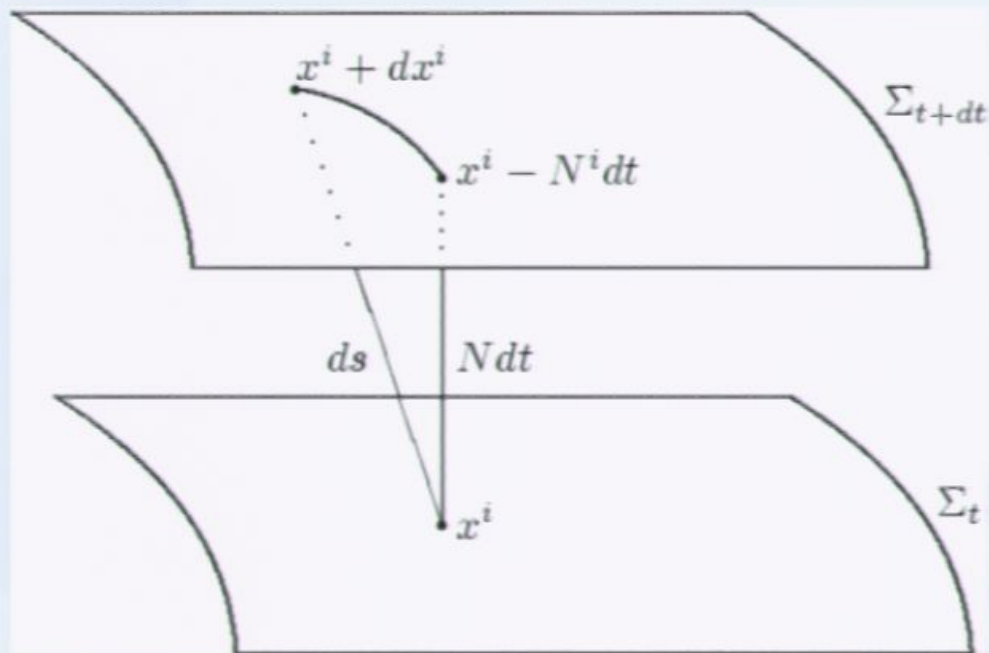


# Let's evolve the system in time!

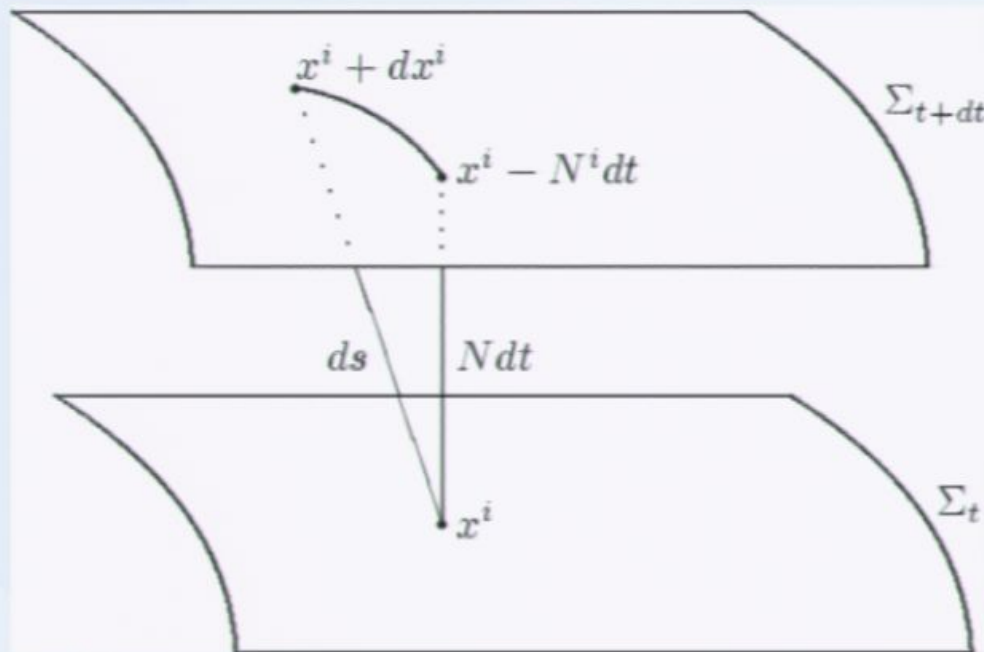




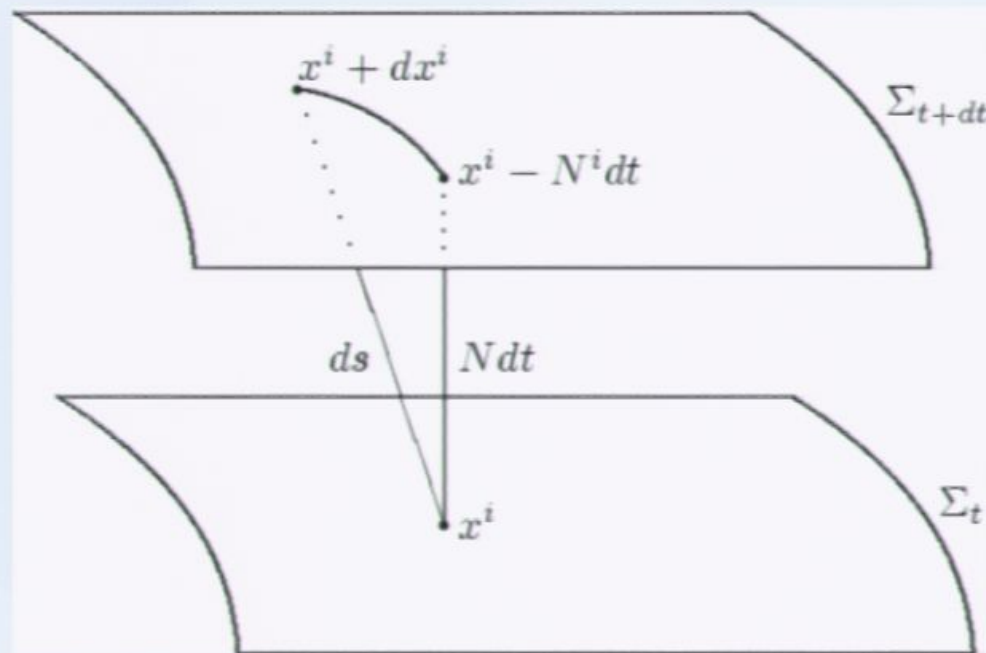
# Let's evolve the system in time!



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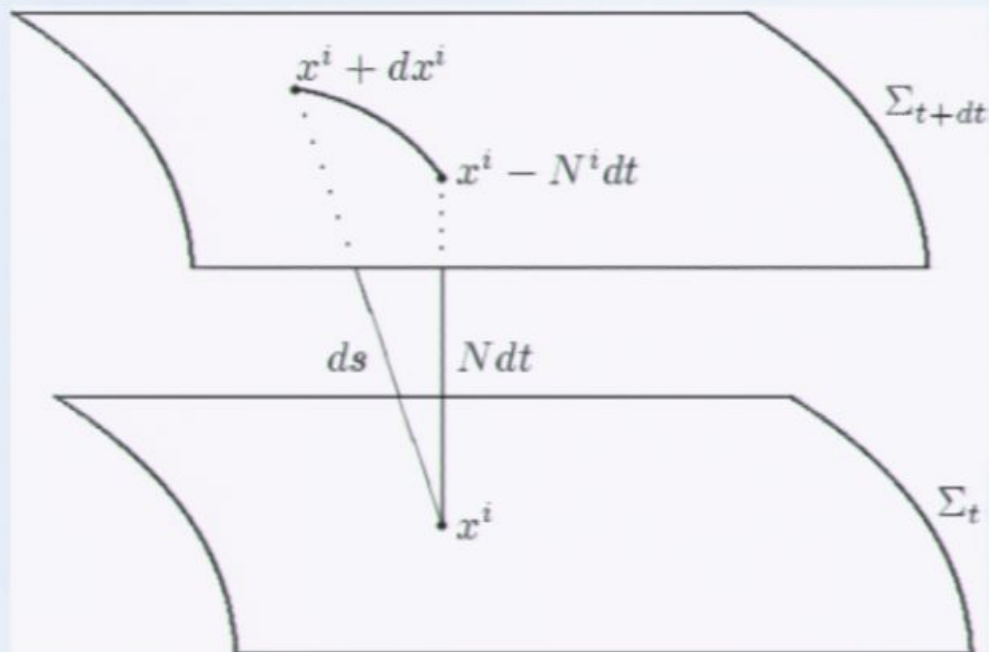


# Let's evolve the system in time!



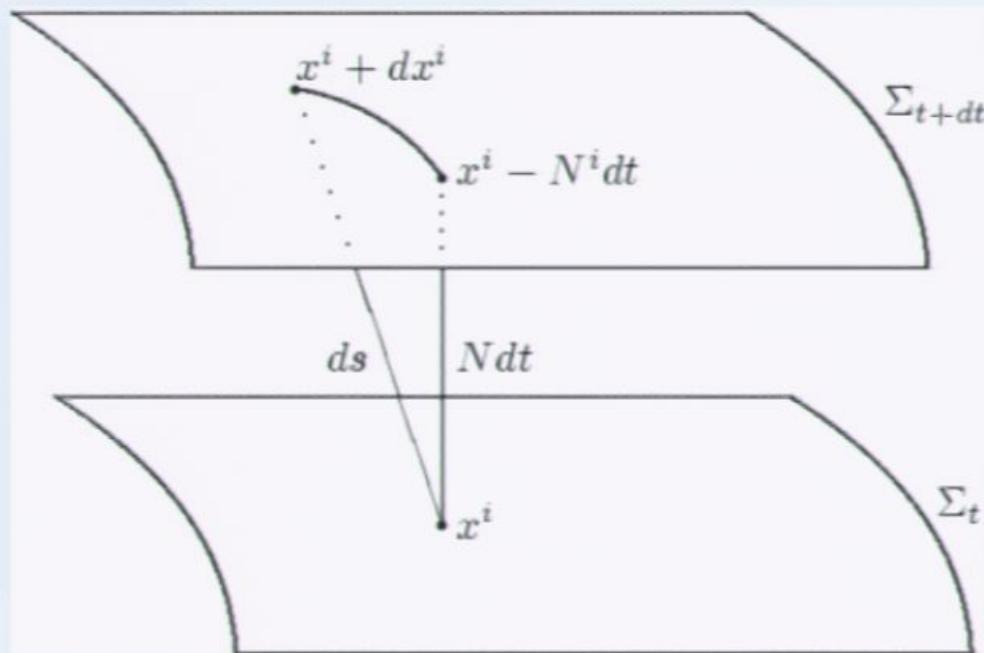
# Let's evolve the system in time!

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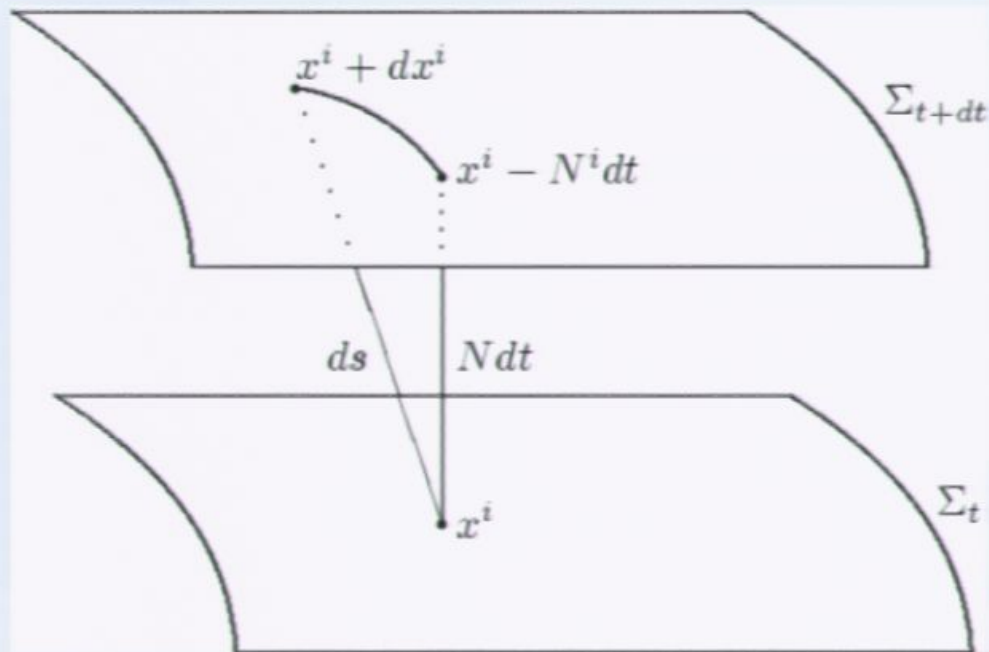




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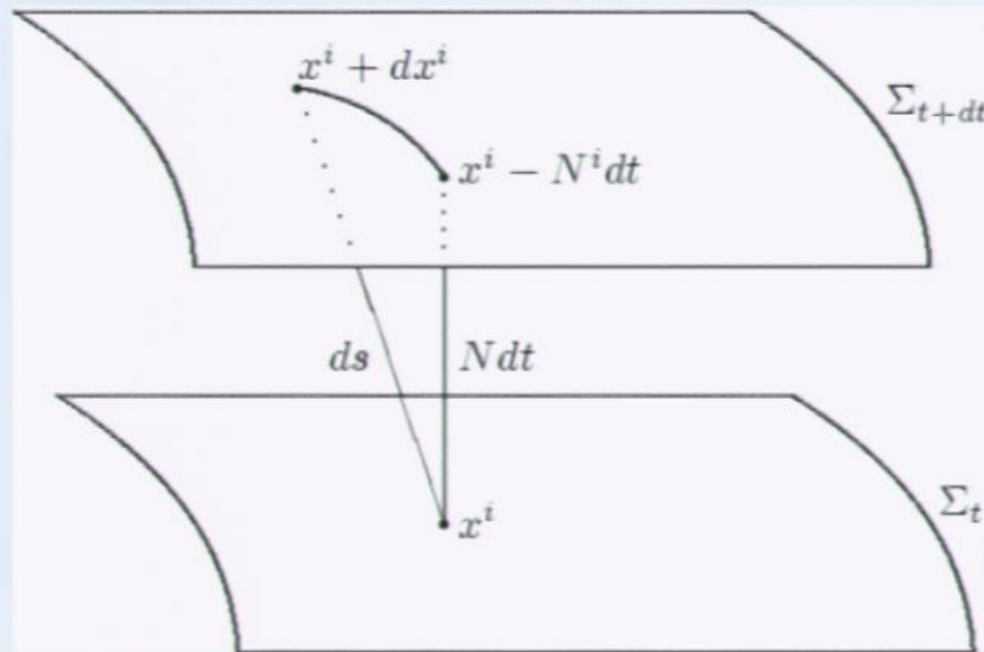


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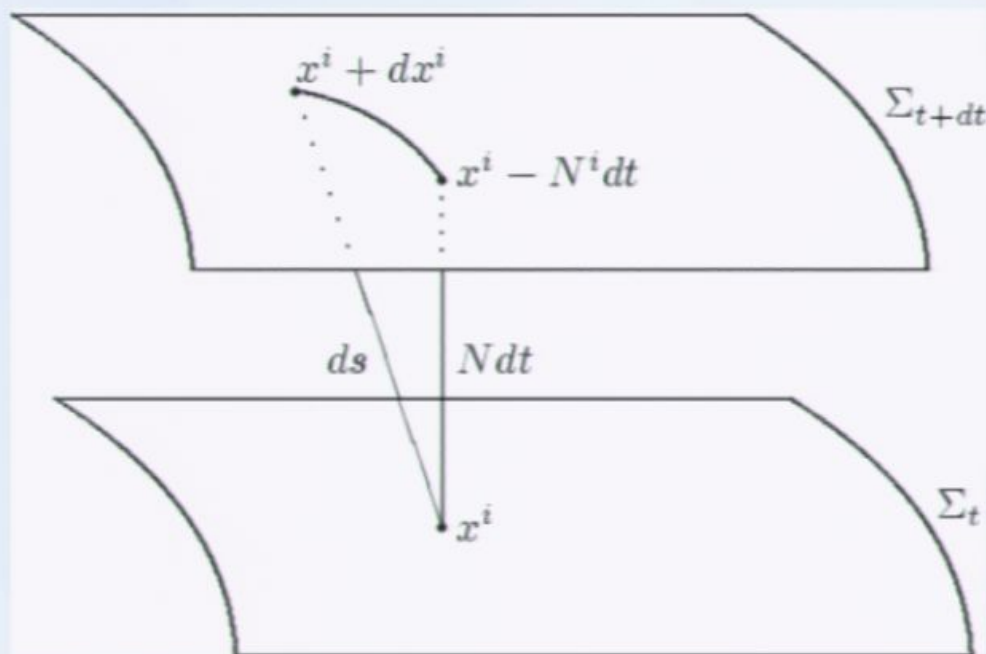


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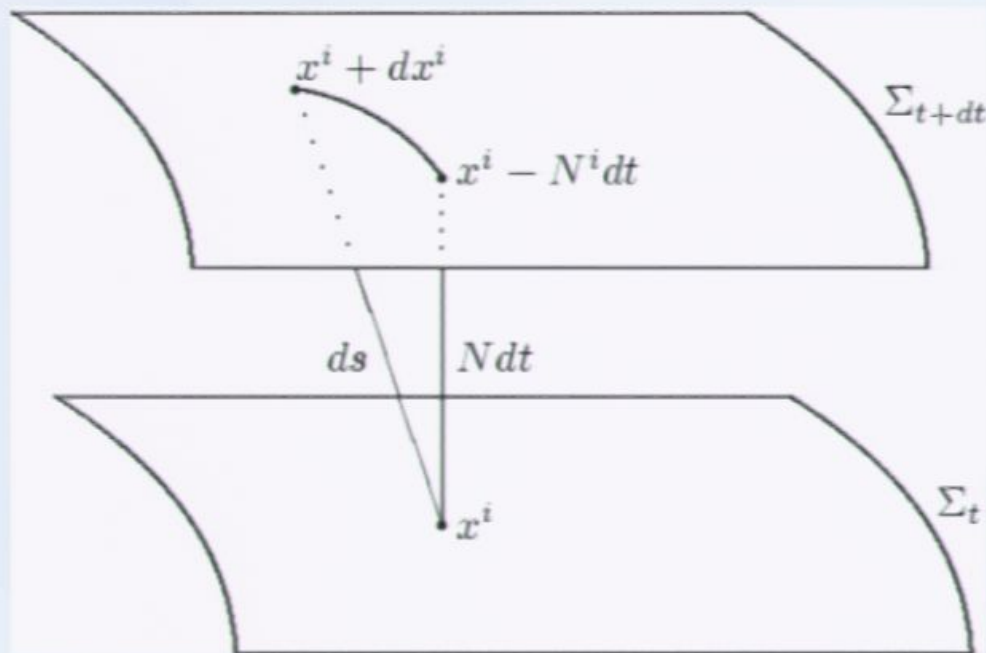


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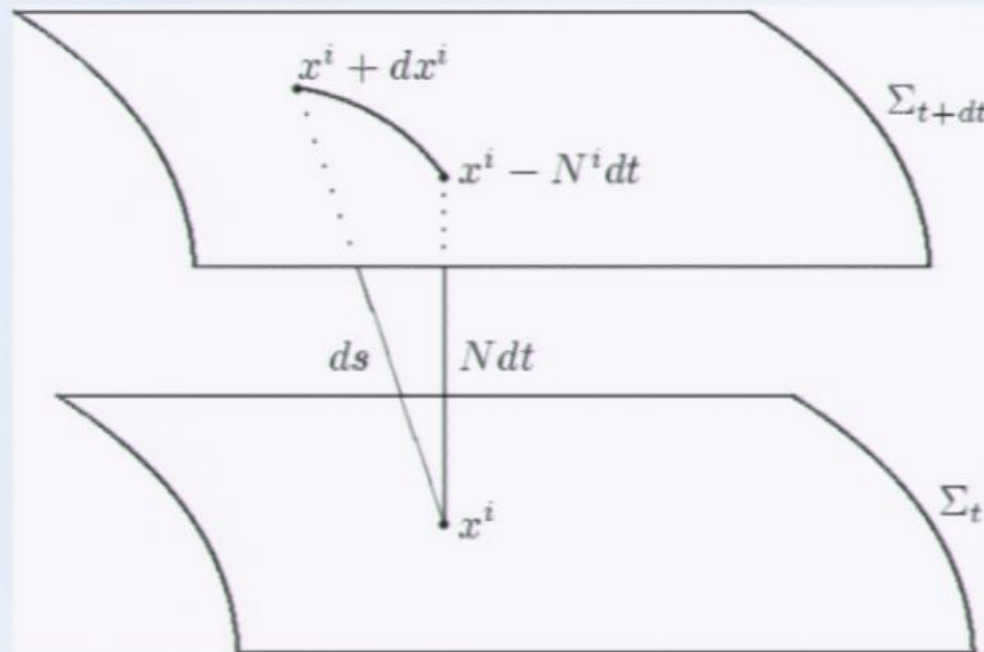




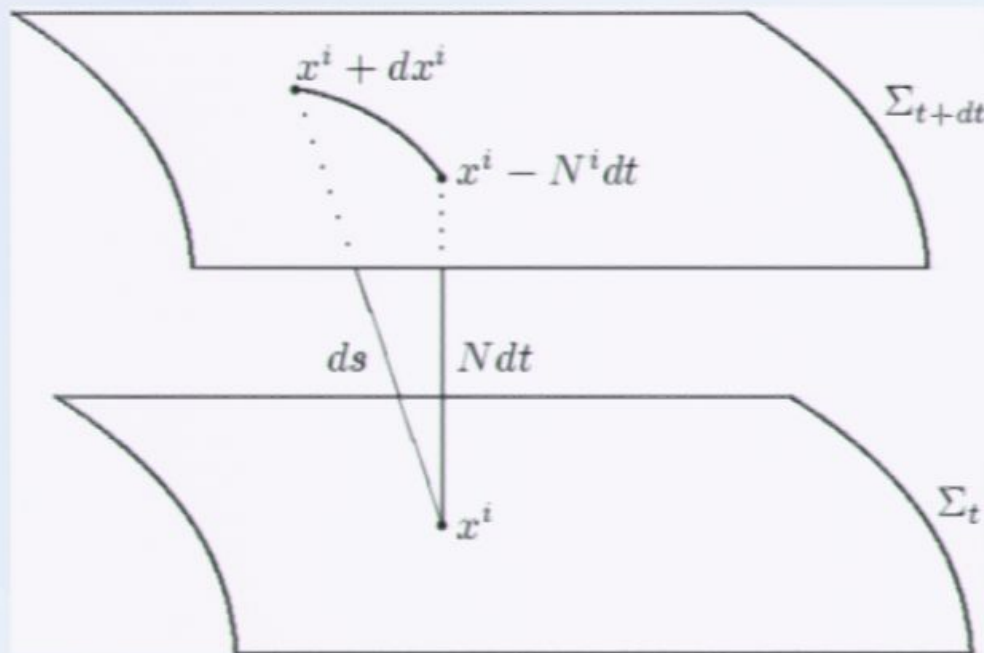
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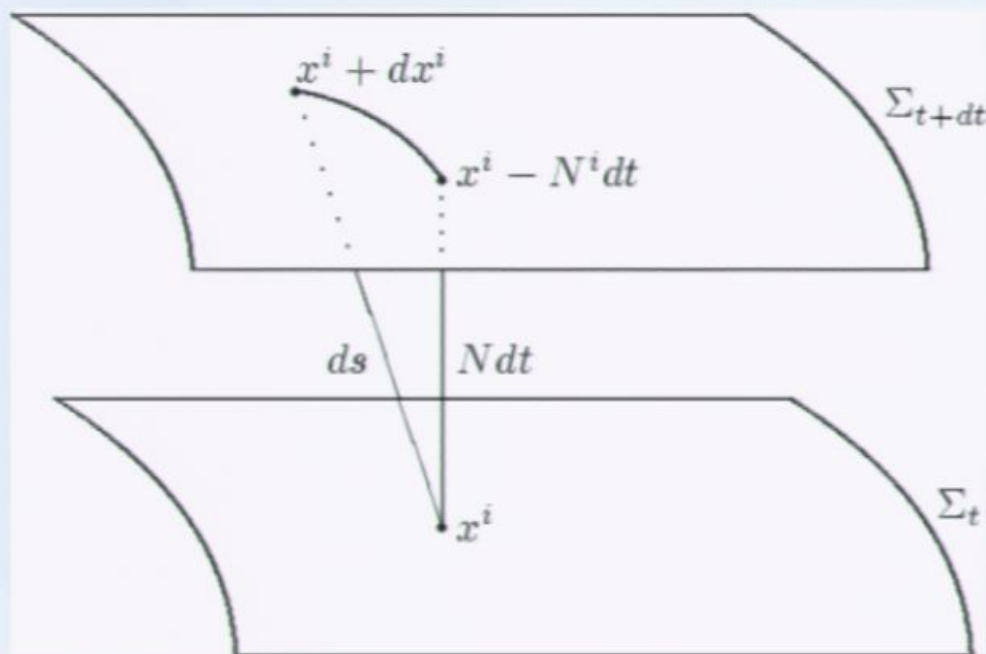
# Let's evolve the system in time!



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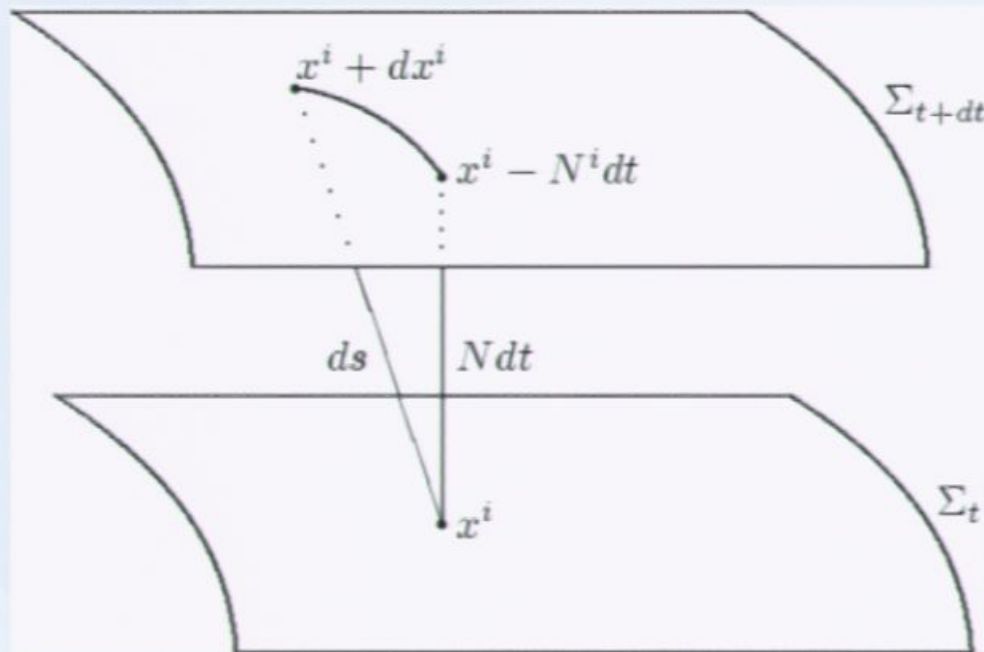
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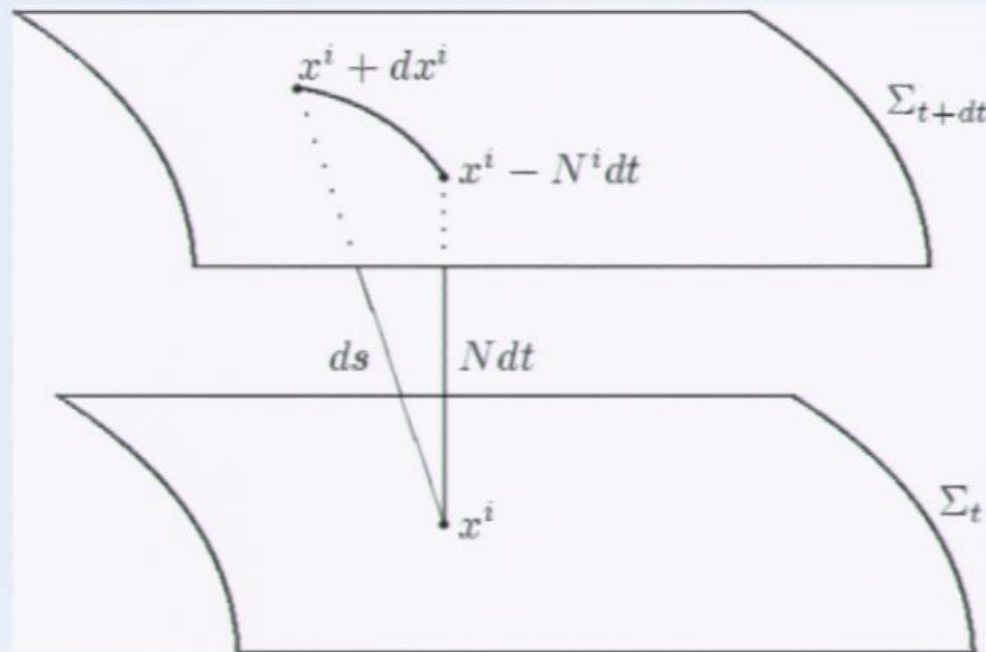


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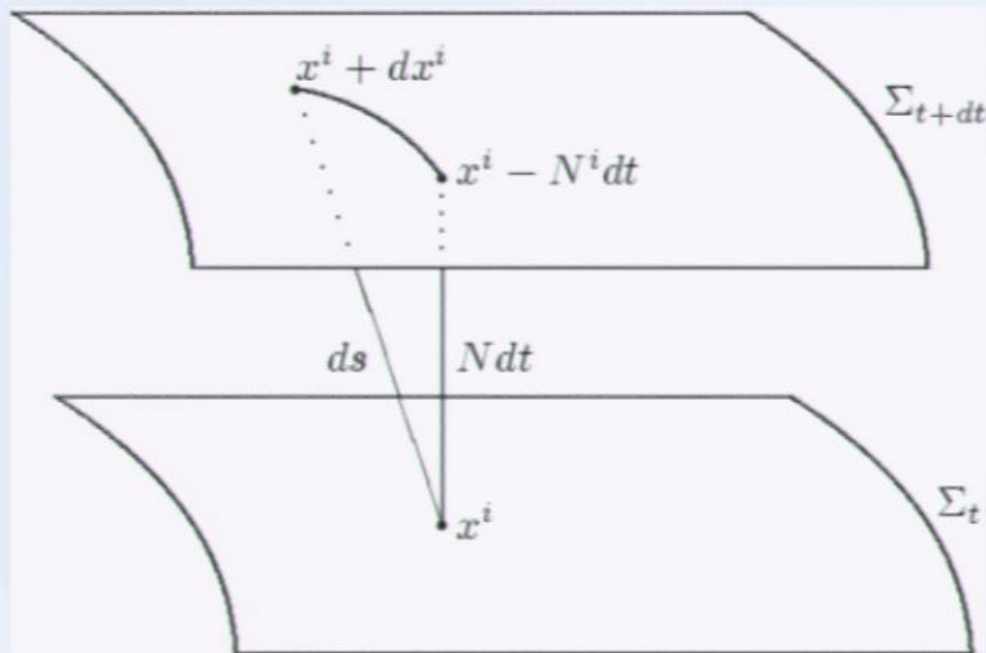


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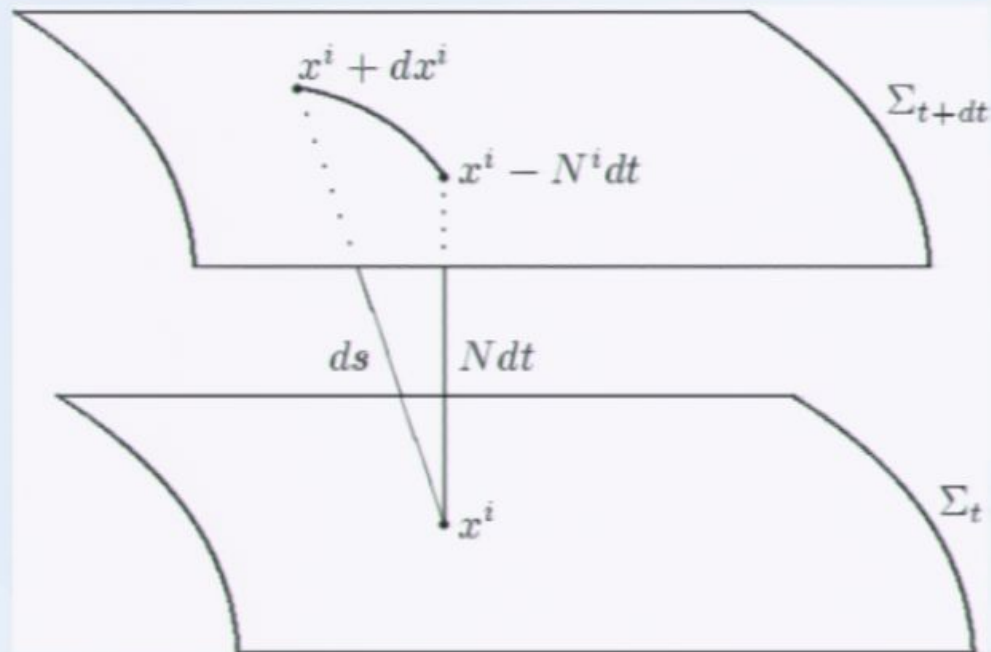


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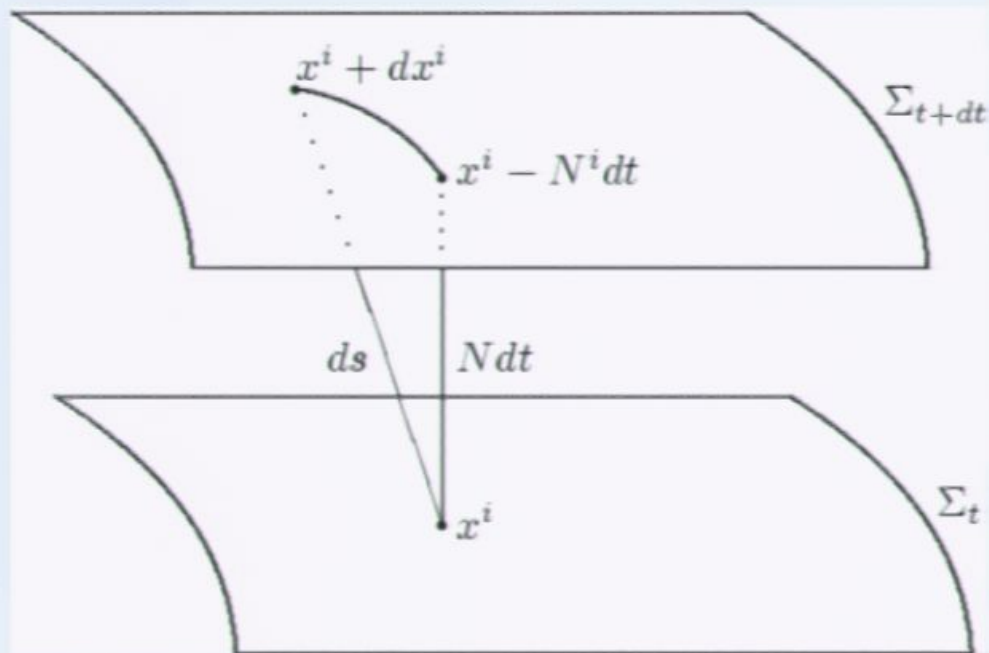


# Let's evolve the system in time!

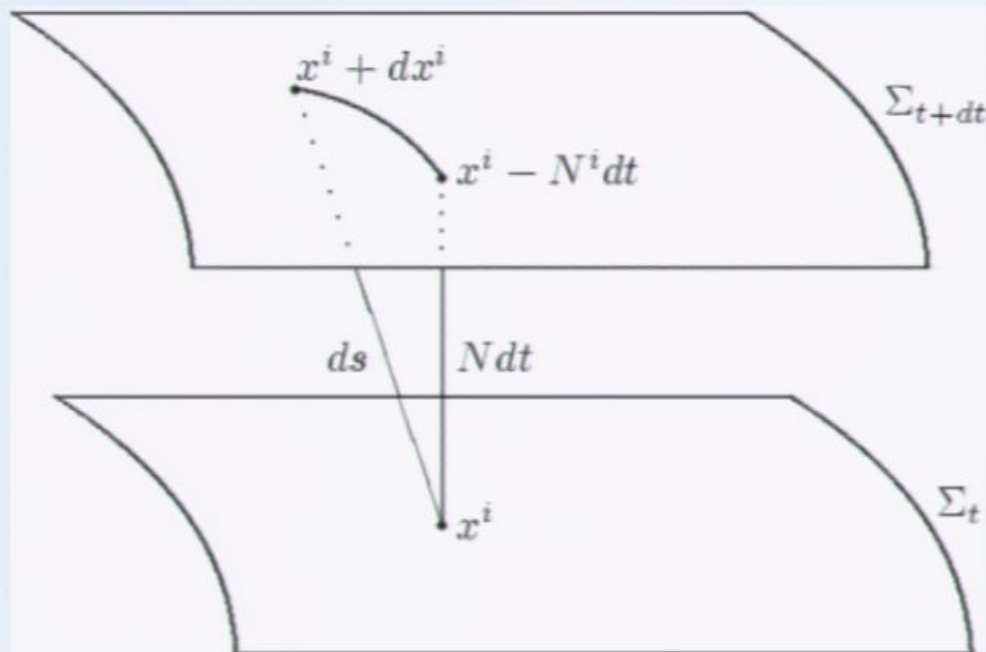




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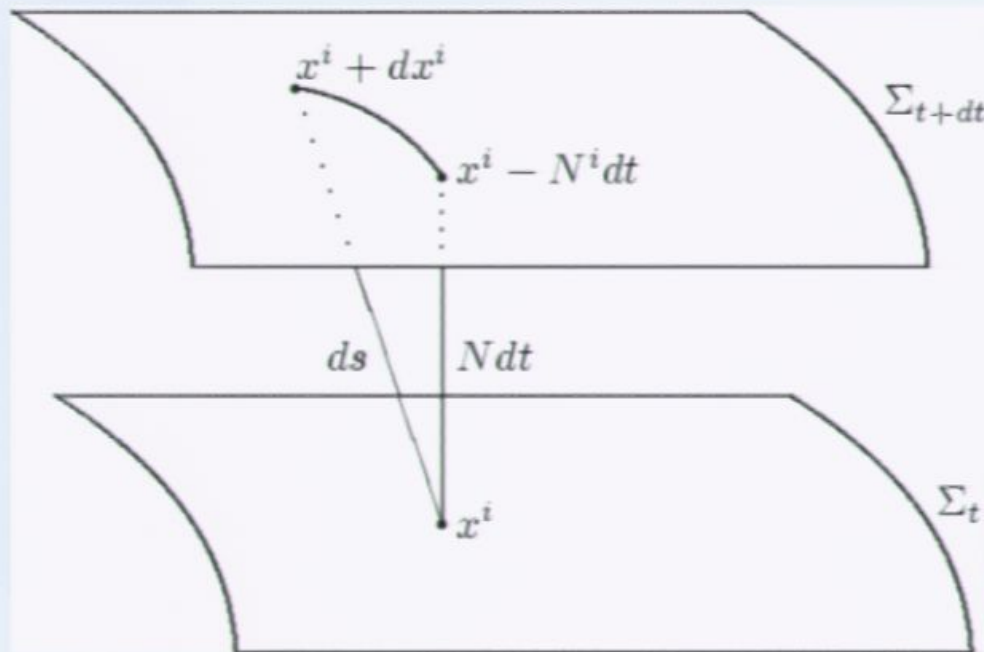


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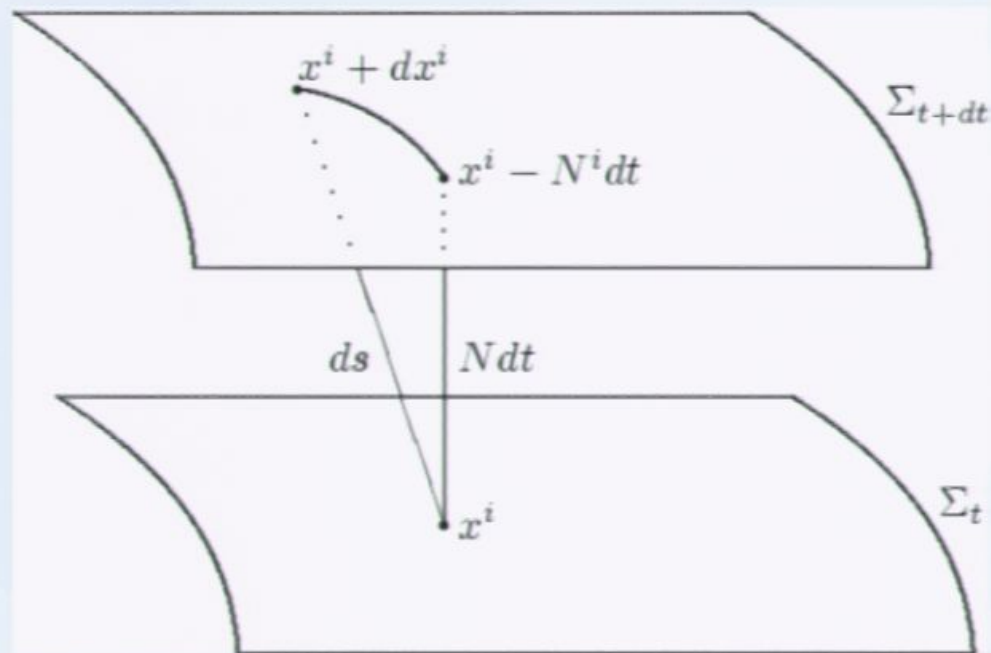


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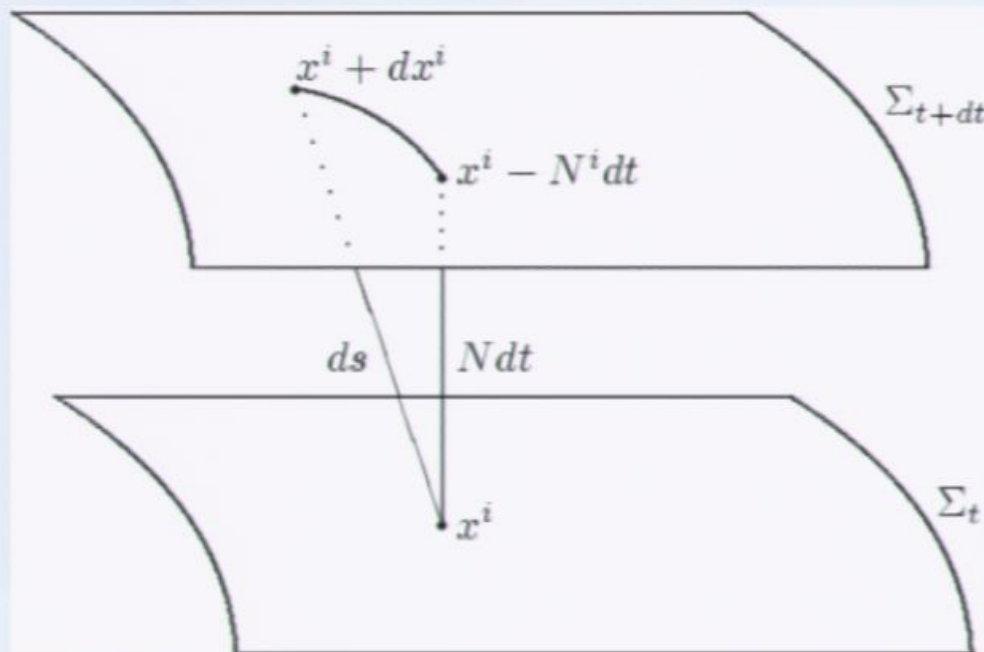


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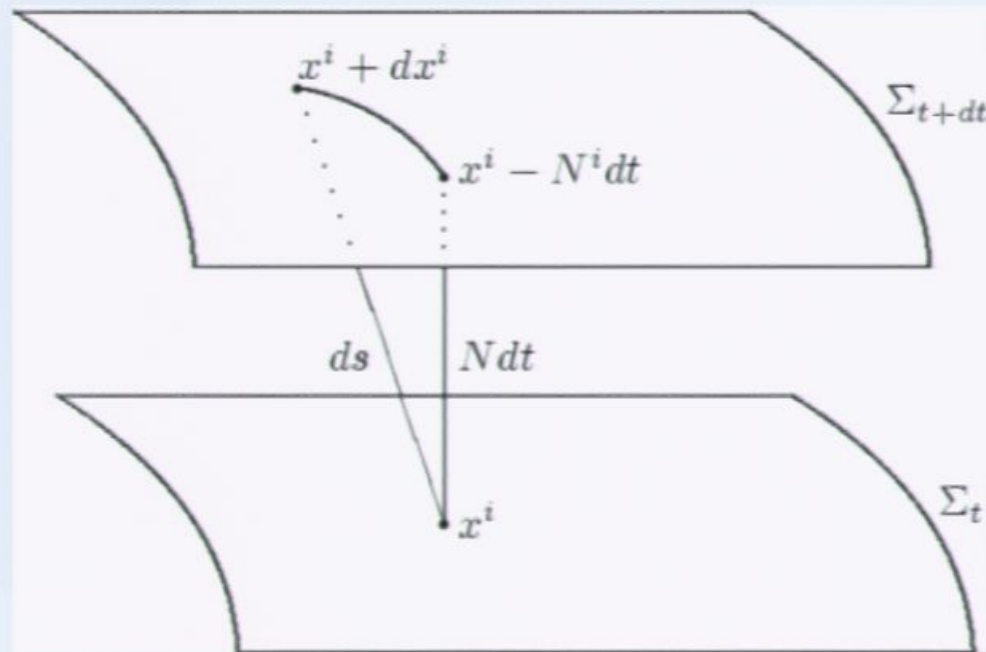




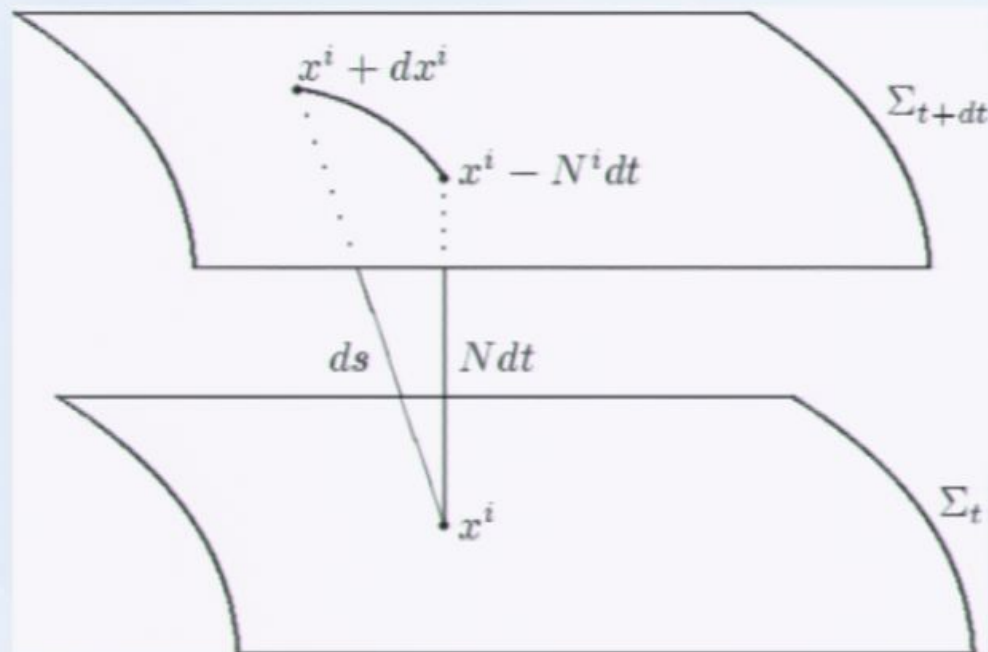
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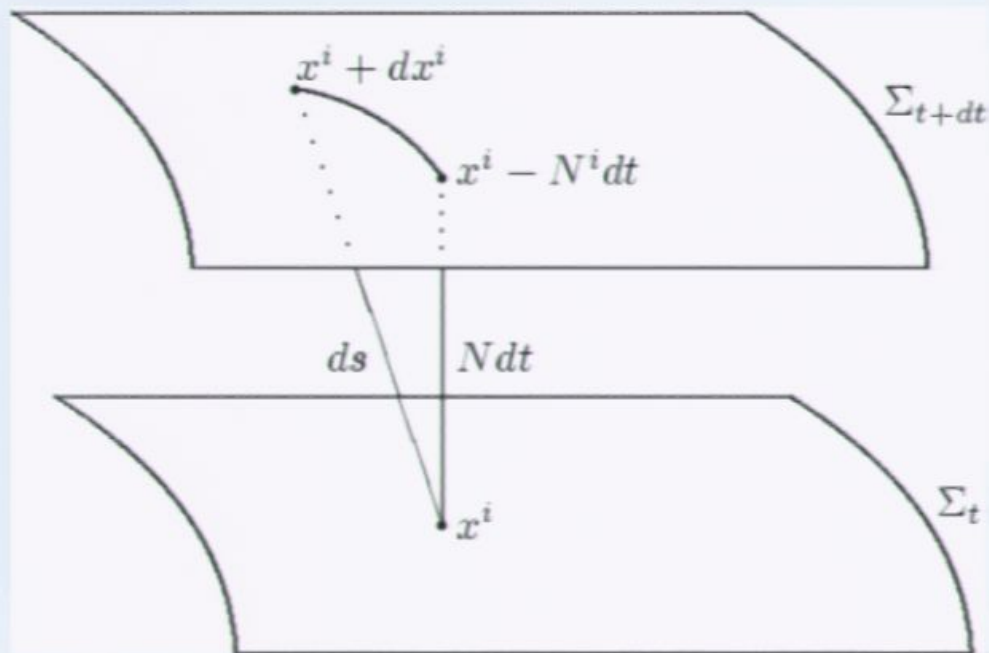


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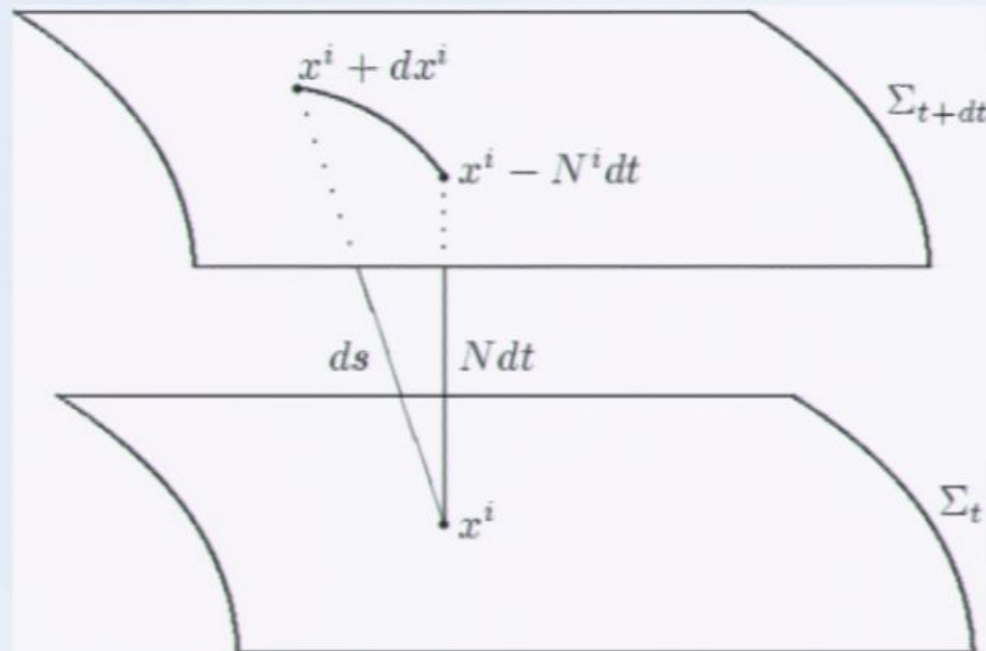
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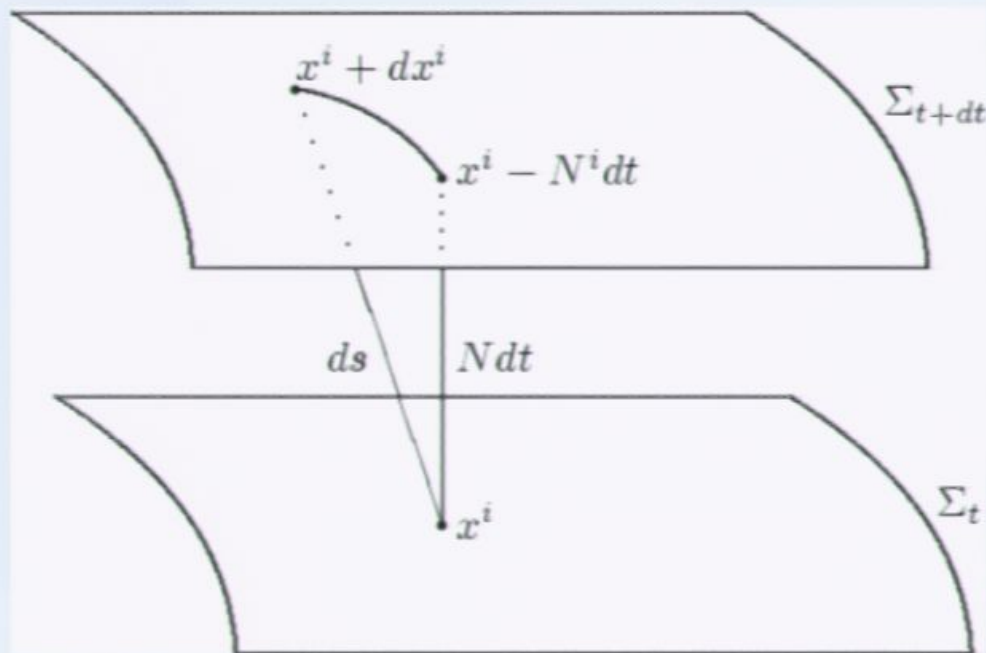


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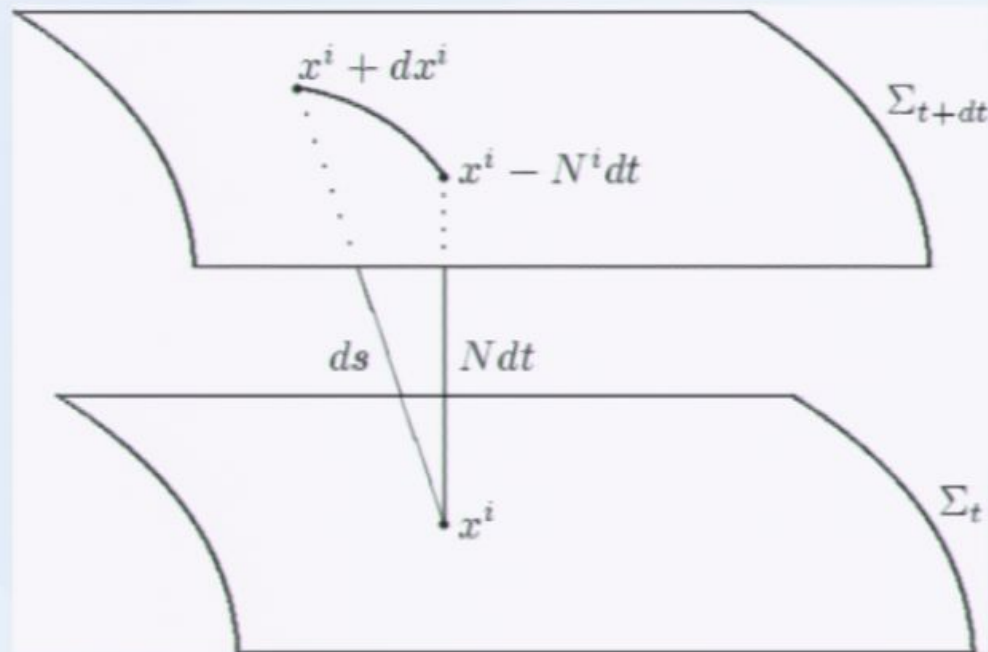
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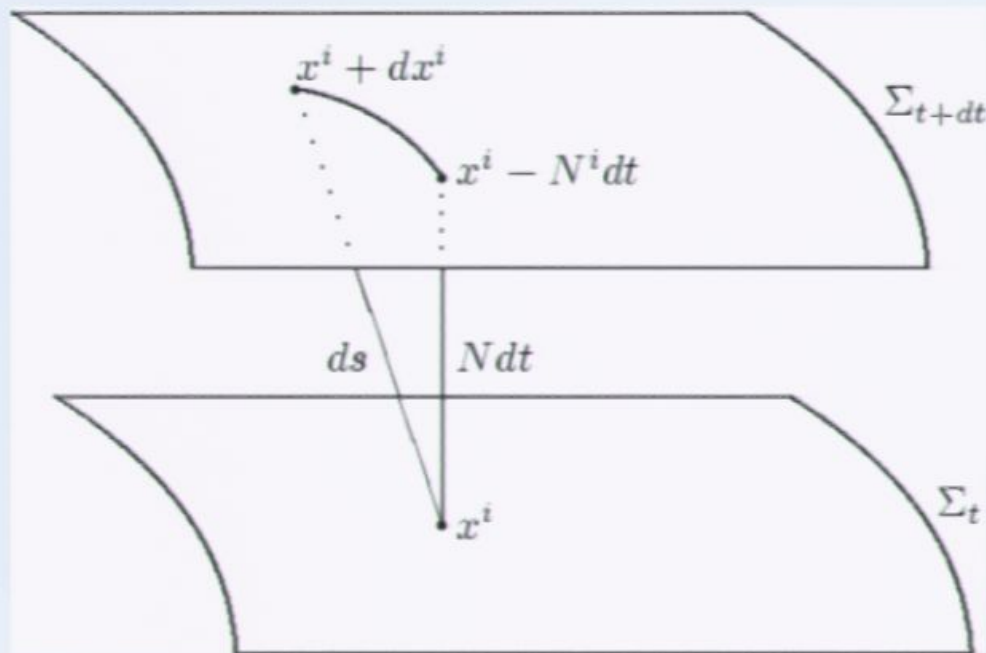


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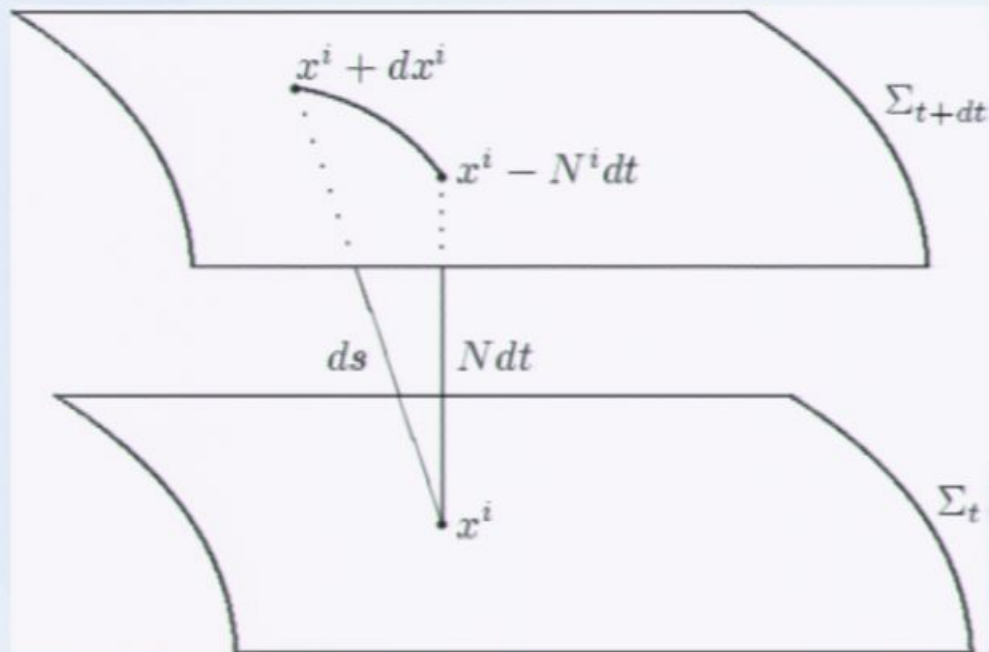


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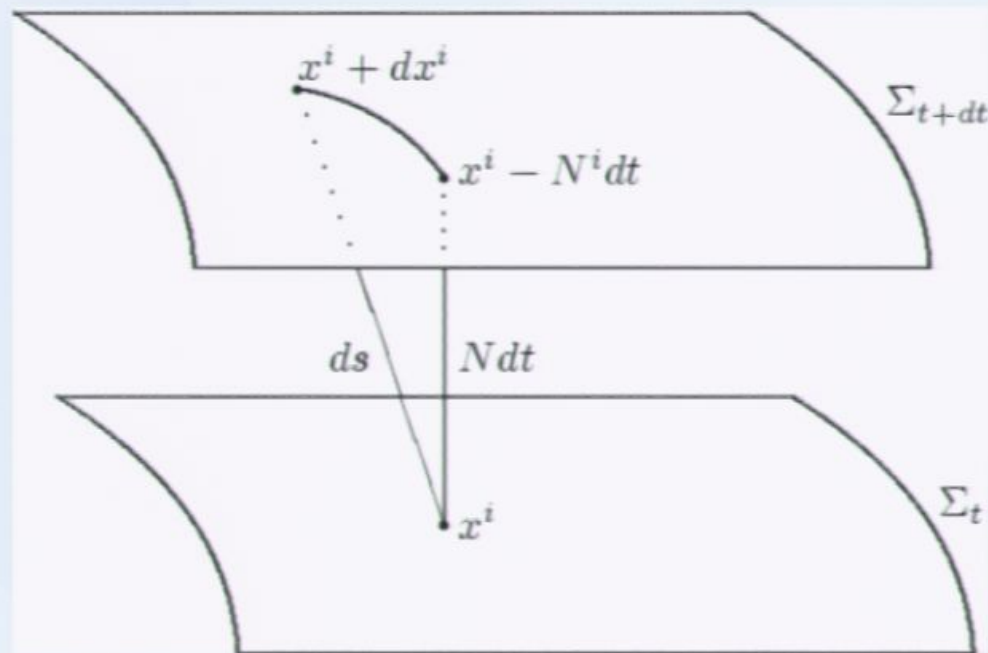




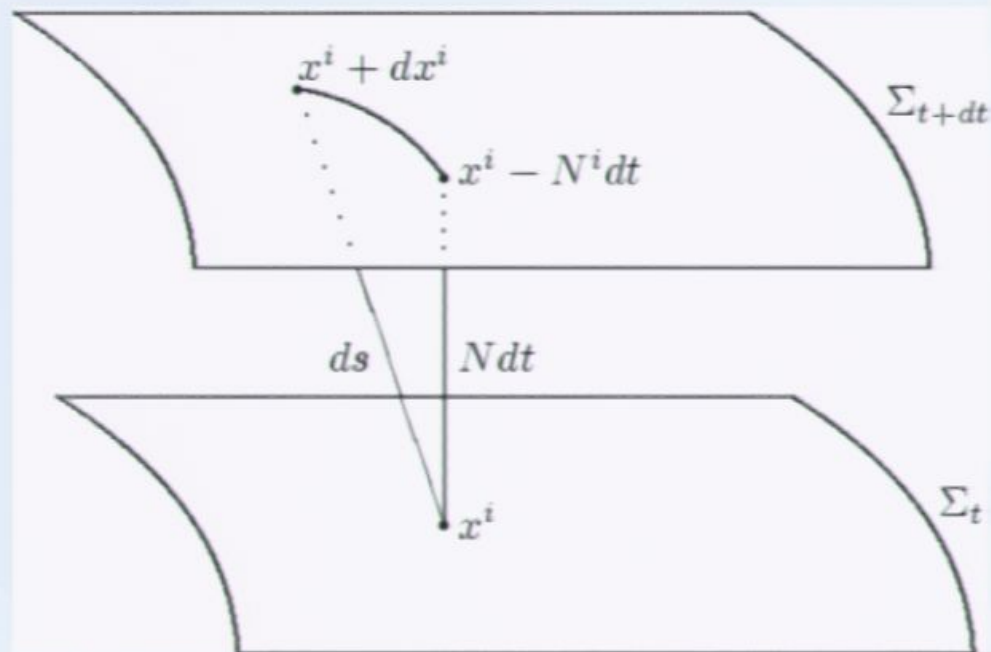
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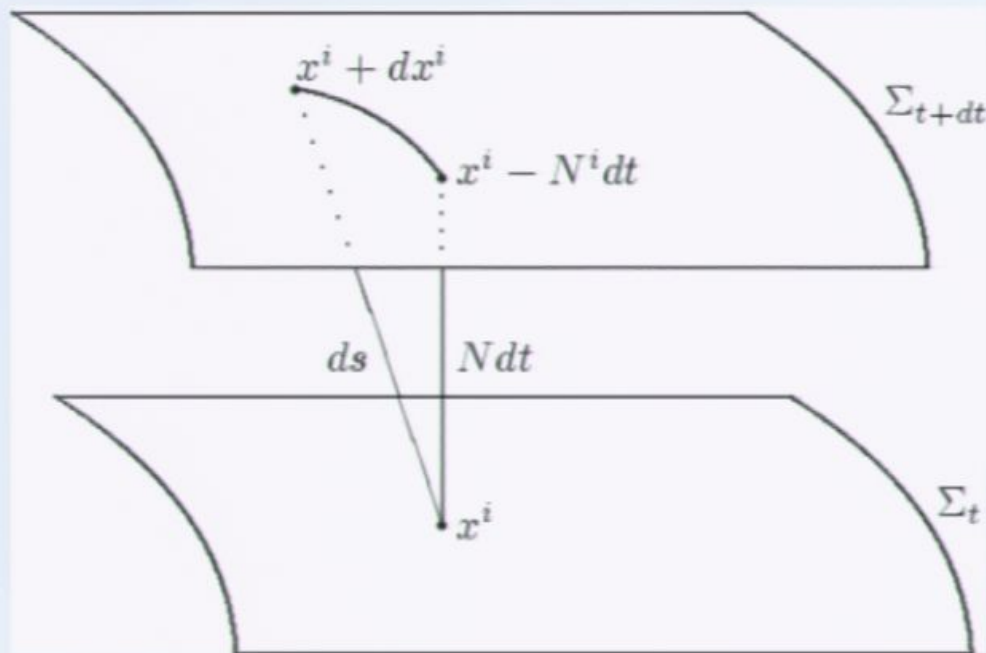
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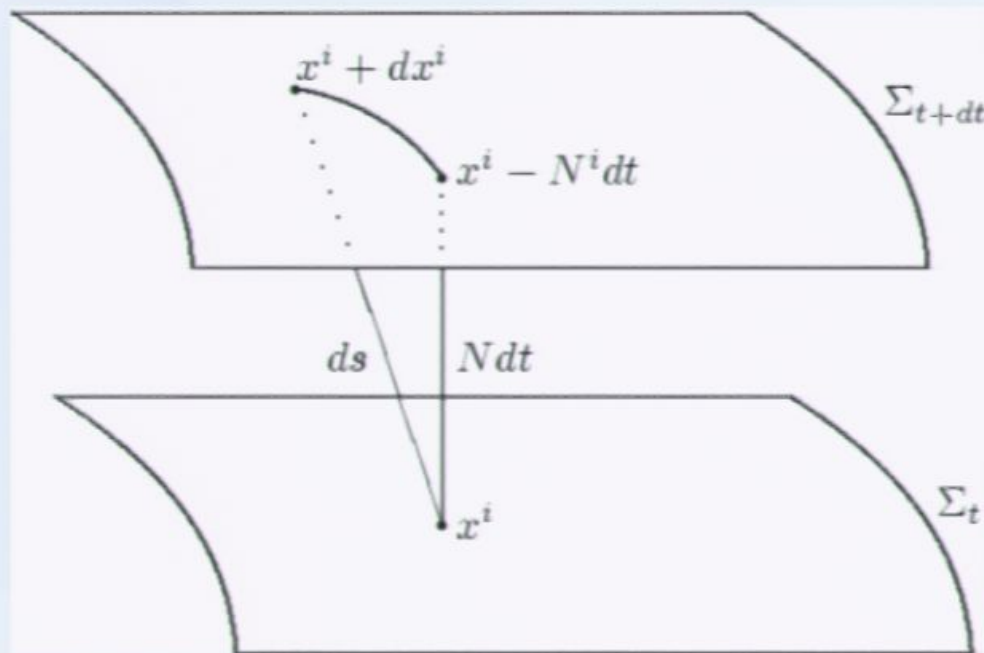


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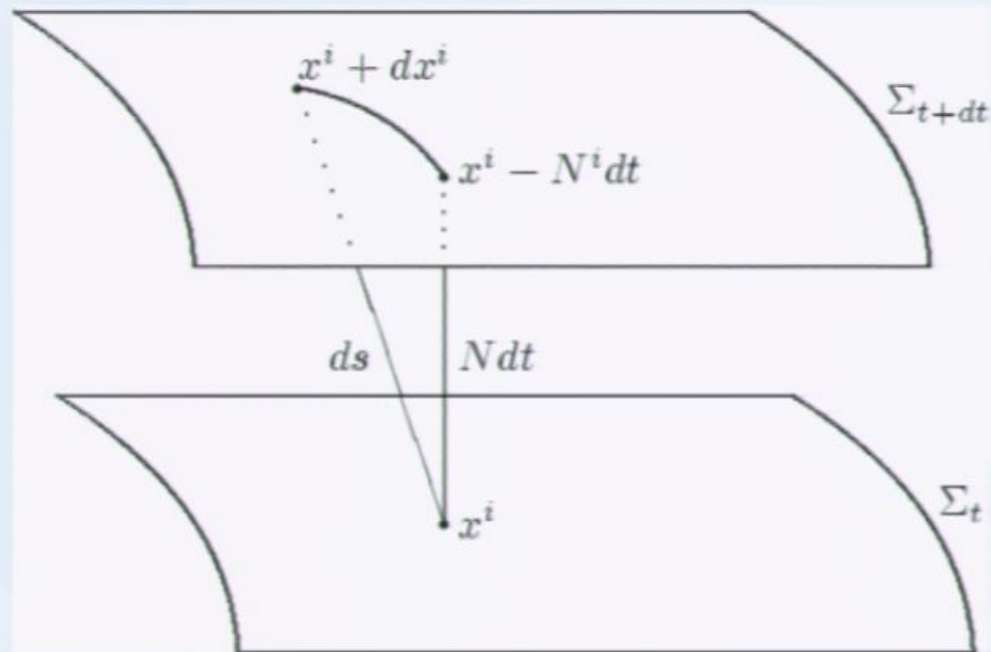




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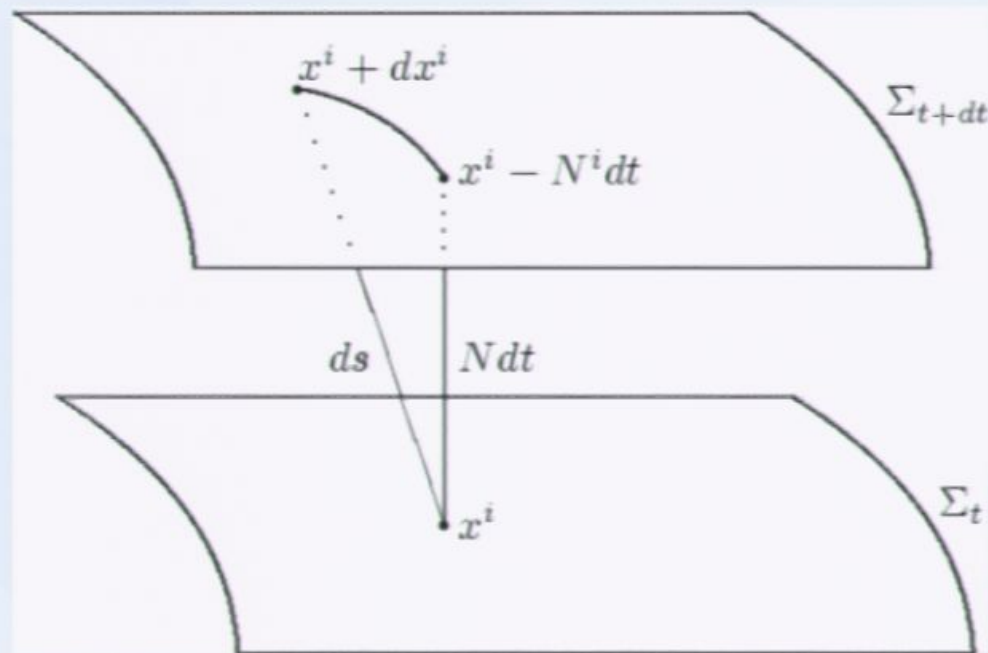


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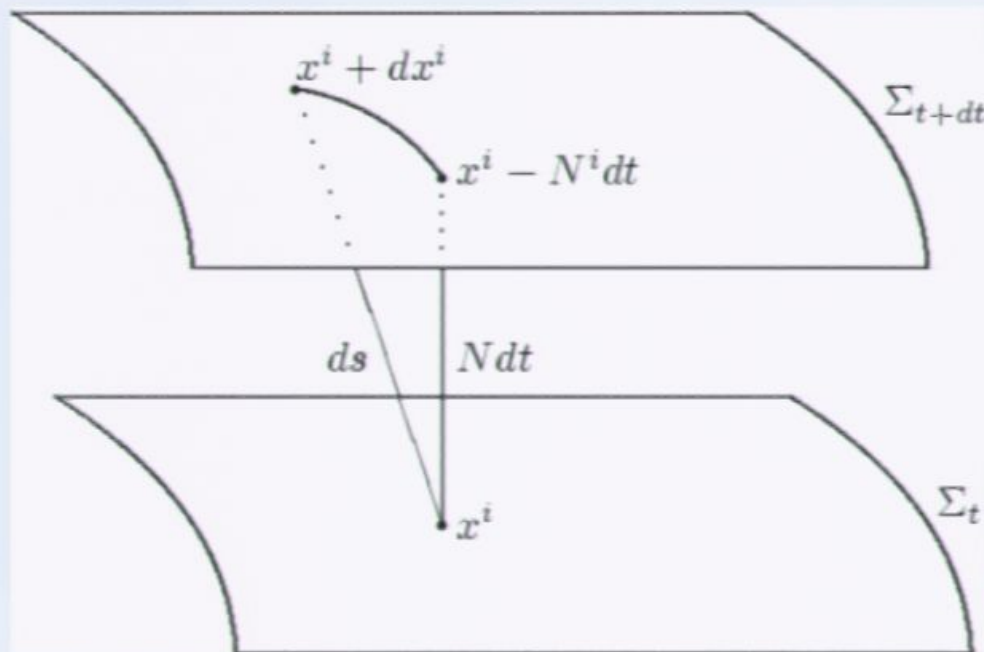


# Let's evolve the system in time!

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# **Victory!**

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