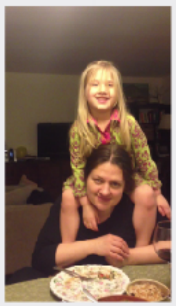
But first, a word of encouragement from my cousins.

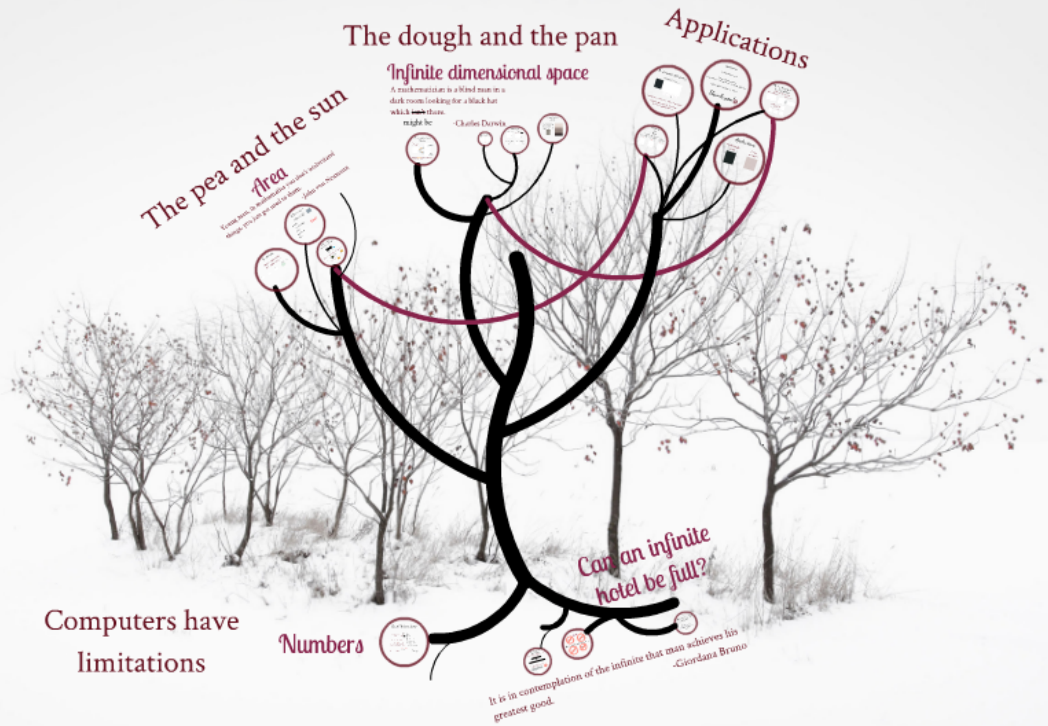


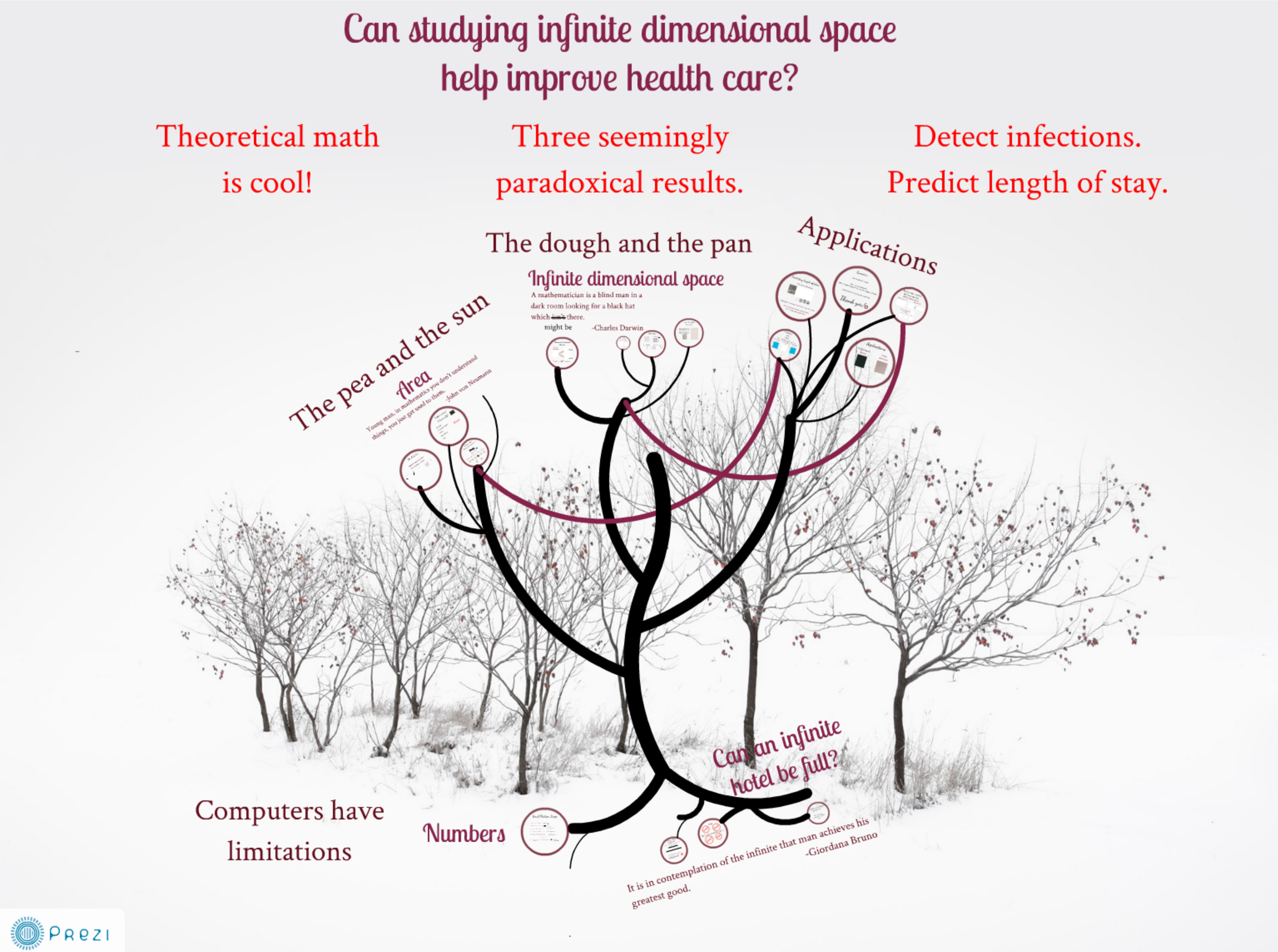
Can studying infinite dimensional space help improve health care?

Theoretical math is cool!

Three seemingly paradoxical results.

Detect infections.
Predict length of stay.

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The dough and the pan
Applications
Infinite dimensional space
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might be
-Charles Darwin
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PREZI

The monk and the mountain.

On the first day, a monk wakes up at sunrise, walks up a mountain trail and sleeps at the top of the trail. On the morning of the second day, the monk wakes up at sunrise and walks down the same trail to where he came from.

Must there be a spot on the trail where he was in the exact same place at the exact same time on both days?

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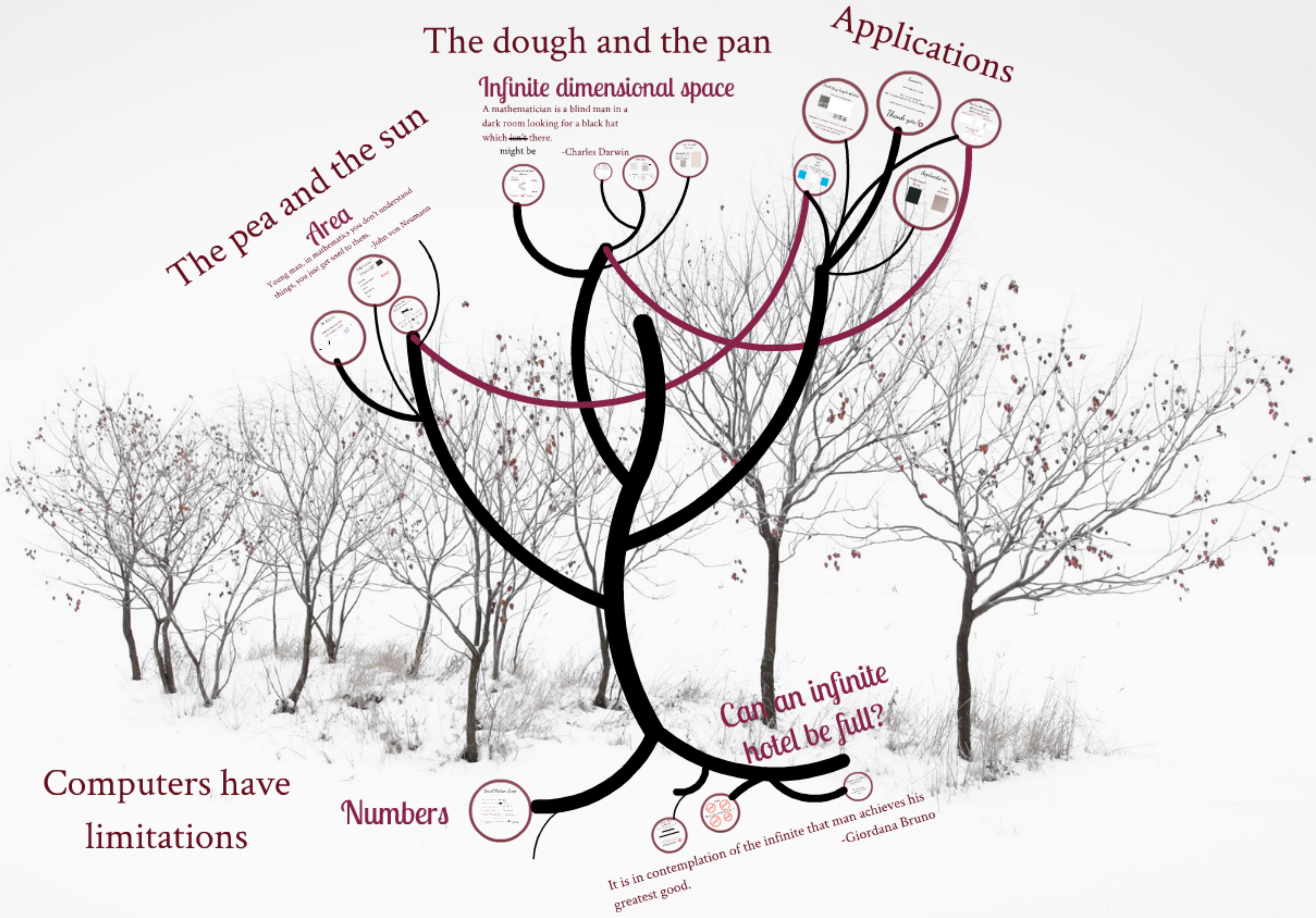

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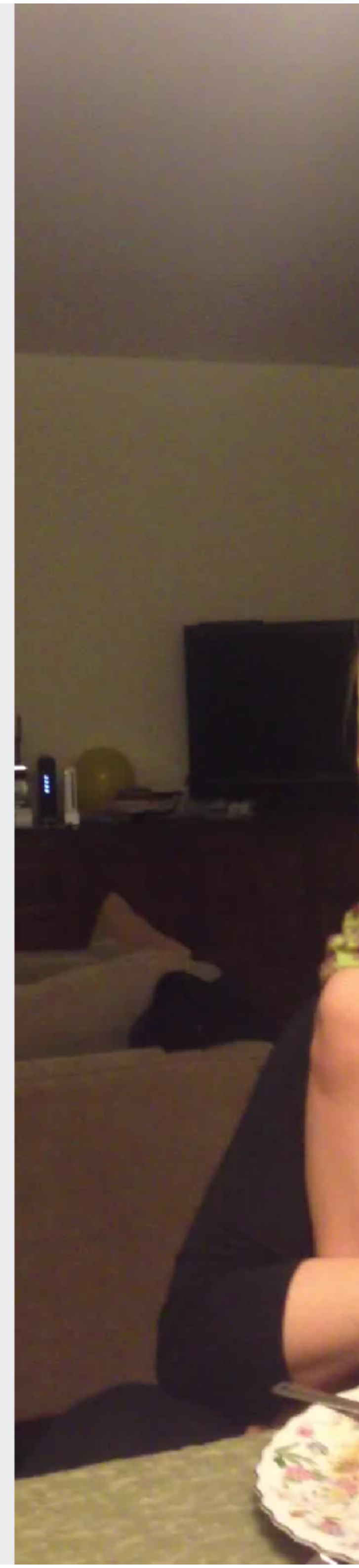

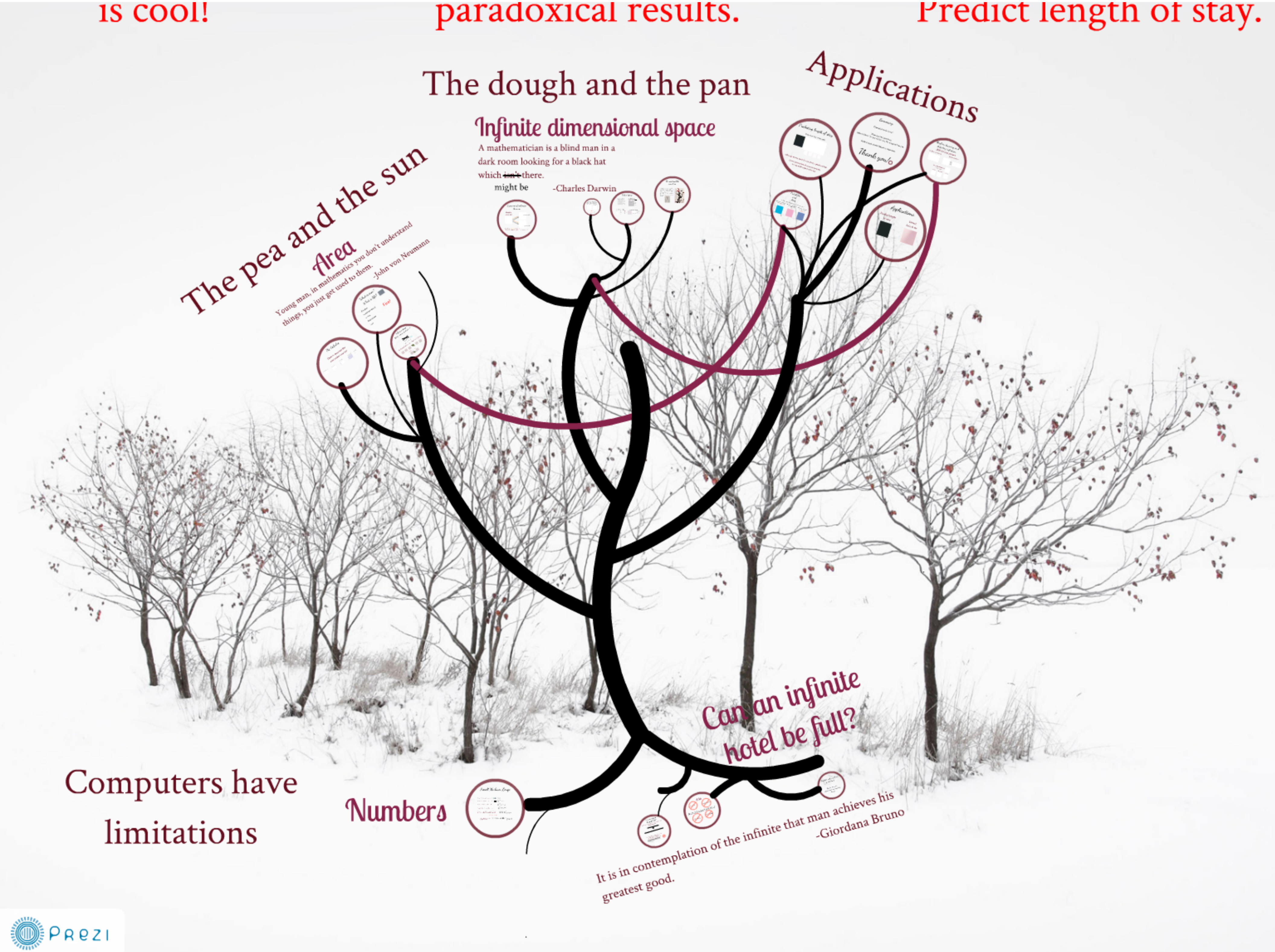
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Numbers

Small Medium Large

The number of rooms in the Burj Al Arab. 202

The diameter in meters of the visible universe. 10^{26}

The number of atoms in the visible universe. 10^{80}

A googol - the number Google was named after. 10^{100}

If each atom of our universe contained a copy of our universe, the number of atoms in all those universes. $10^{80} \cdot 10^{80} = 10^{160}$

Let's see a large number!

The number of ways to arrange 202 people in 202 rooms. $202 \cdot 201 \cdot 200 \ldots 3 \cdot 2 \cdot 1 = 10^{[illegible]}$

Prezi

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The diameter in meters of the visible universe.  10^{26} = 100.000.000.000.000.
000.000.000.000

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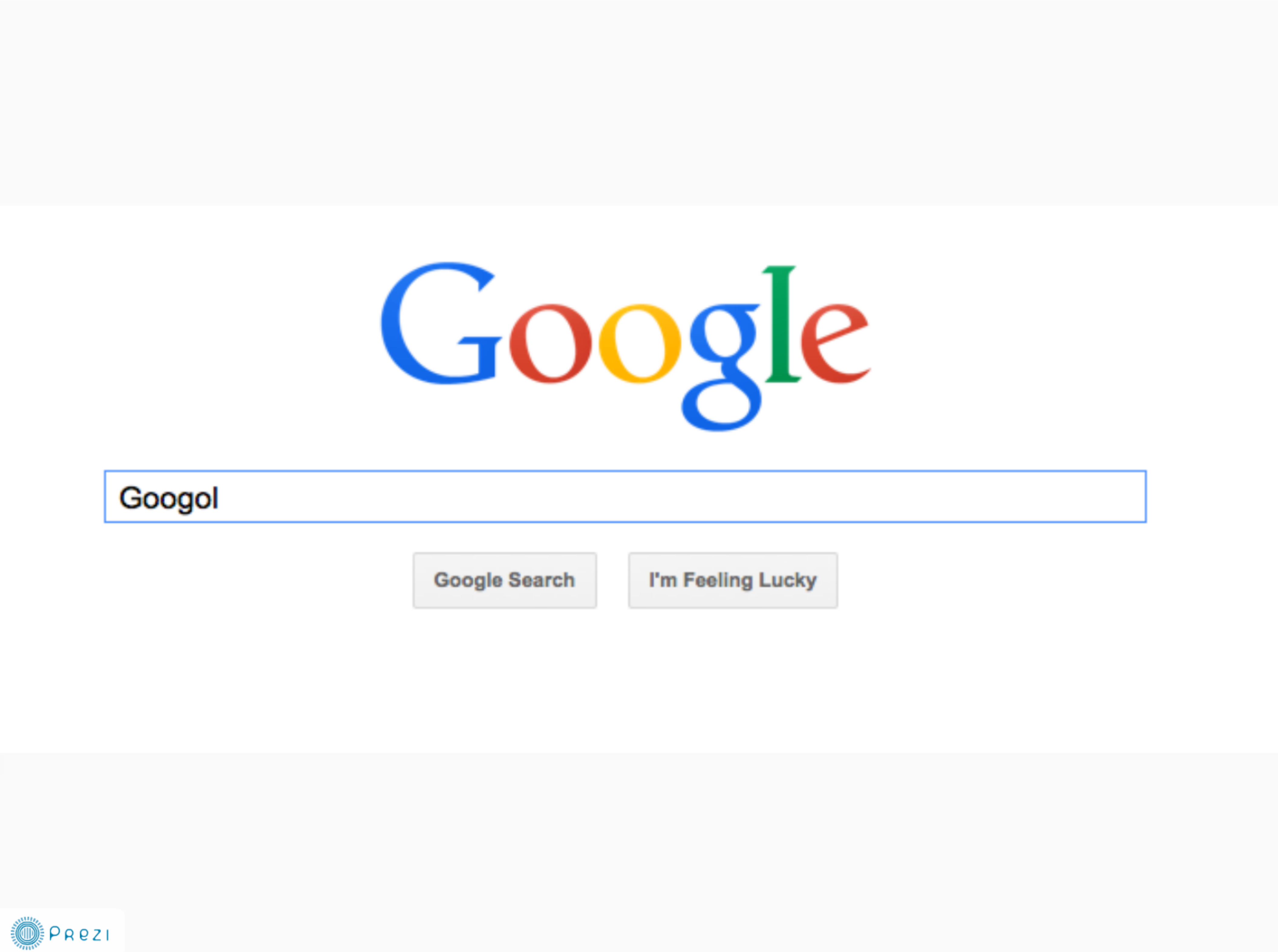
Google
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I'm Feeling Lucky

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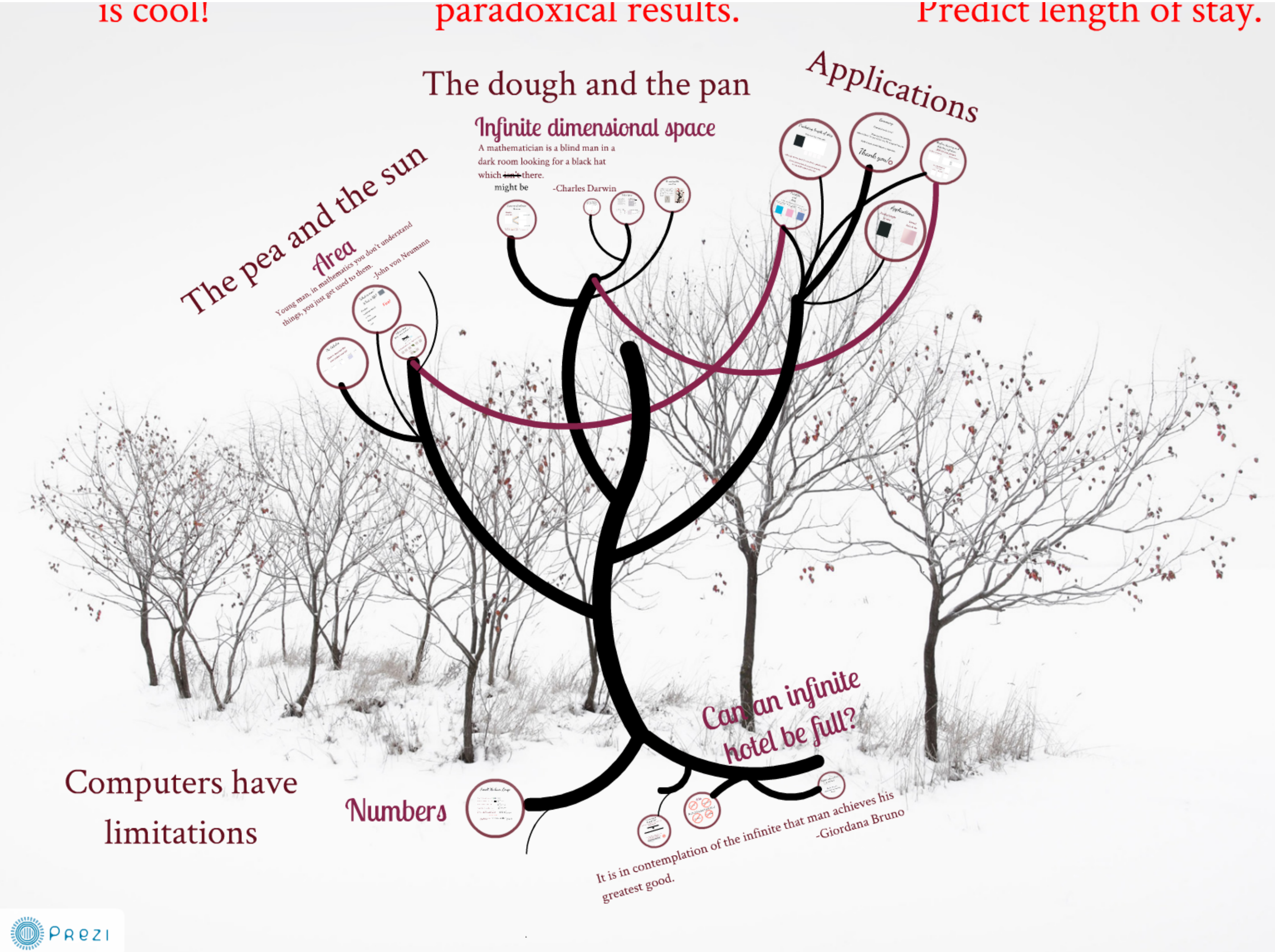
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Can an infinite hotel be full?
A Set
Last number
Infinite number
N={1,2,3,4,5,6,7,8,9,10...}
Growing
Changing
The Rationals are Dense in the Reals
The Cantor set is uncountable and nowhere dense.
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~~Last number~~

~~Infinite number~~

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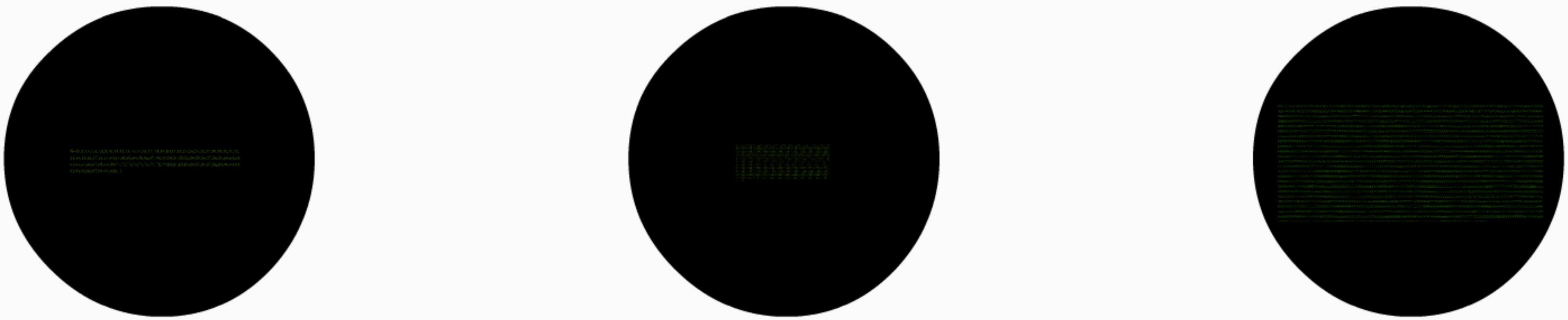

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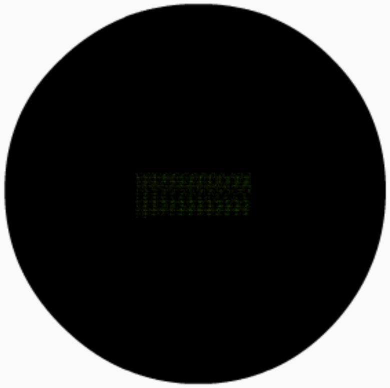
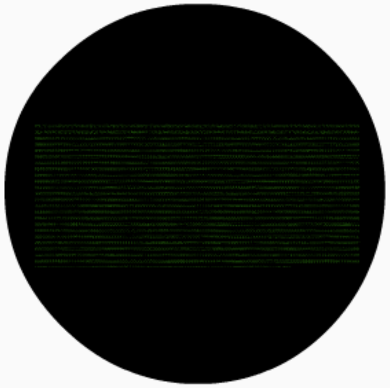




A Set

~~Last number~~

~~Infinite number~~

$$N=\{1,2,3,4,5,6,7,8,9,10...\}$$

~~Growing~~

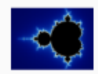
~~Changing~~

Can an infinite hotel be full?

A hotel is full when there is a guest in each room.

Does the size matter?

~~Imagine an infinite hotel.~~



~~Imagine a hotel with infinitely many rooms.~~

Imagine a hotel with one room for each natural number.

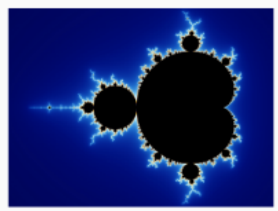
It is **full** if there is a guest in each room.

What happens when a new guest shows up?

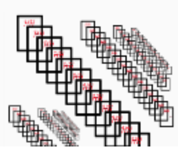
is full when there is a guest in eac

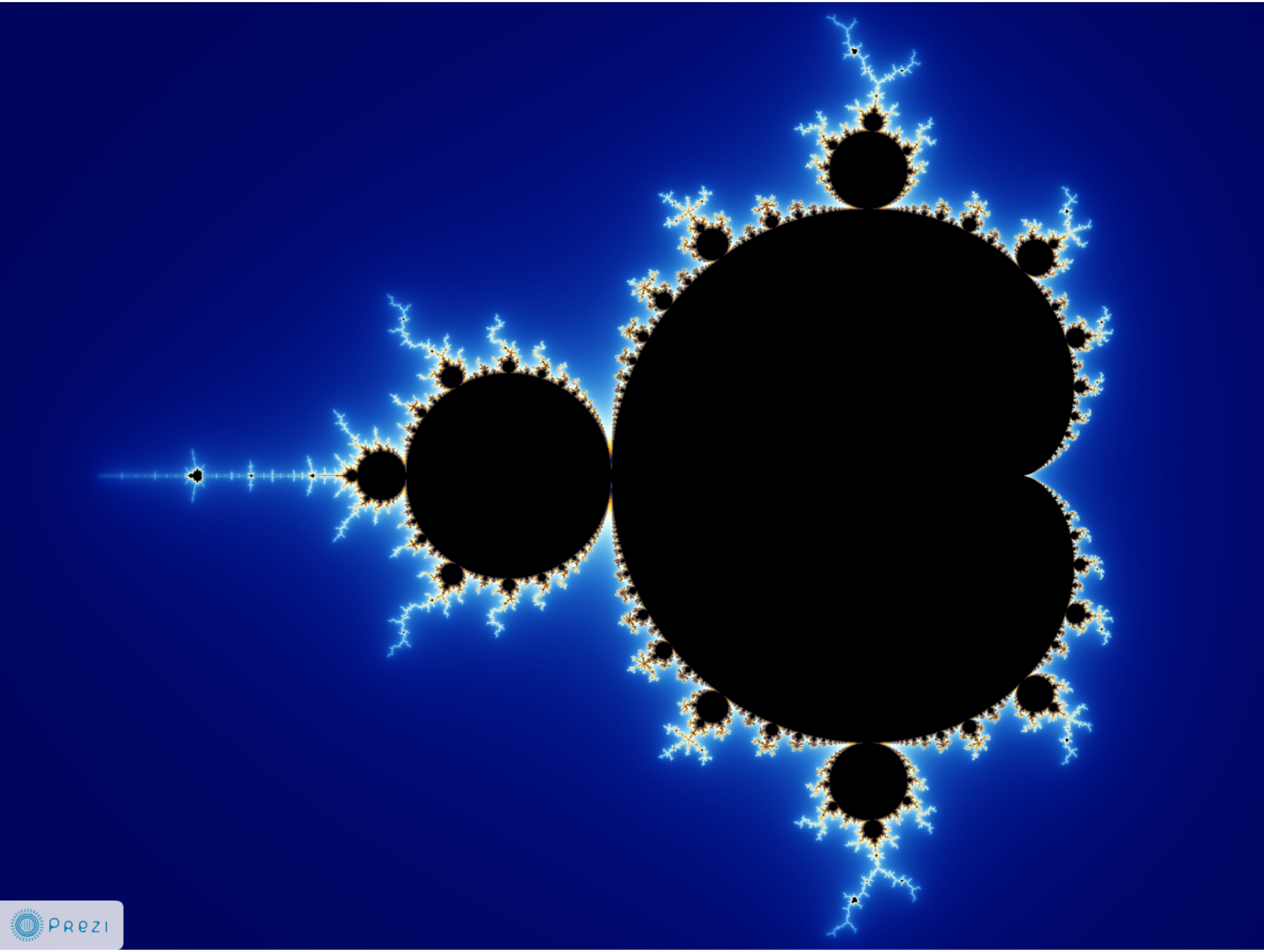
Does the size matter?

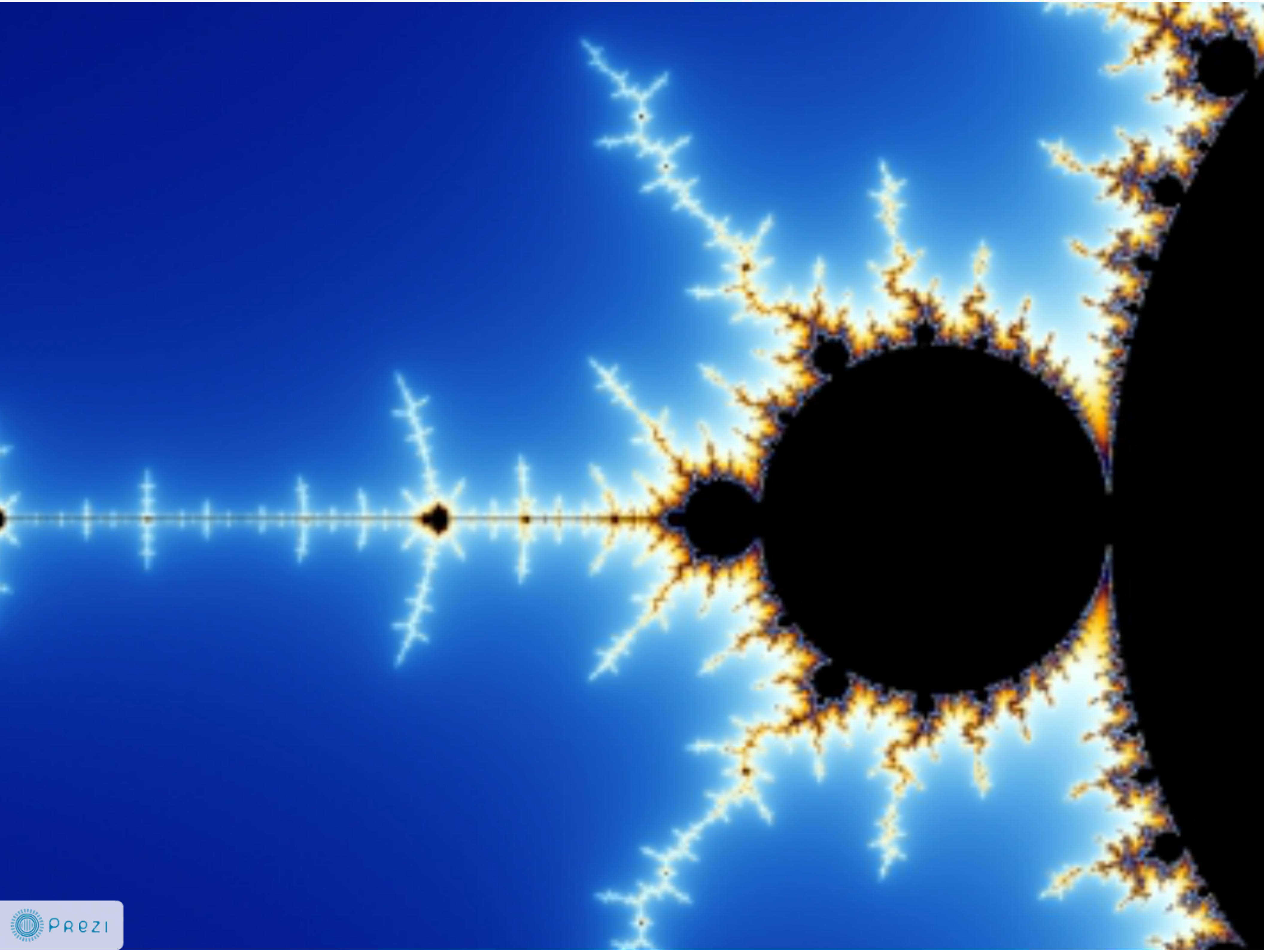
~~Imagine an infinite hotel.~~



~~gine a hotel with infinitely many ro~~



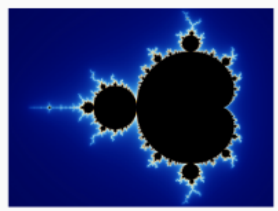




is full when there is a guest in eac

Does the size matter?

~~Imagine an infinite hotel.~~



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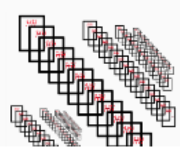

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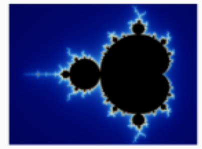
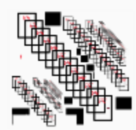
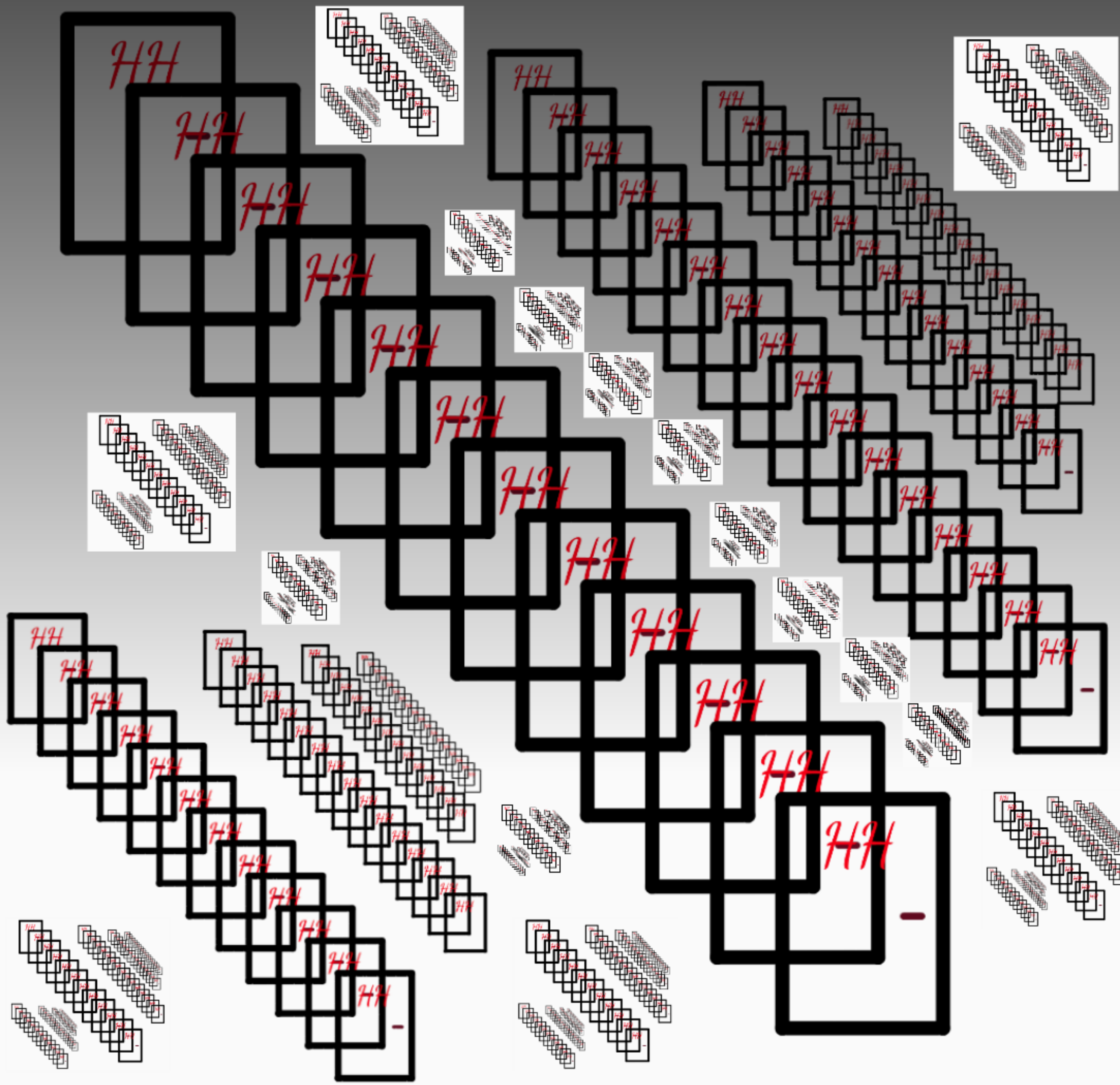


~~Imagine a hotel with infinitely many rooms.~~



Imagine a hotel with one room for each natural number.
It is **full** if there is a guest in each room.
What happens when a new guest shows up?


HH

Does the size matter?

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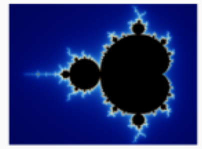

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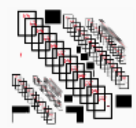

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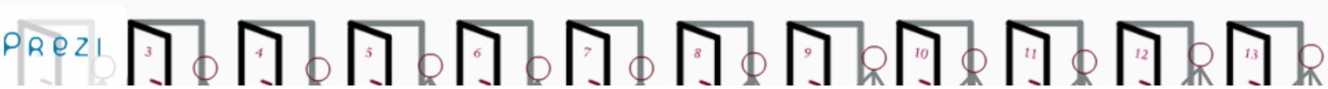

• • •

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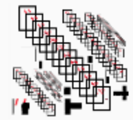


Imagine a hotel with one room for each natural number.

It is **full** if there is a guest in each room.

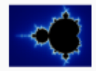
What happens when a new guest shows up?

Can an infinite hotel be full?

A hotel is full when there is a guest in each room.

Does the size matter?

~~Imagine an infinite hotel.~~



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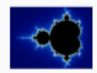

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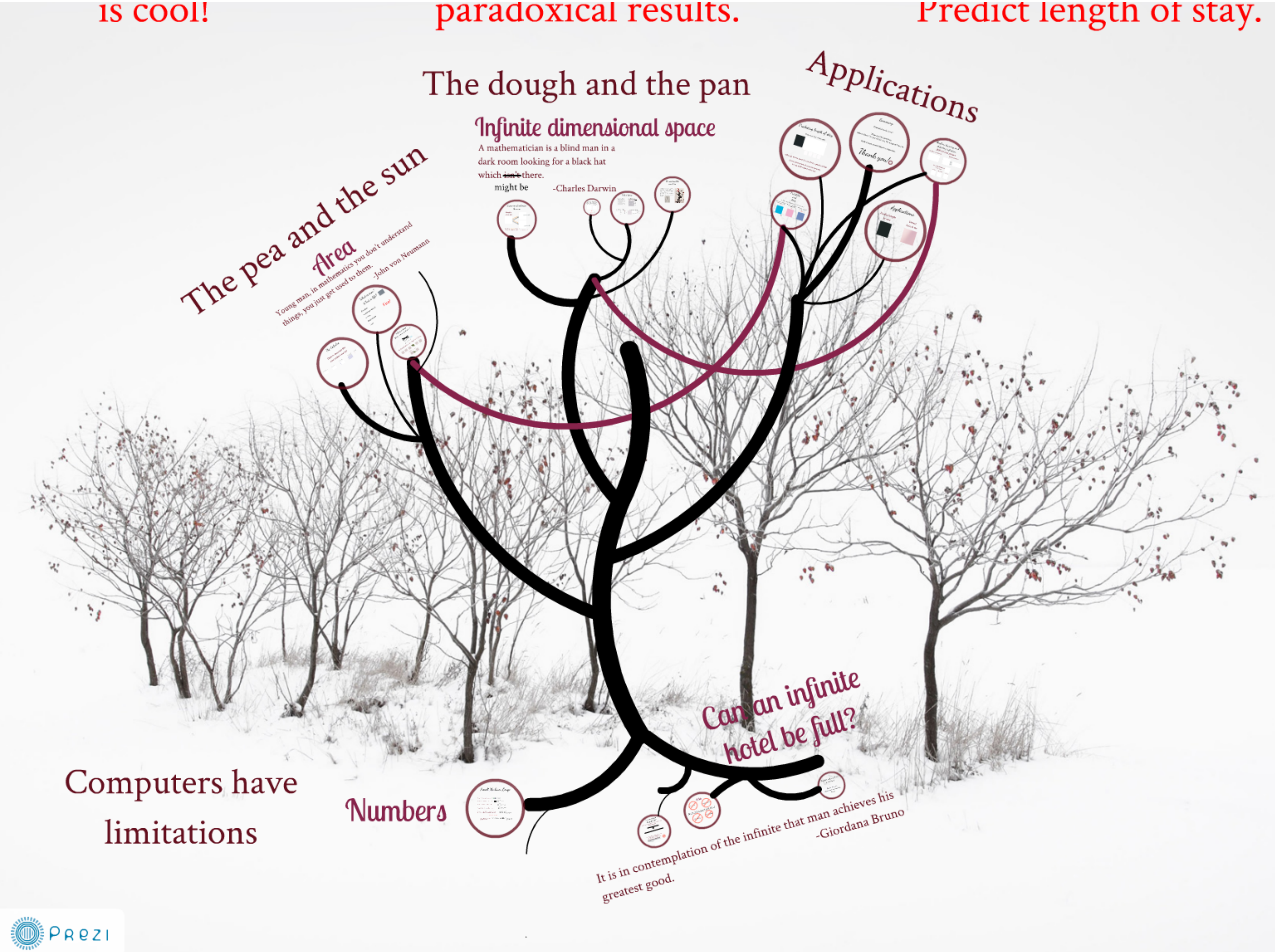
What happens when a new guest shows up?

The Rationals are Dense in the Reals

The Cantor set is uncountable and nowhere dense.


is cool!
paradoxical results.
Predict length of stay.
The dough and the pan
Applications
Infinite dimensional space
A mathematician is a blind man in a dark room looking for a black hat which ~~isn't~~ might be there.
-Charles Darwin
The pea and the sun
Area
Young man, in mathematics you don't understand things, you just get used to them.
-John von Neumann
Can an infinite hotel be full?
It is in contemplation of the infinite that man achieves his greatest good.
-Giordana Bruno
Computers have limitations
Numbers
Prezi

Area

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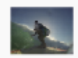
-John von Neumann

What is area?

What is life?



Breathes

Consumes energy

Grows

Reproduces

Dies

Fire?

The Calculus

How to measure the area under a curve?

What is Area?

What properties should it have?

The Banach Tarski paradox - The Pea and The Sun

Prezi

The Calculus

How to measure the area under a curve?

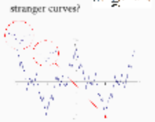
Area under a half circle

area = $\frac{\pi r^2}{2} = \frac{\pi}{2}$

For more complex curves

One can measure the area with more advanced math

What about even stranger curves?



The Calculus

How to measure the area under a curve?

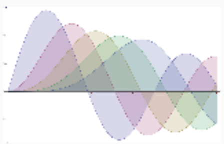
Area under a half circle

$x^2 + y^2 = 1$ $\quad y^2 = 1 - x^2$ $\quad y = \sqrt{1 - x^2}$

$$\text{area} = \frac{\pi r^2}{2} = \frac{\pi}{2}$$

For more complex curves

One can measure the area with more advanced math



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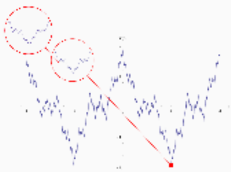

Area under a half circle

$$x^2 + y^2 = 1$$

$$y^2 = 1 - x^2$$

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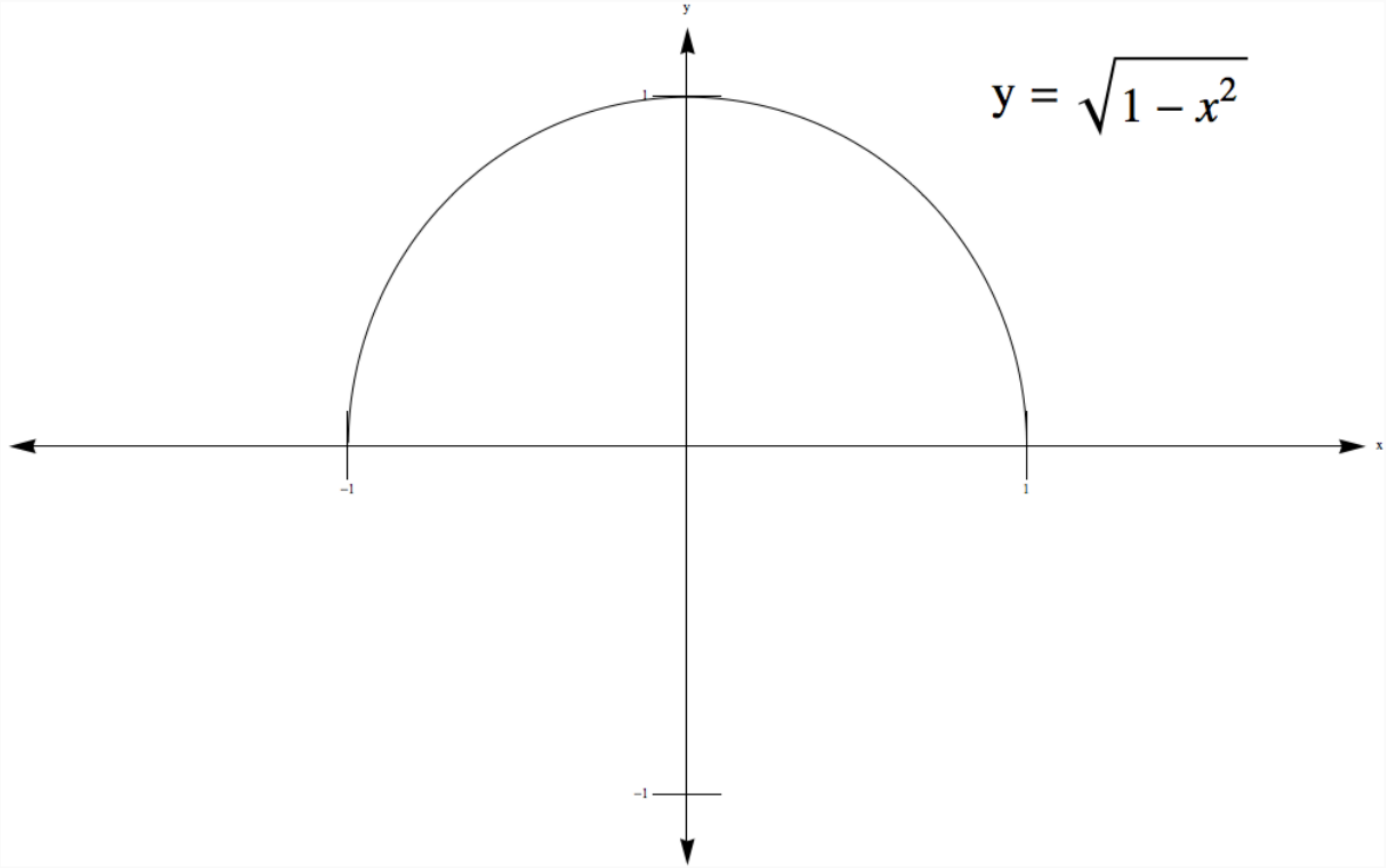
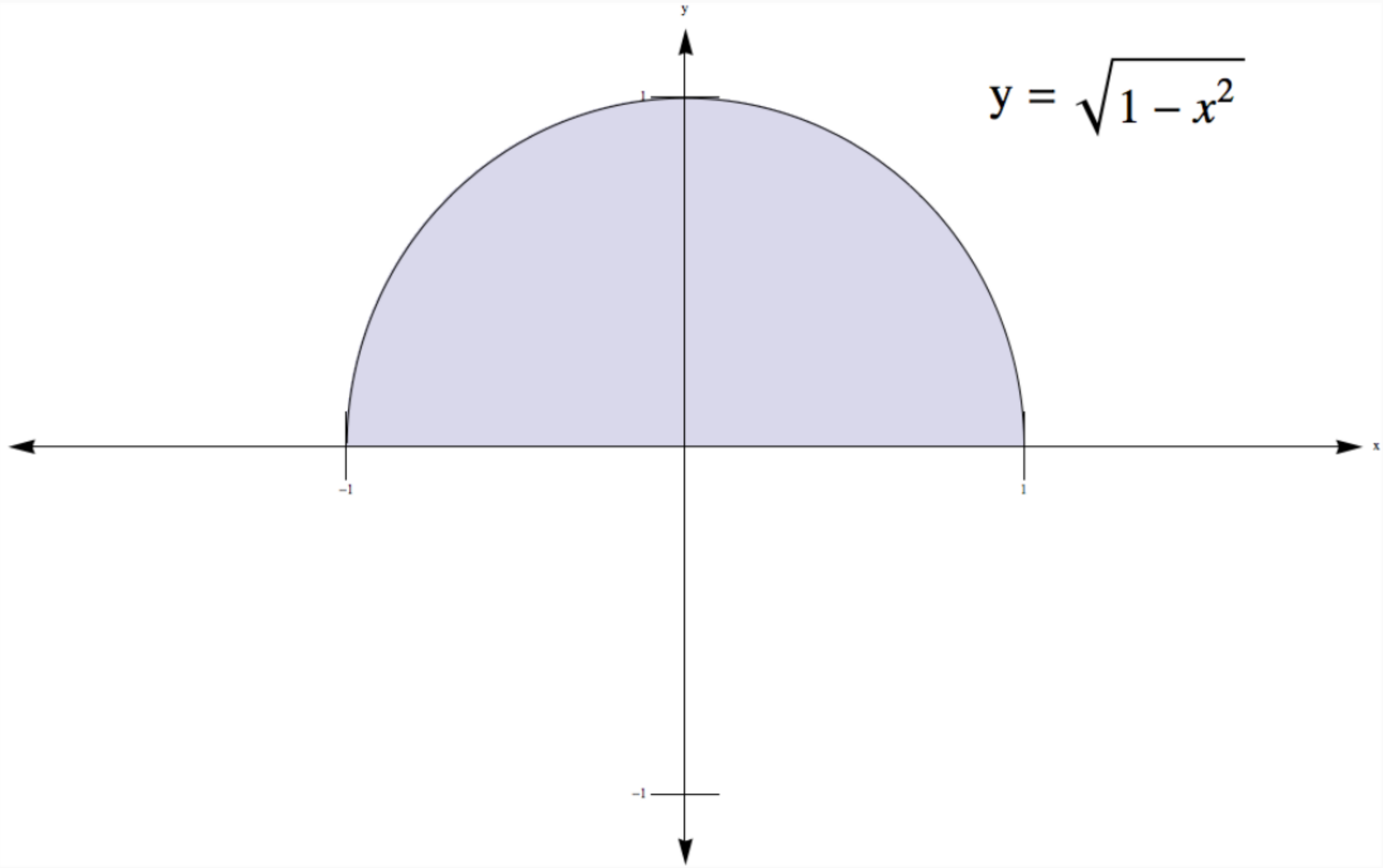
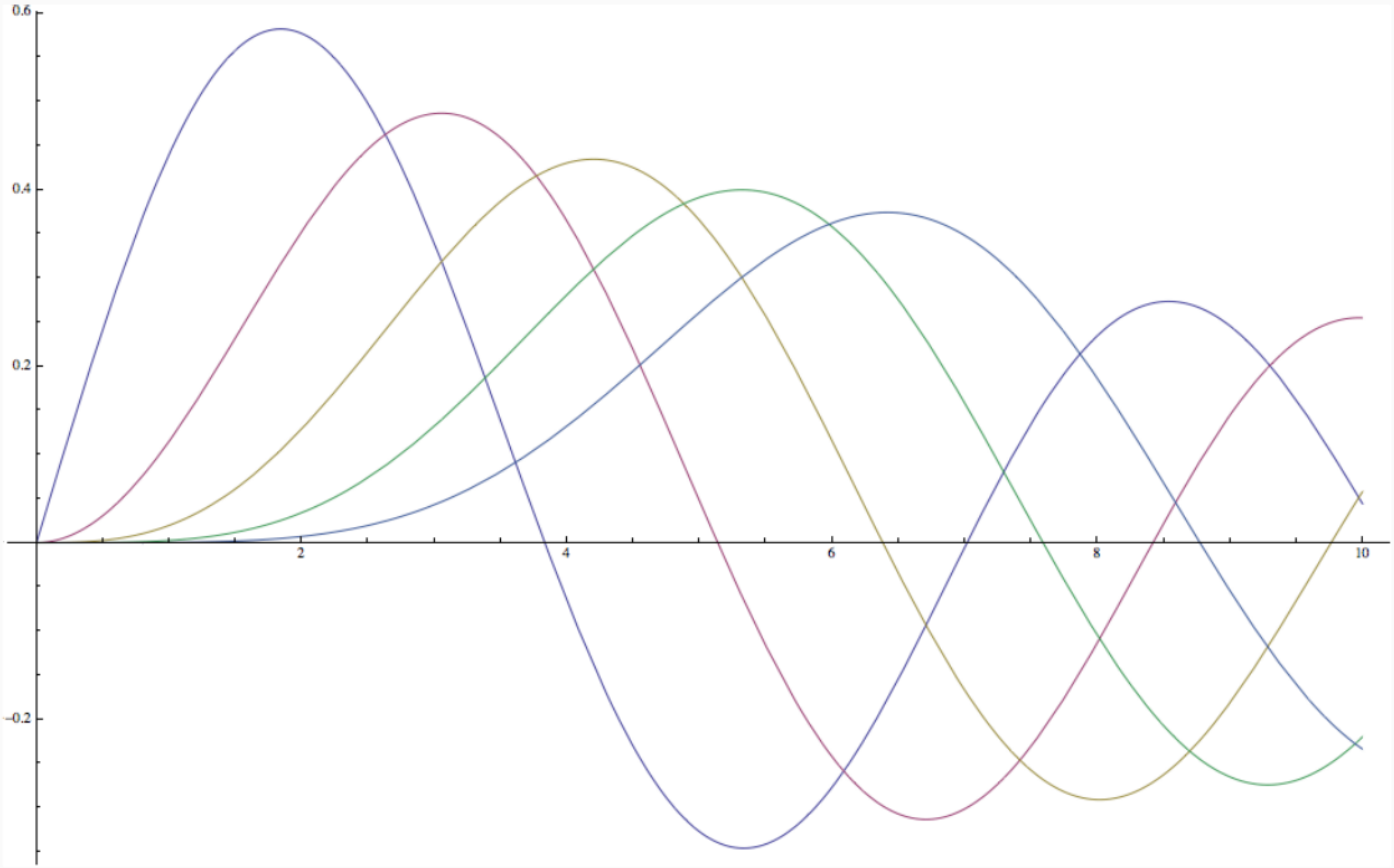


$$\text{area} = \frac{\pi r^2}{2} = \frac{\pi}{2}$$



For more complex curves



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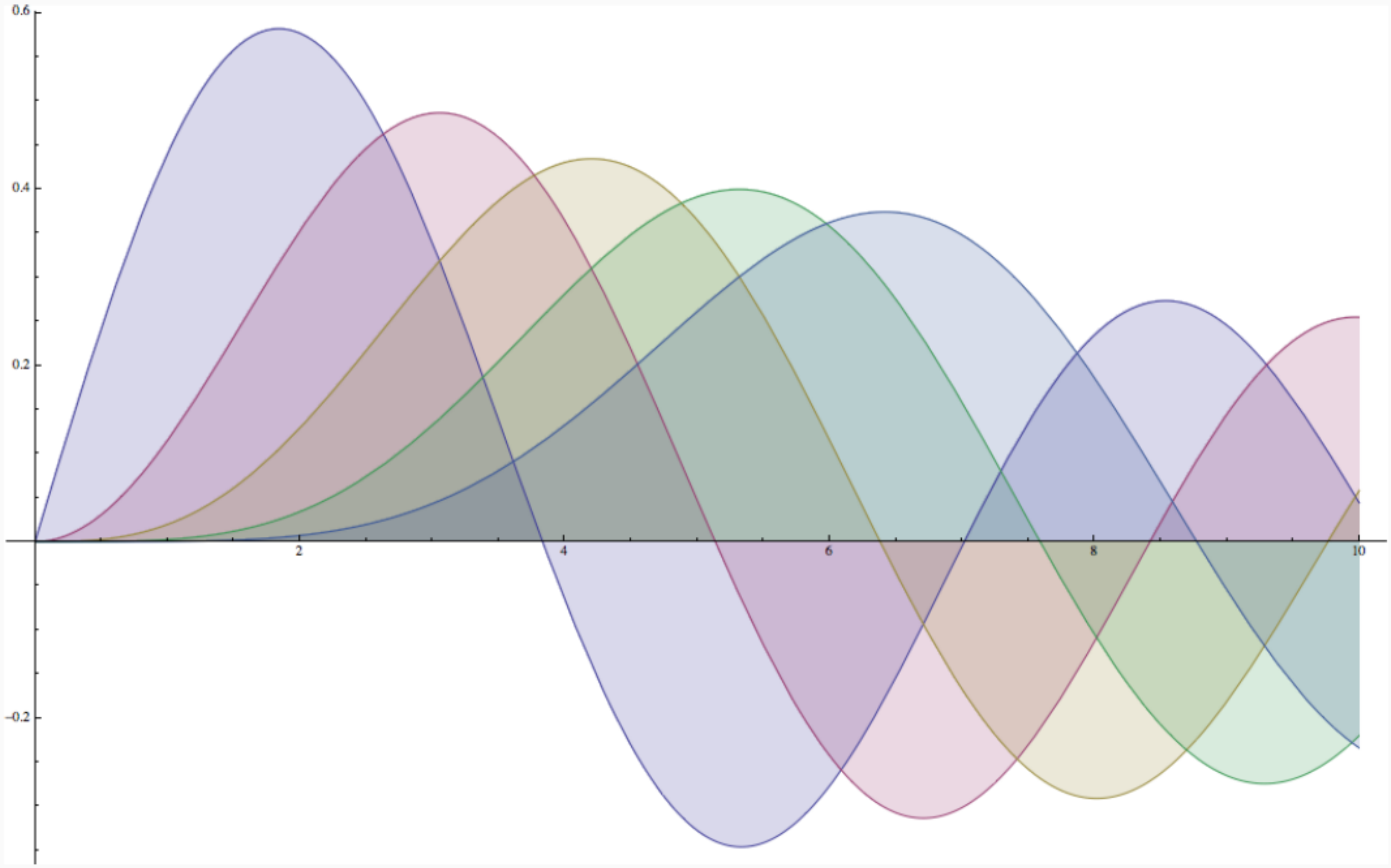
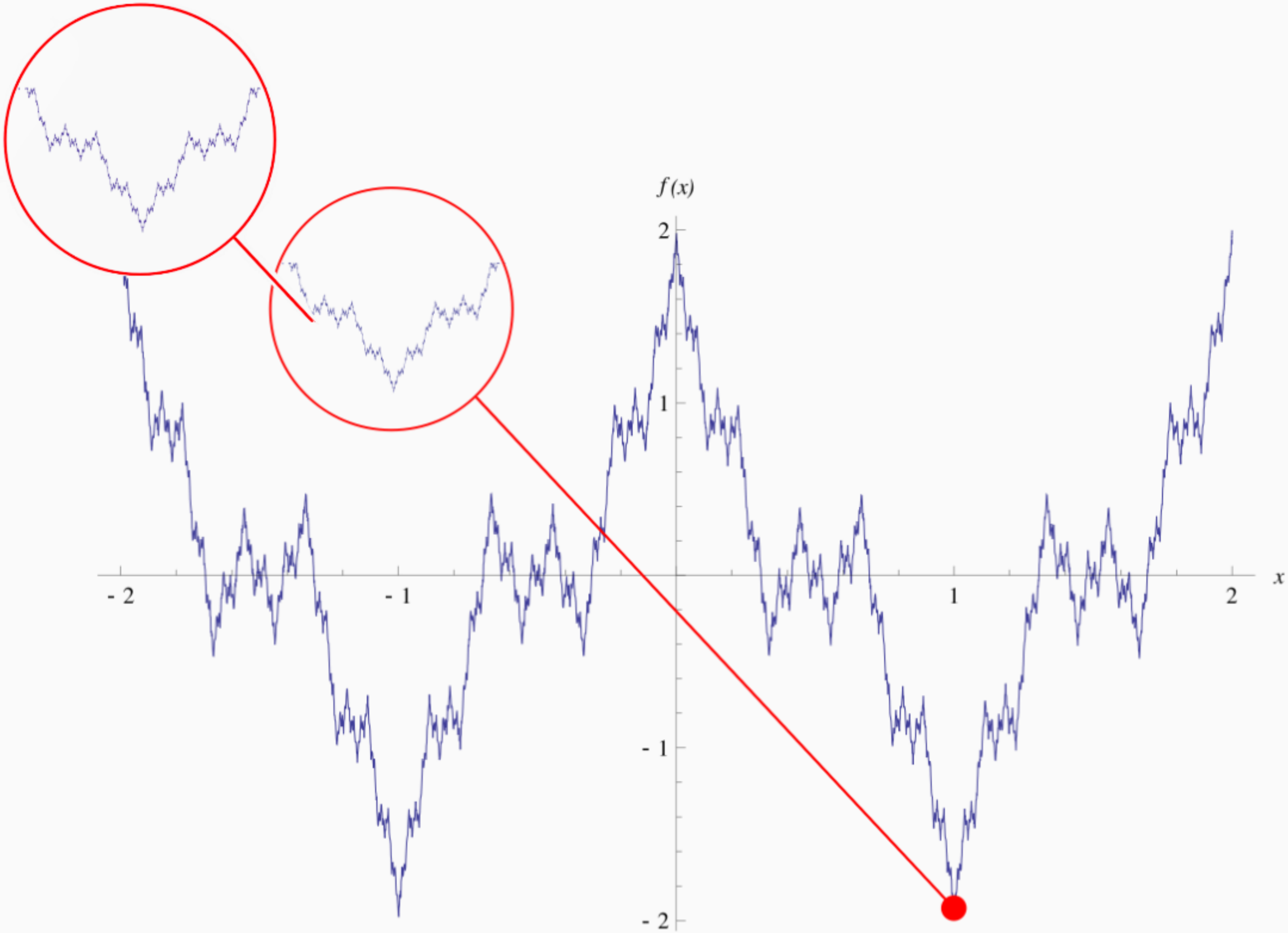


What about even stranger curves?

$$f(x) = \sum_{n=0}^{\infty} a^n \cos(b^n \pi x)$$



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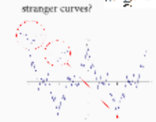


What is area?

What is life?

Breathes

Consumes energy

Grows

Reproduces

Dies

Fire?

What is area?

What is life? 

Breathes

Consumes energy

Grows

Reproduces

Dies

Fire?

What is Area?

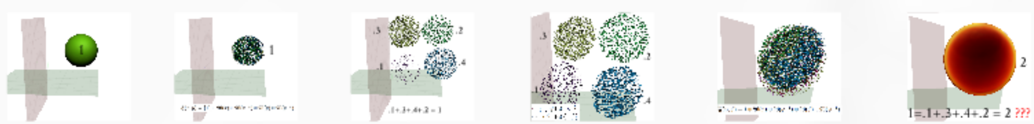
What properties should it have?

~~Any set of points should have an area.~~

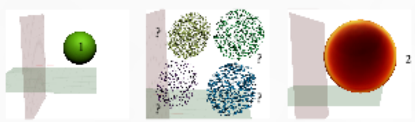
The cutting an object into pieces should not changes its area.

Moving or rotating an object should not change its area.

The Banach Tarski paradox - The Pea and The Sun



Did they break math? No!



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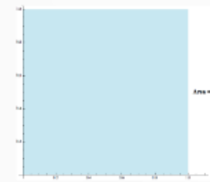

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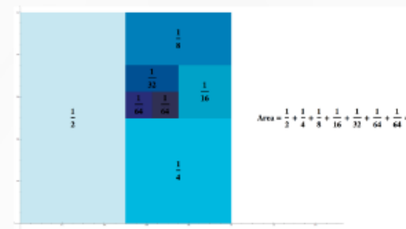

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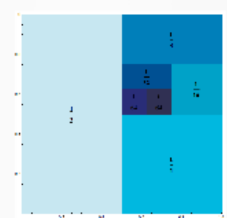
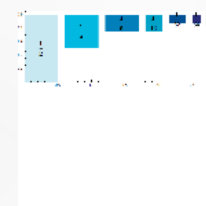
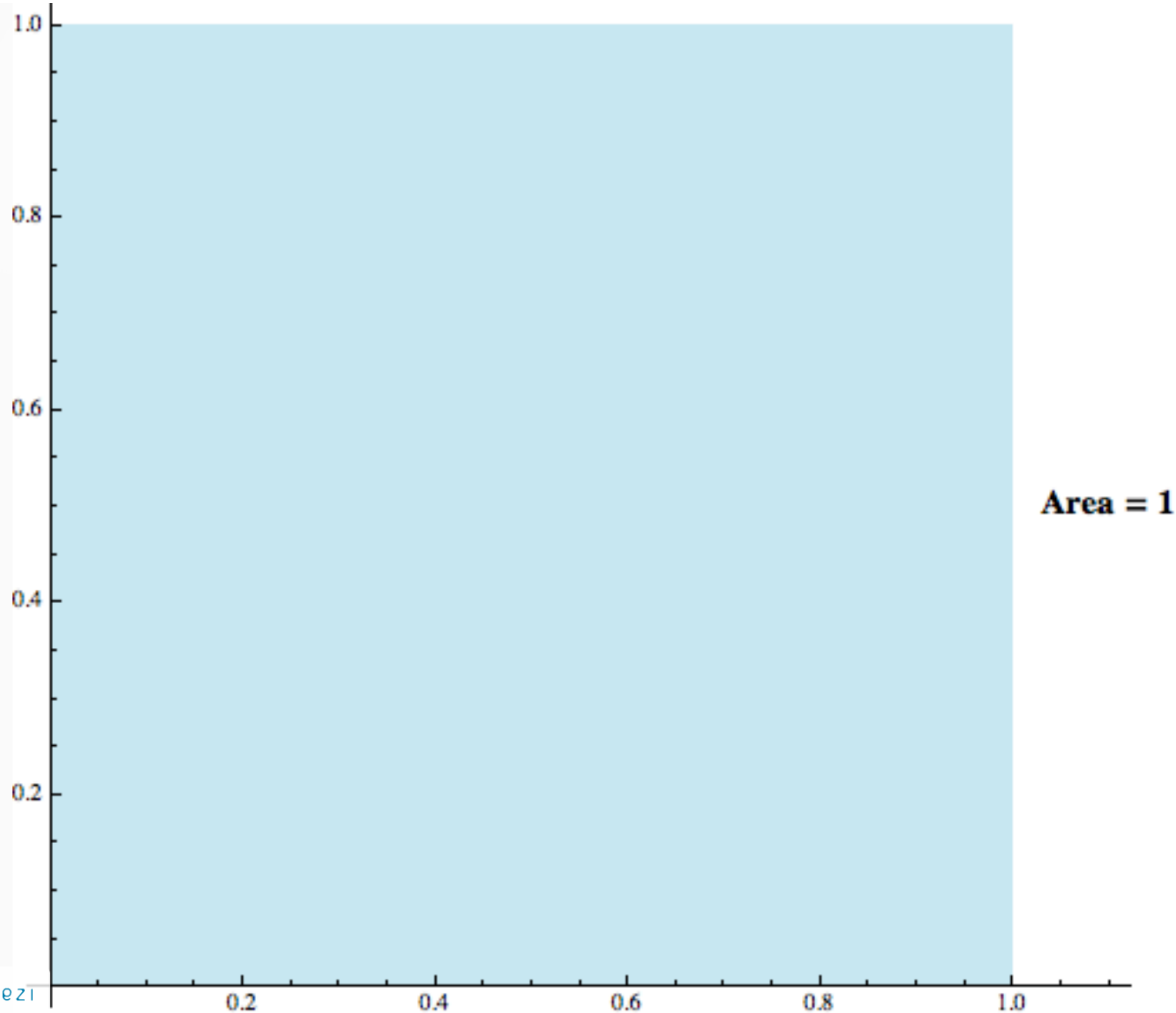
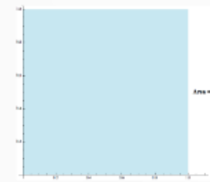





1.0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1.0
Area = 1

~~Any set of points should have an area.~~



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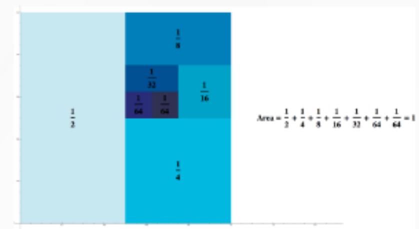
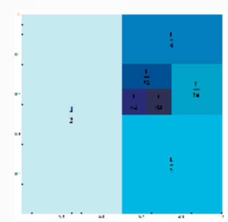
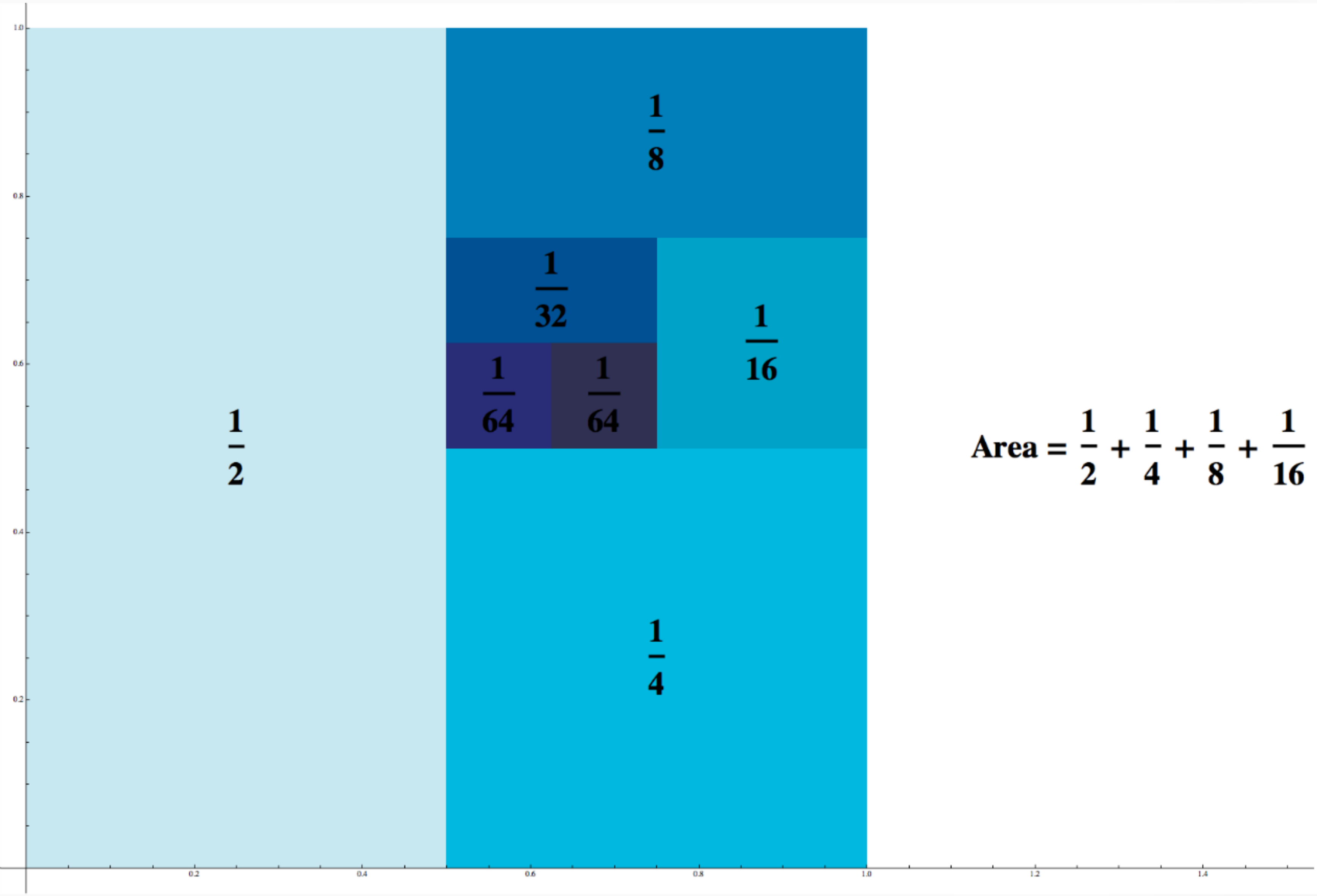


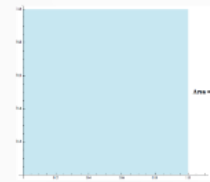
Moving or rotating an object should not change its area.





$$\text{Area} = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{64} = 1$$

~~Any set of points should have an area.~~



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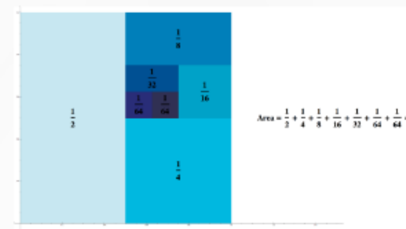

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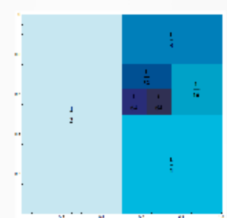
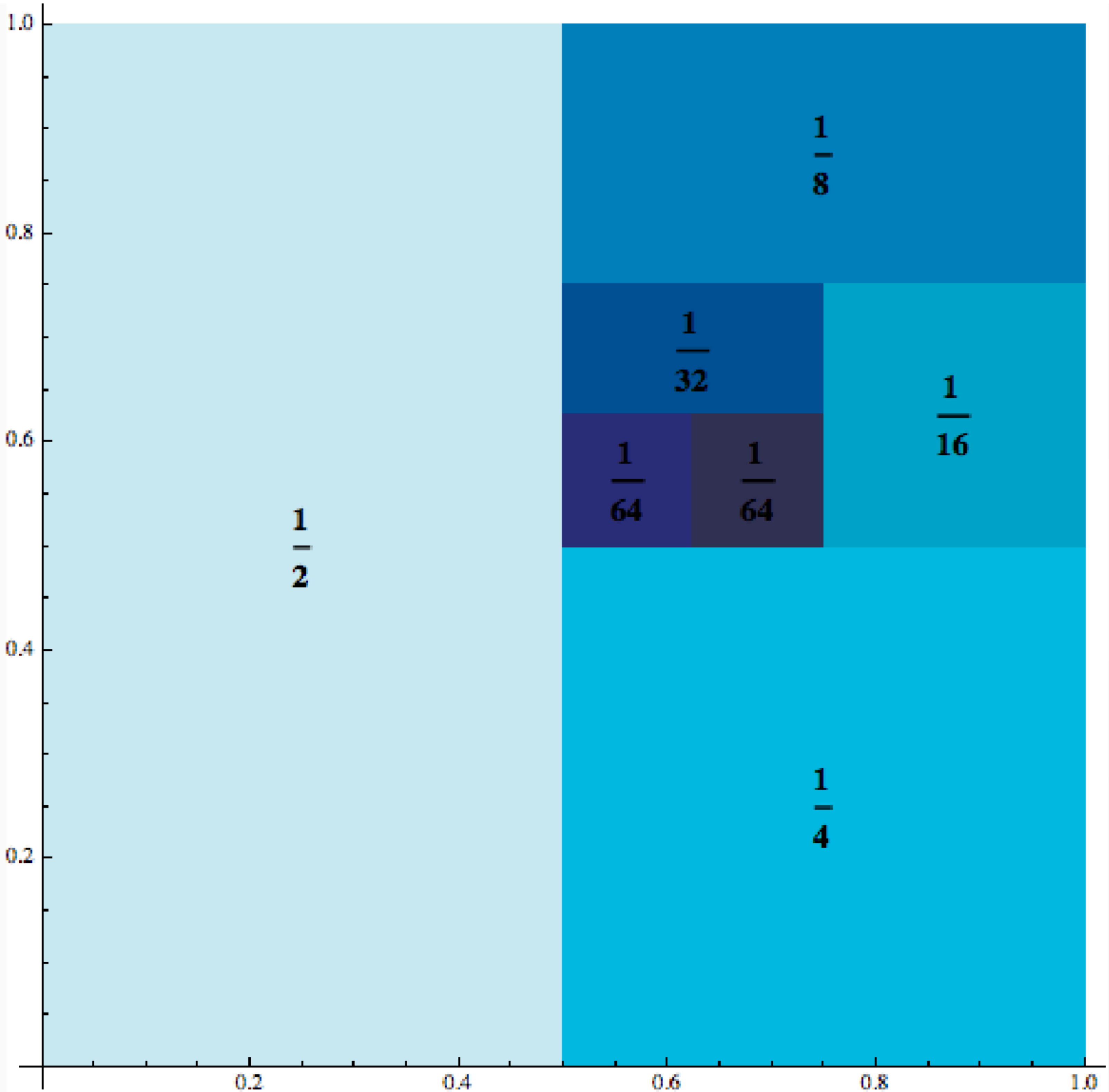
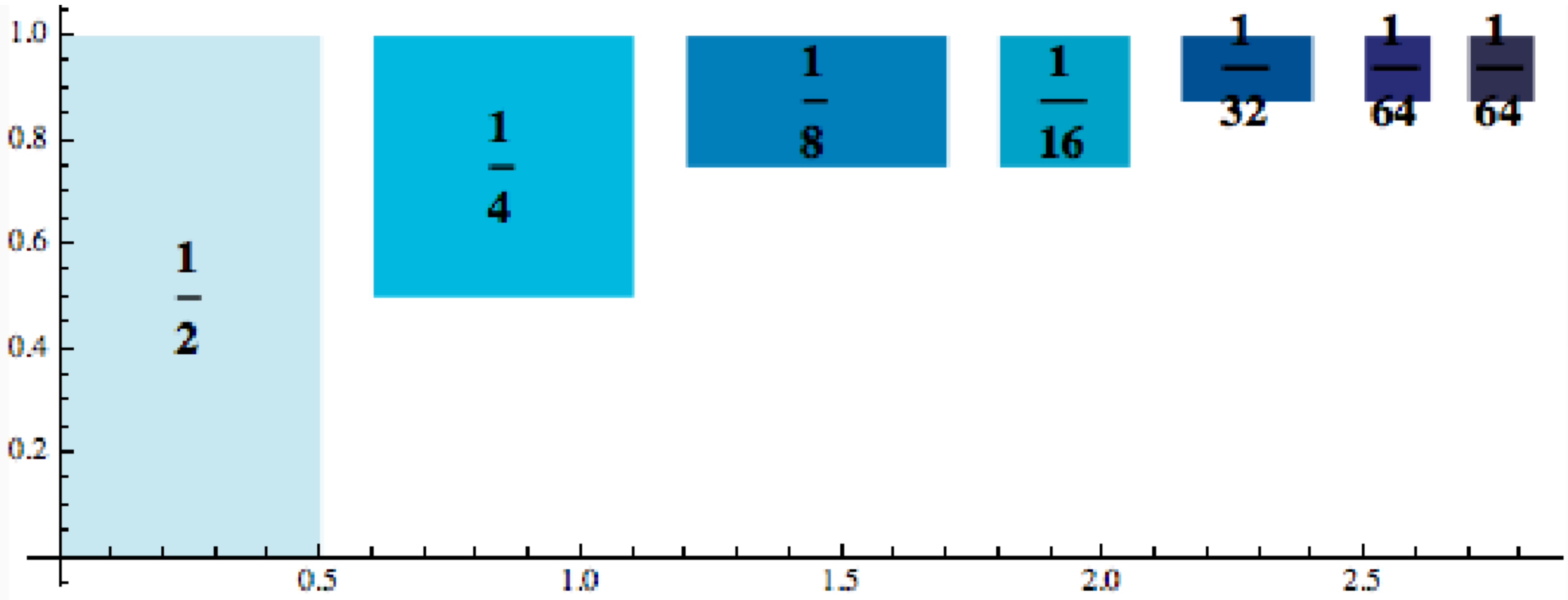



1.0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1.0
1/2
1/8
1/32
1/16
1/64
1/64
1/4



Prezi

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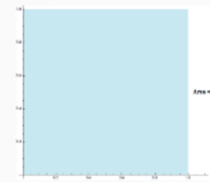

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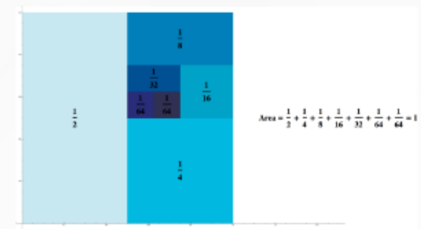
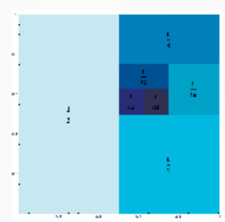
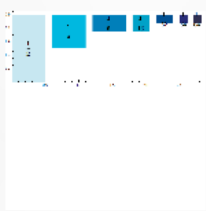


Moving or rotating an object should not change its area.





What is Area?

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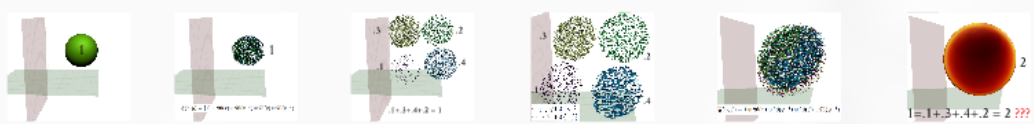
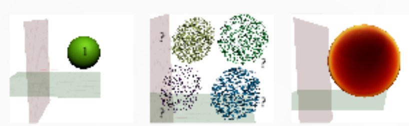
The Banach Tarski paradox - The Pea and The Sun



Did they break math? No!



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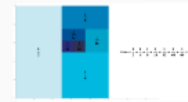

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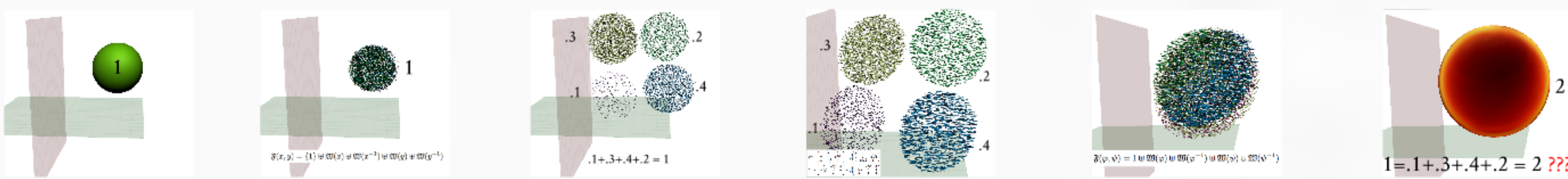

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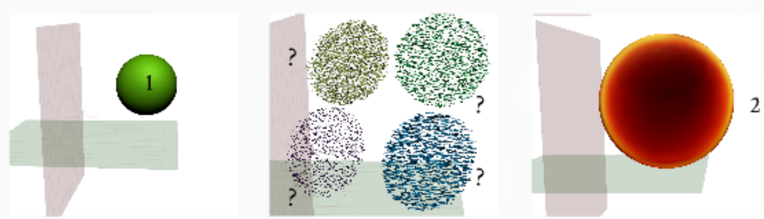
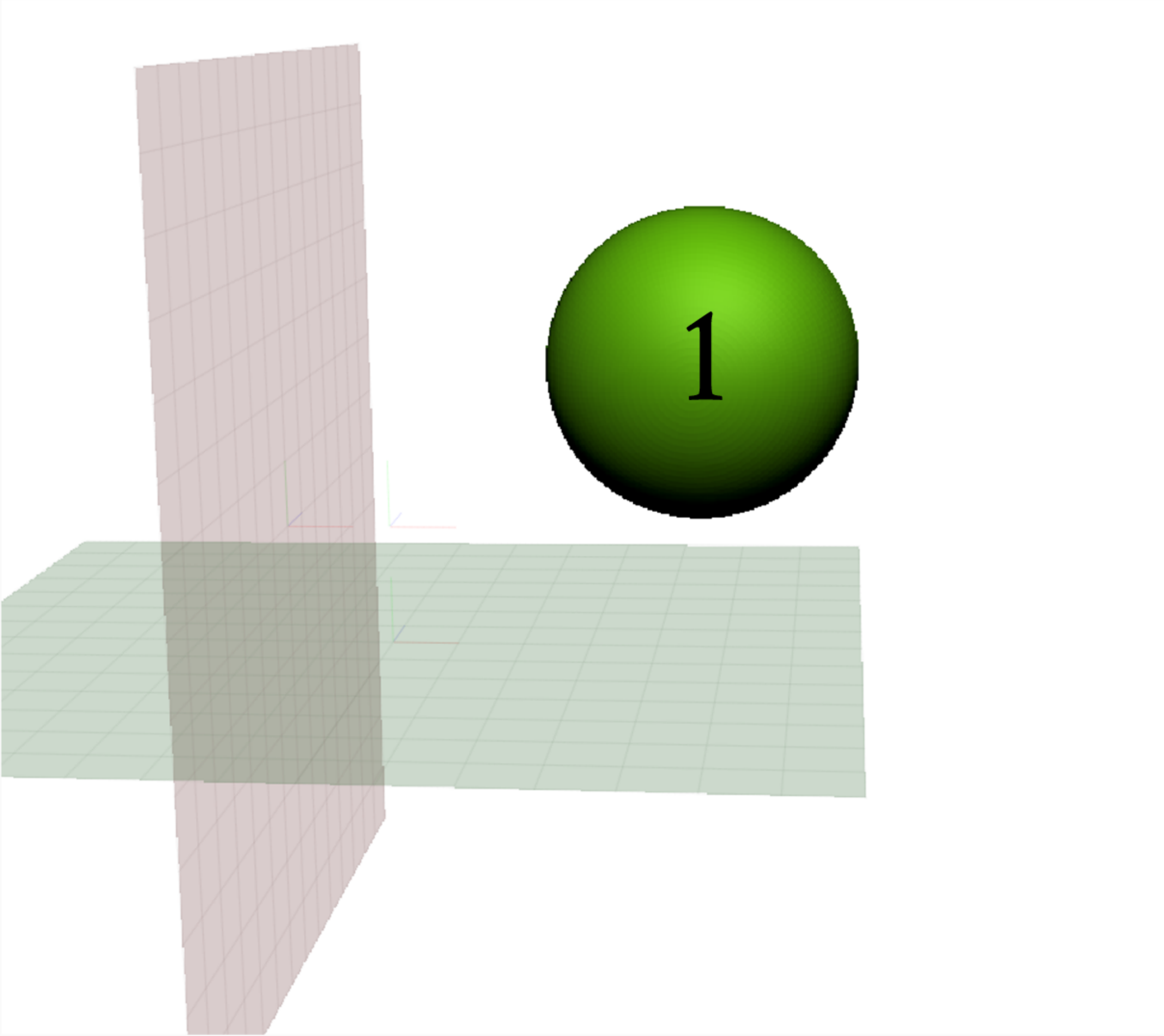
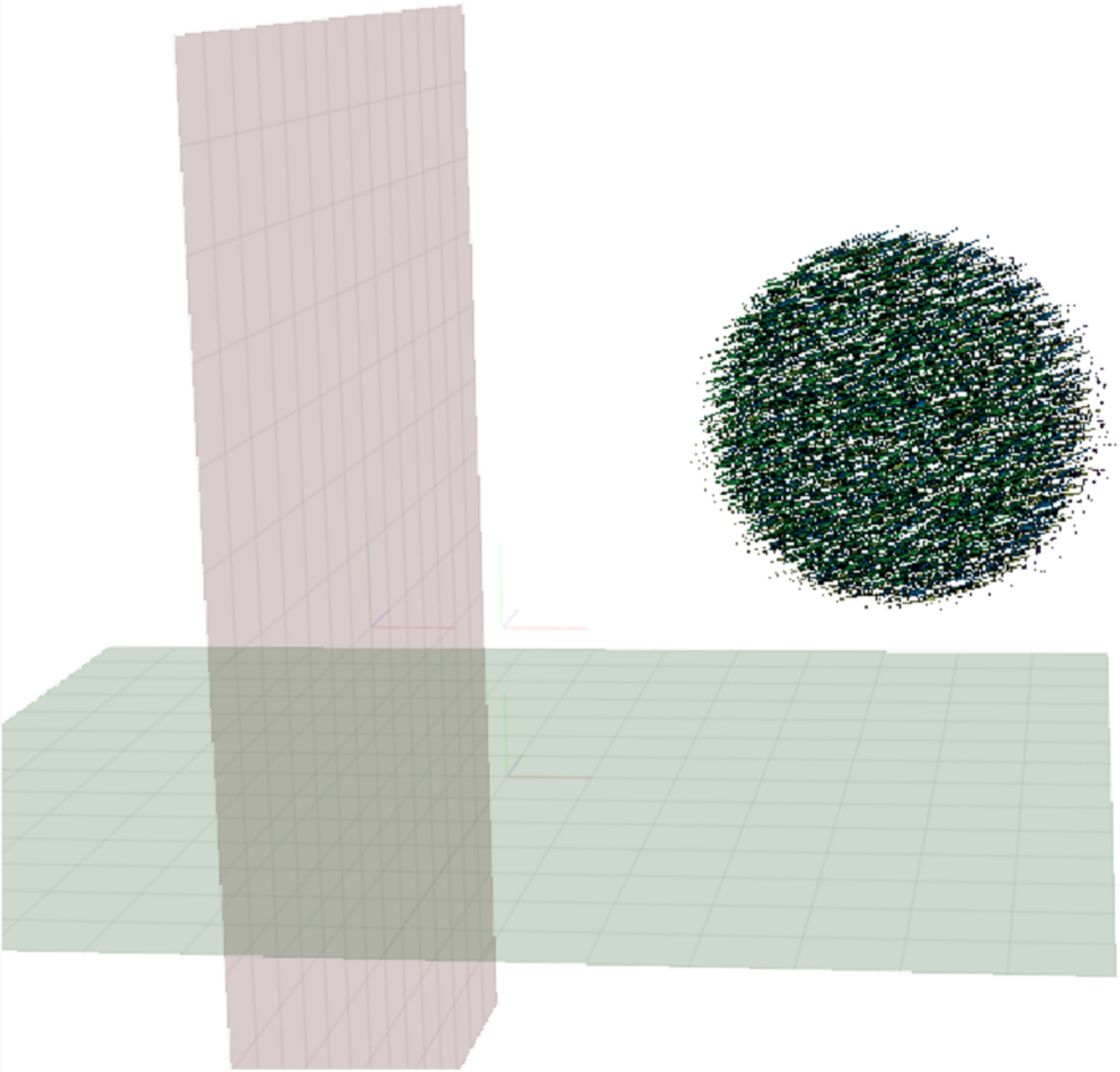
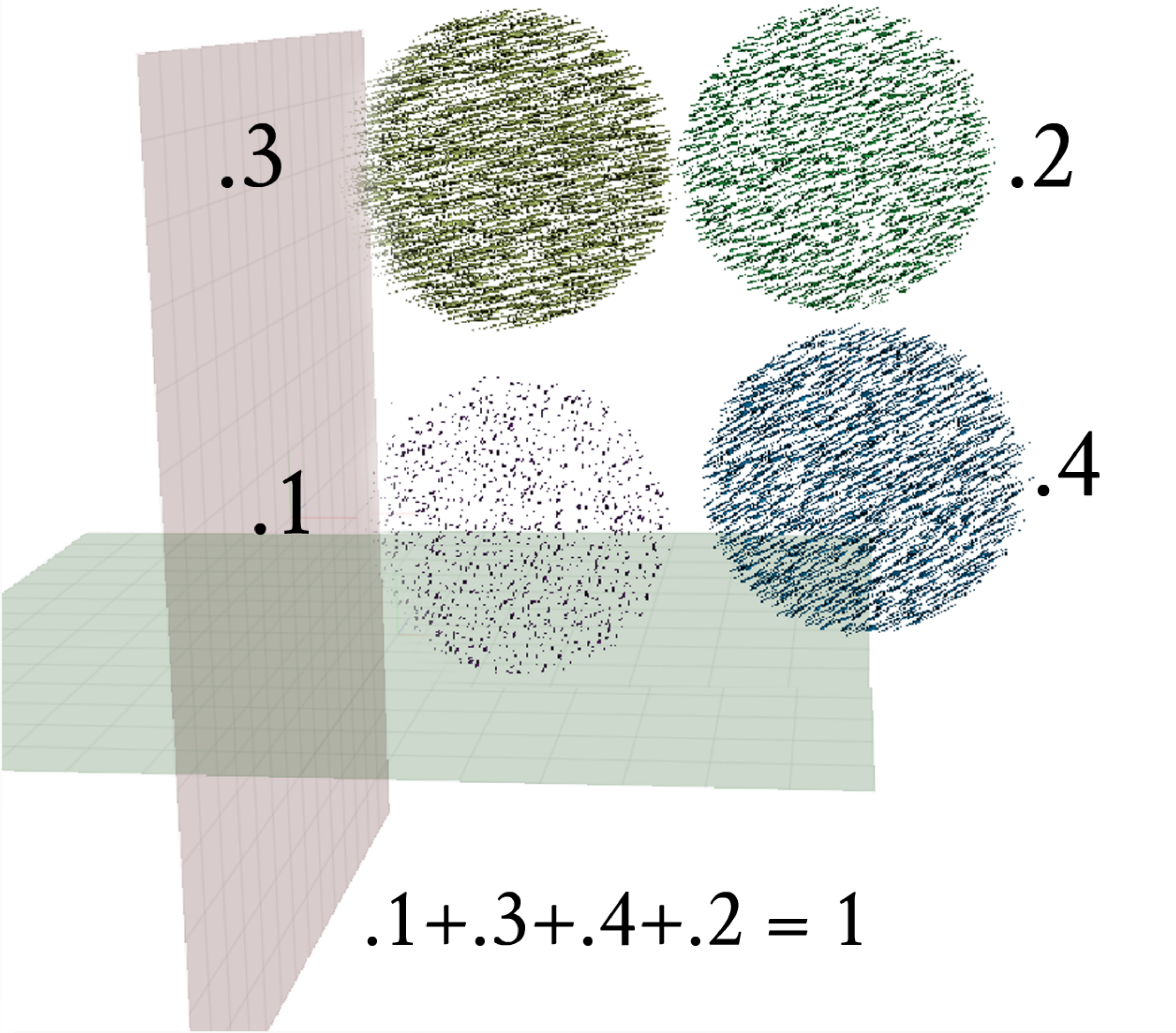



1

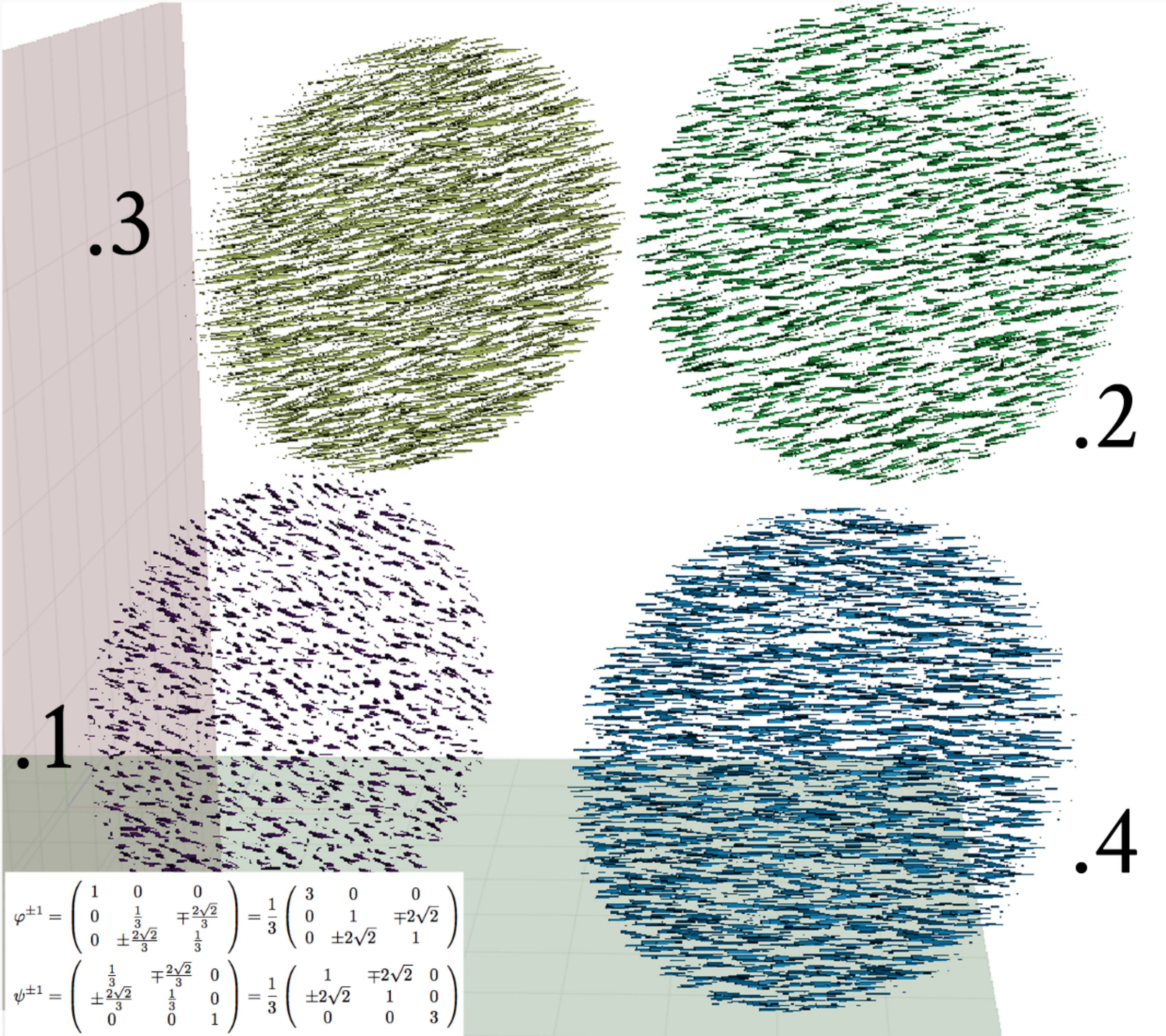


1

$$\mathfrak{F}(x,y) = \{1\} \uplus \mathfrak{W}(x) \uplus \mathfrak{W}(x^{-1}) \uplus \mathfrak{W}(y) \uplus \mathfrak{W}(y^{-1})$$

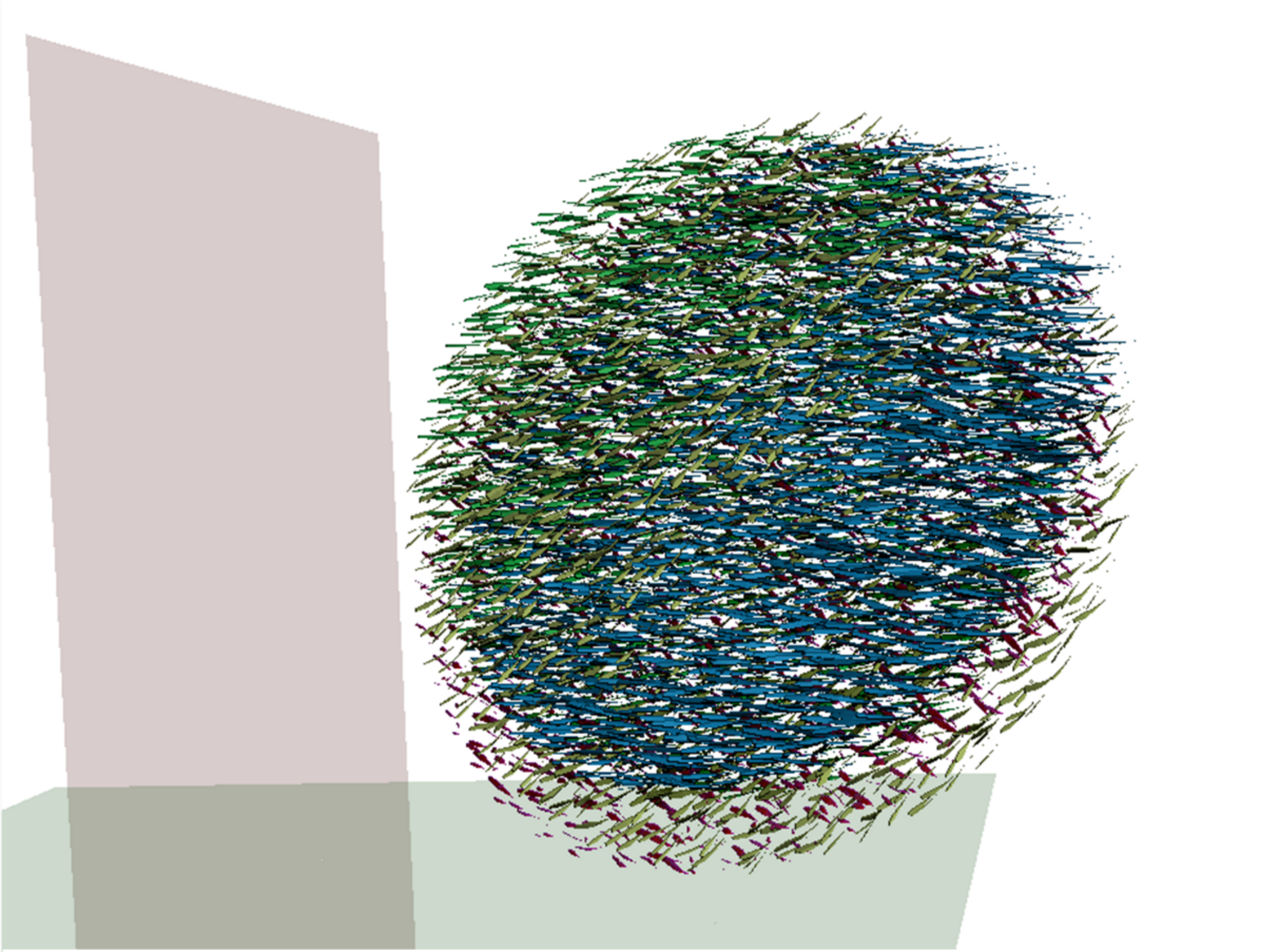


.3
.2
.1
.4
.1+.3+.4+.2 = 1

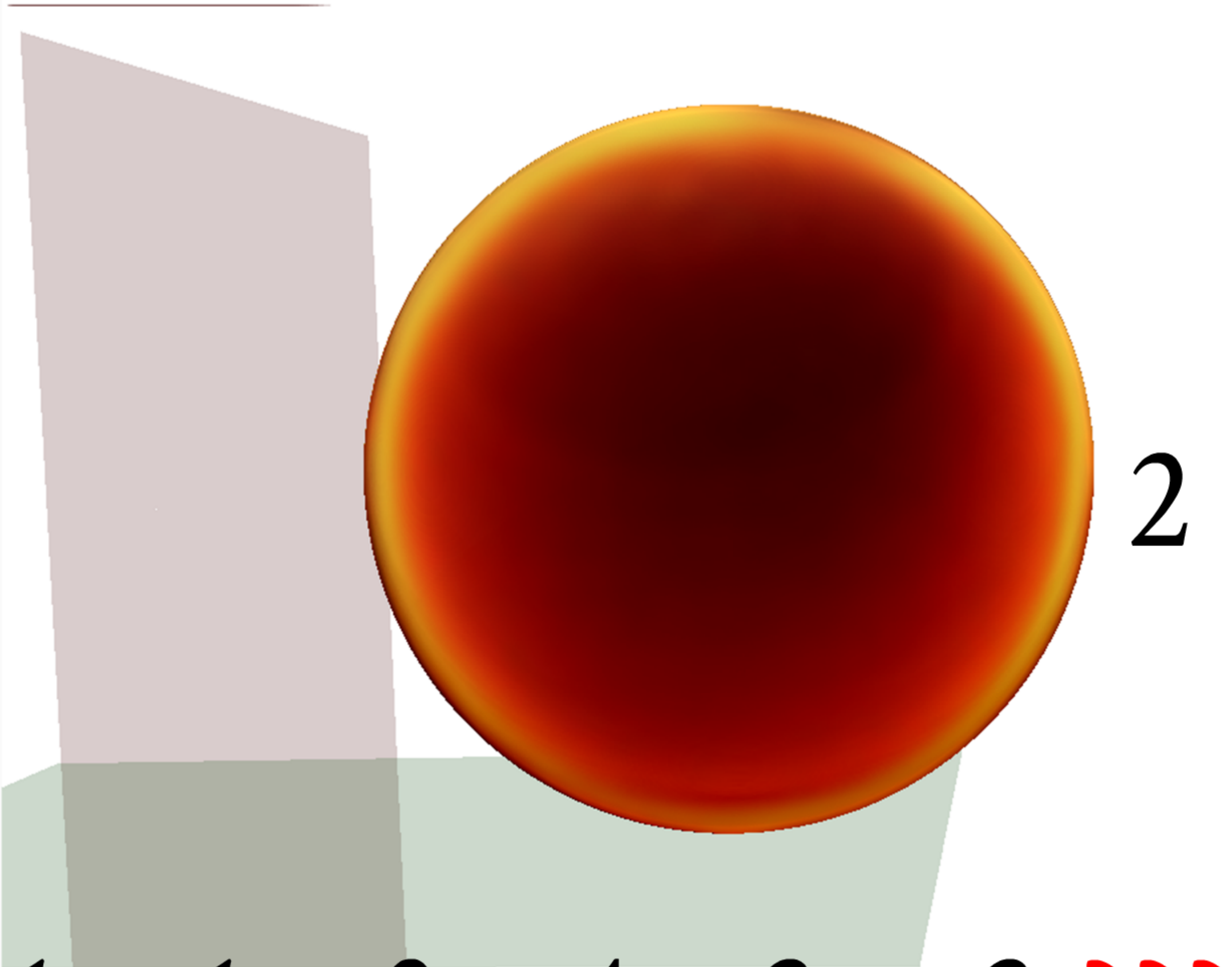


$$\varphi^{\pm 1} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{3} & \mp\frac{2\sqrt{2}}{3} \\ 0 & \pm\frac{2\sqrt{2}}{3} & \frac{1}{3} \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 3 & 0 & 0 \\ 0 & 1 & \mp 2\sqrt{2} \\ 0 & \pm 2\sqrt{2} & 1 \end{pmatrix}$$

$$\psi^{\pm 1} = \begin{pmatrix} \frac{1}{3} & \mp\frac{2\sqrt{2}}{3} & 0 \\ \pm\frac{2\sqrt{2}}{3} & \frac{1}{3} & 0 \\ 0 & 0 & 1 \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 1 & \mp 2\sqrt{2} & 0 \\ \pm 2\sqrt{2} & 1 & 0 \\ 0 & 0 & 3 \end{pmatrix}$$

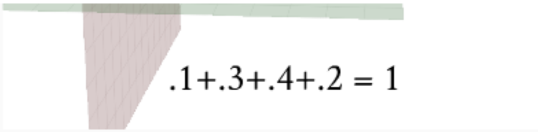


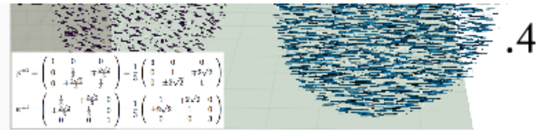
$$\mathfrak{F}(\varphi, \psi) = 1 \uplus \mathfrak{W}(\varphi) \uplus \mathfrak{W}(\varphi^{-1}) \uplus \mathfrak{W}(\psi) \uplus \mathfrak{W}(\psi^{-1})$$



$$1 = .1 + .3 + .4 + .2 = 2 \; ???$$

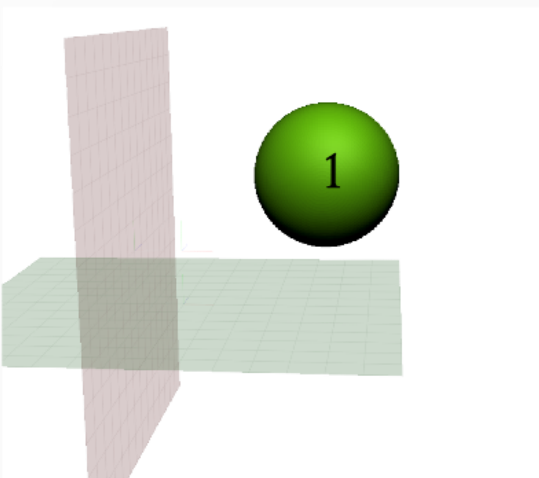
$) \uplus \mathfrak{W}(y^{-1})$

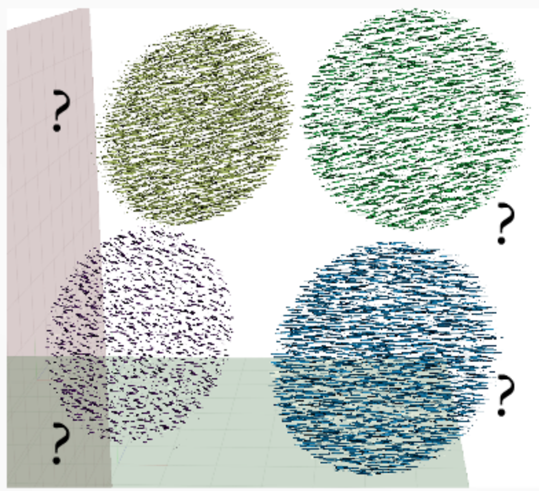


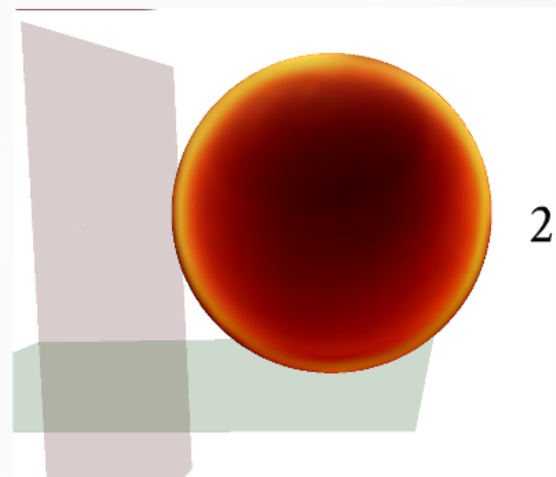


$\mathfrak{F}(\varphi, \psi) = 1 \uplus$

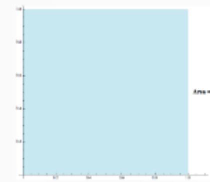
Did they break math? No!



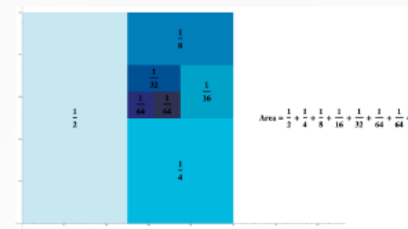




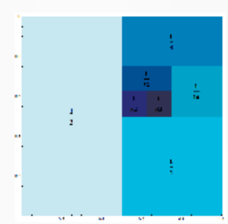
~~Any set of points should have an area.~~

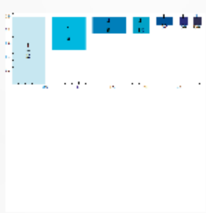


The cutting an object into pieces should not changes its area.



Moving or rotating an object should not change its area.





What is Area?

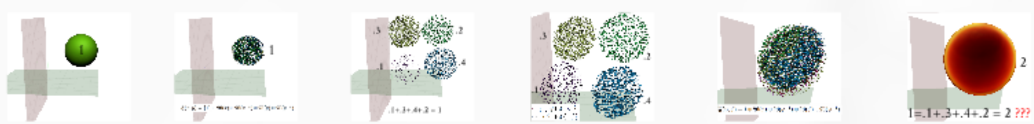
What properties should it have?

~~Any set of points should have an area.~~

The cutting an object into pieces should not changes its area. 

Moving or rotating an object should not change its area. 

The Banach Tarski paradox - The Pea and The Sun



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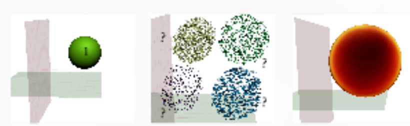


Prezi

The pea and the sun

Area

Young man, in mathematics you don't understand things, you just get used to them.

-John von Neumann

What is area?

What is life?

Breathes

Consumes energy

Grows

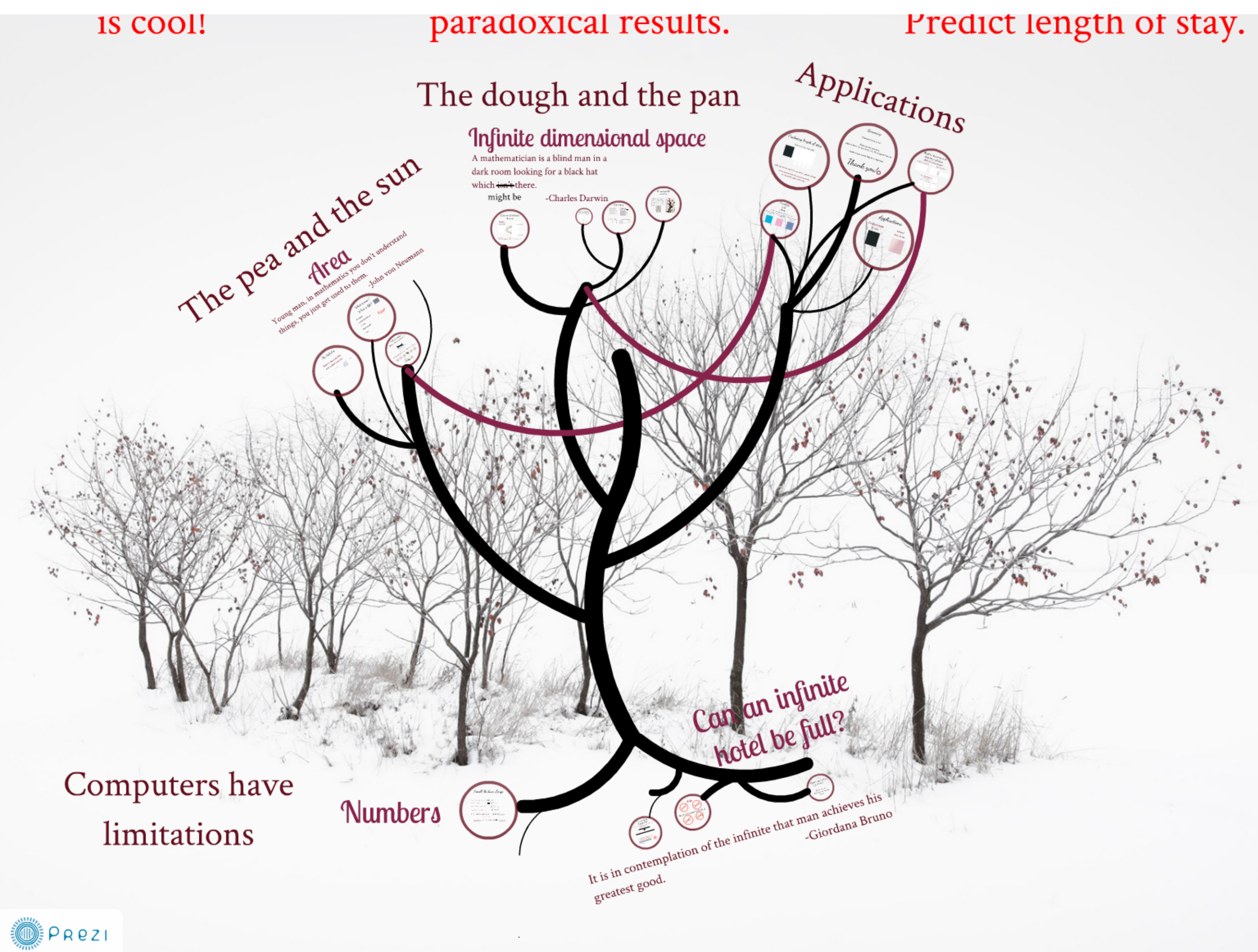
Reproduces

Dies

Fire?

The Calculus

How to measure the area under a curve?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Predict length of stay.
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Infinite dimensional space
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Thank you!

Infinite dimensional space

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might be

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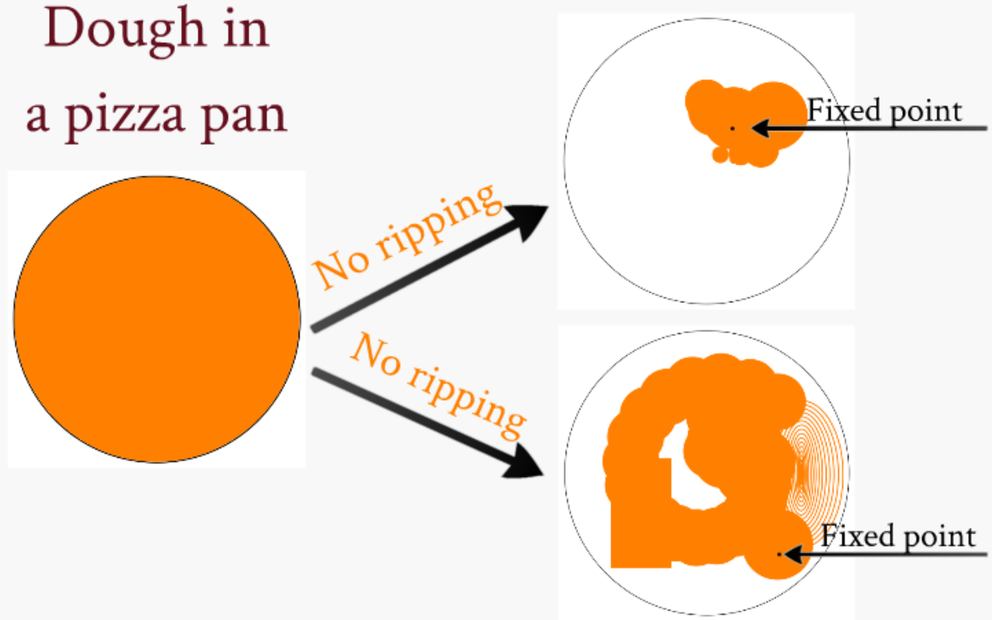
Brouwer's fixed point theorem

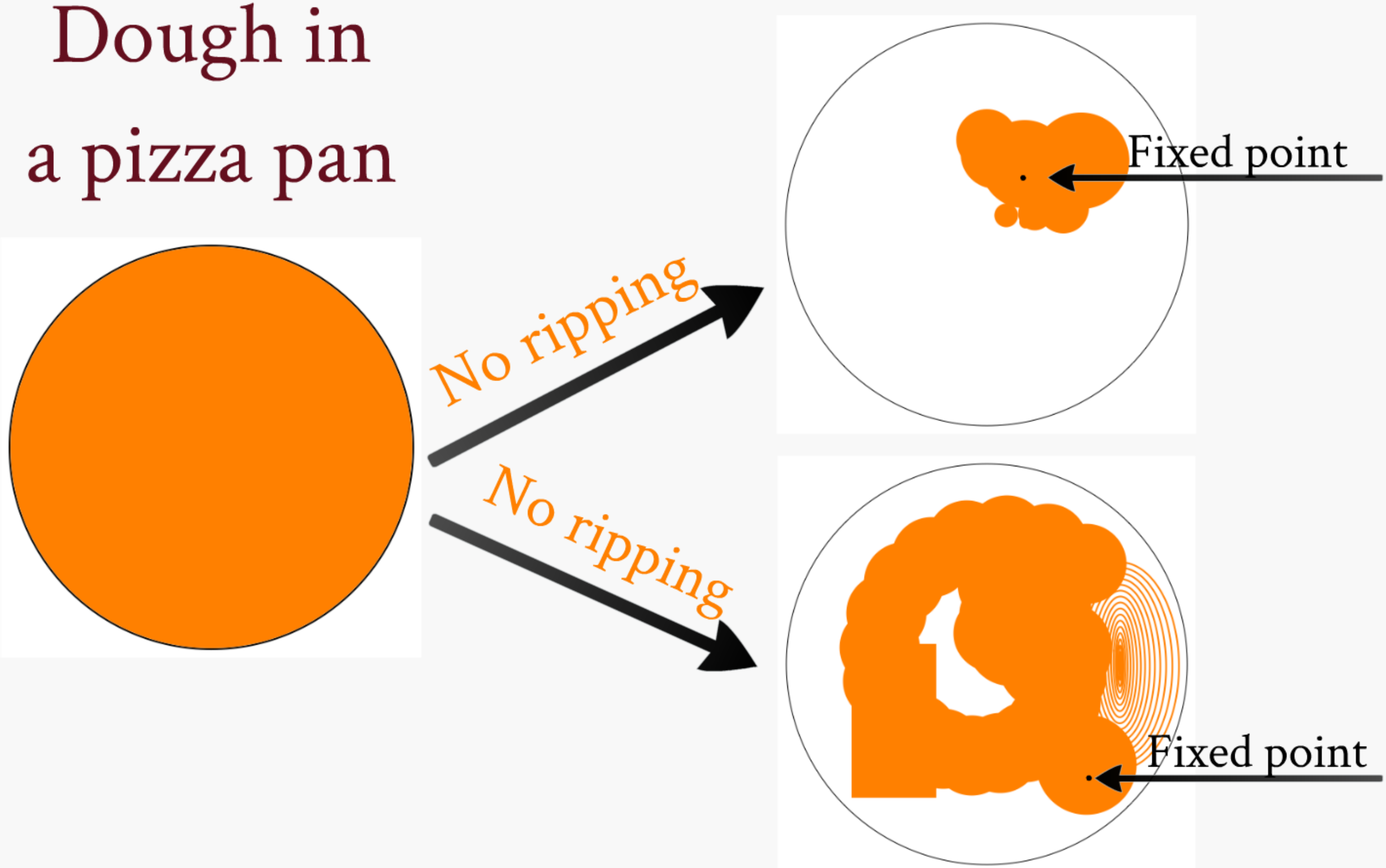
Dough in
a pizza pan



Theorem: each continuous map of the disk to itself has a fixed point.

In any dimension!

Dough in
a pizza pan



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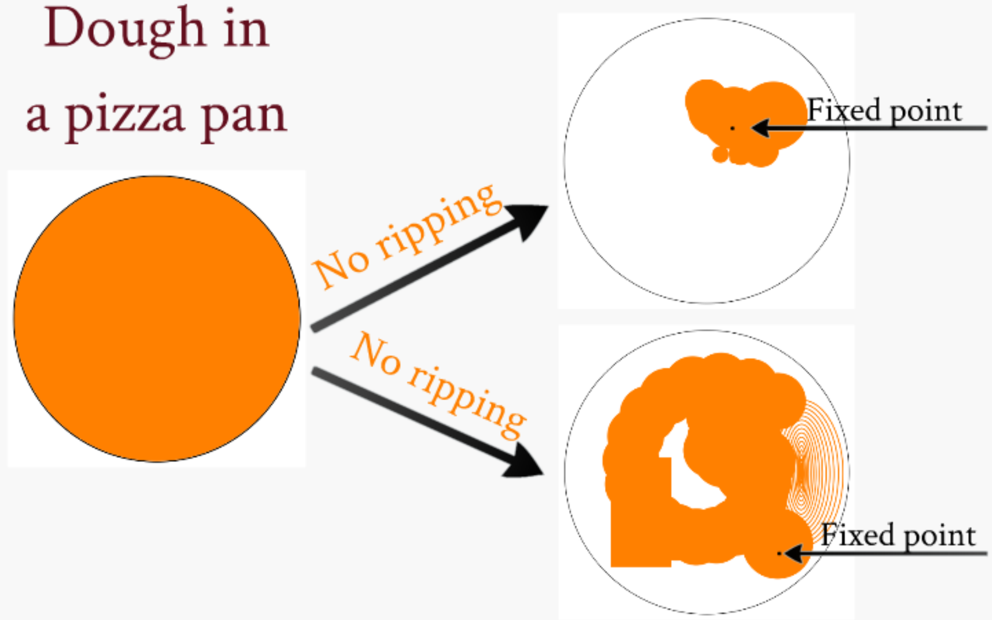

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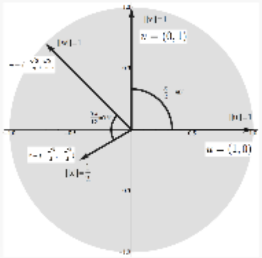
Hilbert Space

Two dimensional space

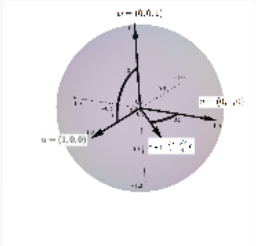


1. Vectors
2. Angles
3. Lengths

Geometry

Three dimensional space

A mathematician is a machine for converting coffee into theorems. ~~Paul Erdos~~ -Alfred Renyi



1. Vectors
2. Angles
3. Lengths

Geometry

n-dimensional space

(n = 7)

$u = (1, 0, 0, 0, 0, 0, 0)$ $||u|| = 1$

$v = (0, 0, 0, 0, 0, 1, 0)$ $||v|| = 1$

$w = (0, 0, \frac{\sqrt{2}}{2}, 0, 0, \frac{\sqrt{2}}{2}, 0)$ $||w|| = 1$

$x = (-\frac{\sqrt{2}}{4}, 0, 0, 0, 0, 0, \frac{1}{4})$ $||x|| = 1/2$

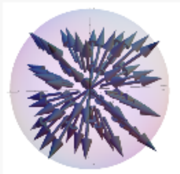
Angles between vectors

<u,v> = 0

<v,w> = 1/2

<w,x> = 0

Infinite dimensional space



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<u,v> = 0

<v,w> = 1/16

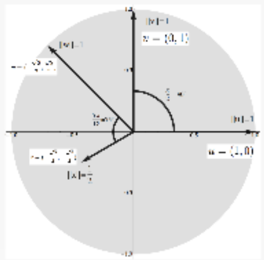
The unit sphere is the set of all vectors x with length 1:

$$||x|| = 1$$

Prezi

Hilbert Space

Two dimensional space



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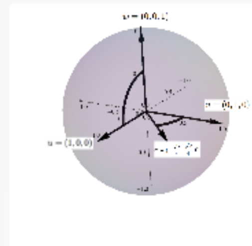

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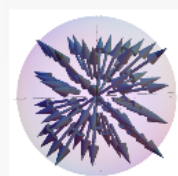
Infinite dimensional space



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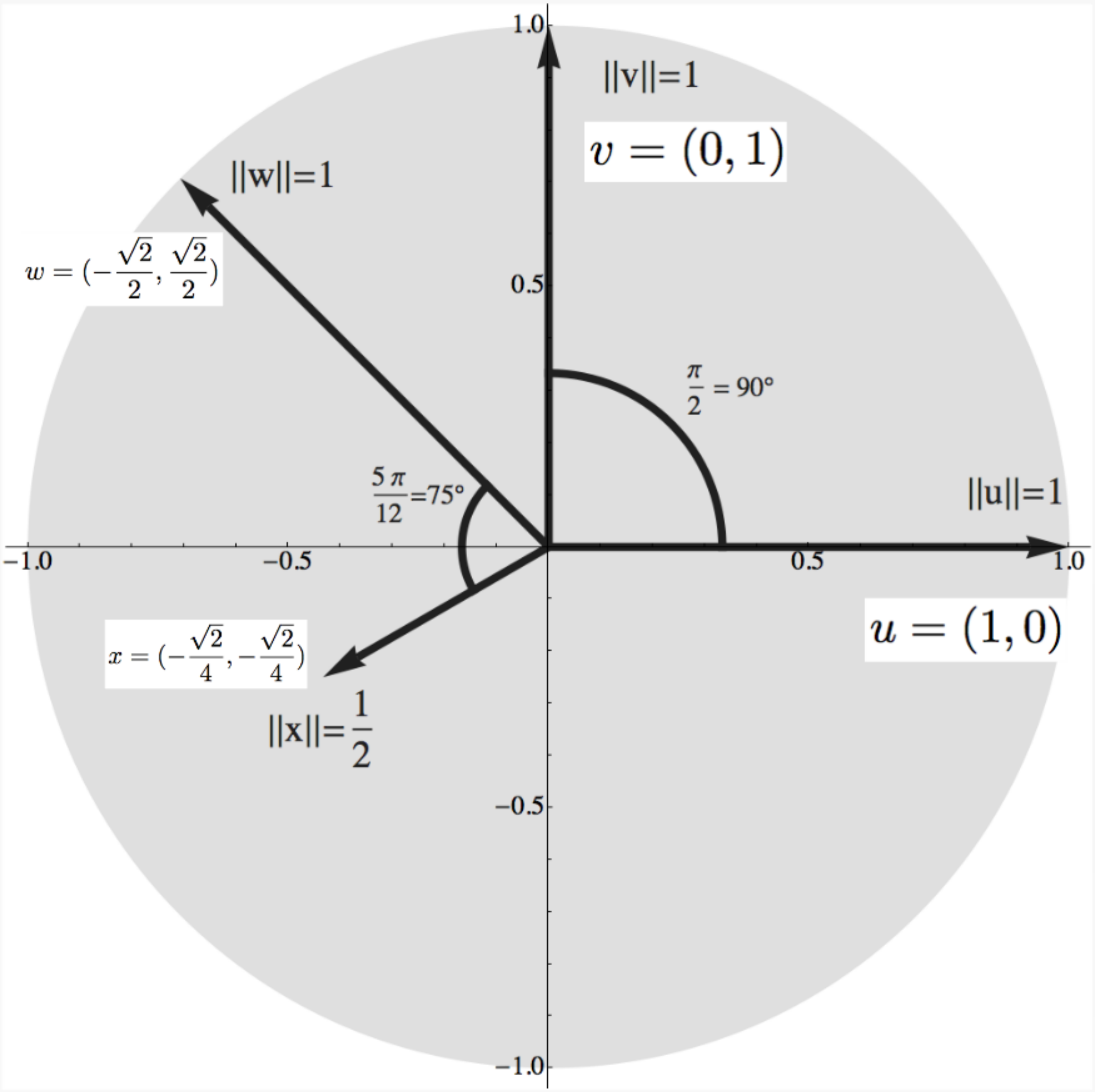

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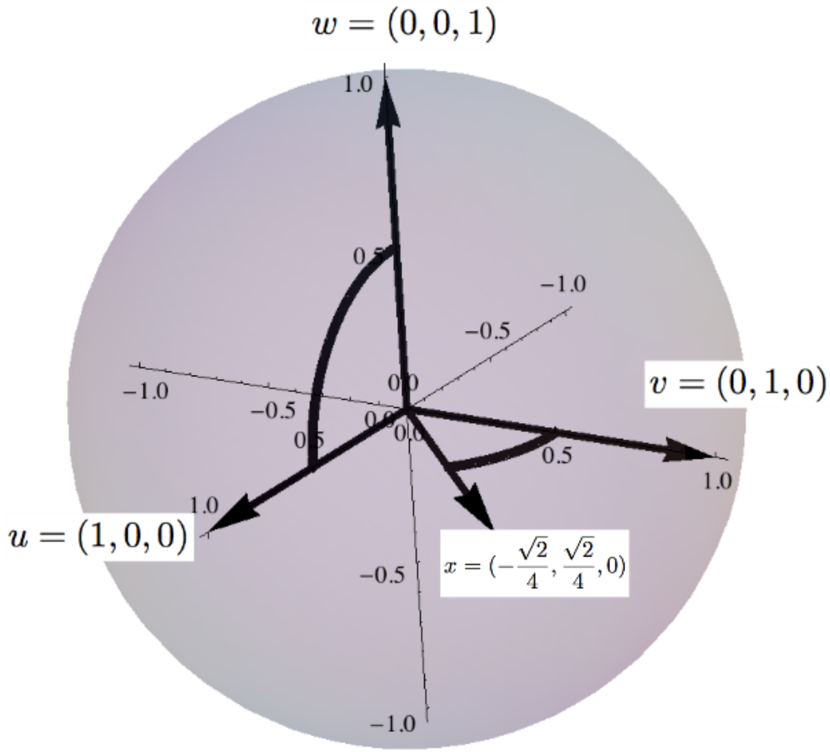

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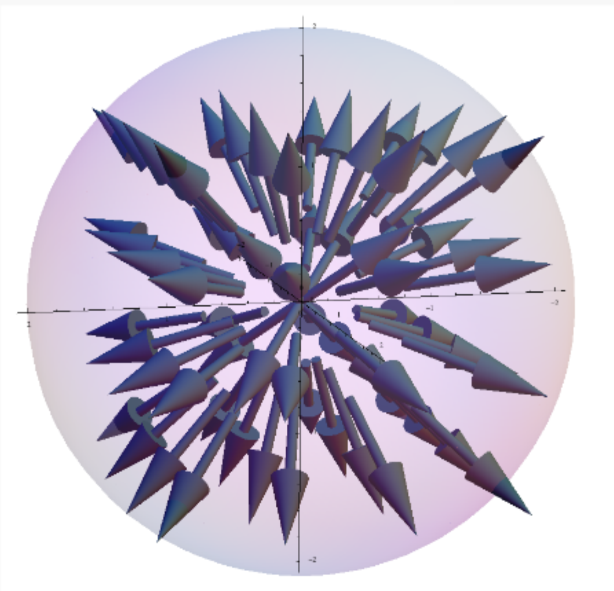

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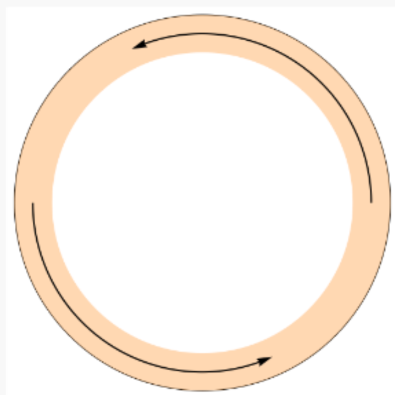
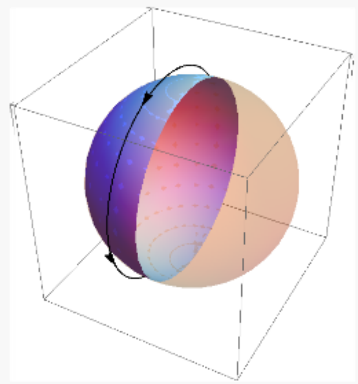
Brouwer's Theorem in infinite dimensional space

If we could break the rules



In infinite dimensional space we don't have to



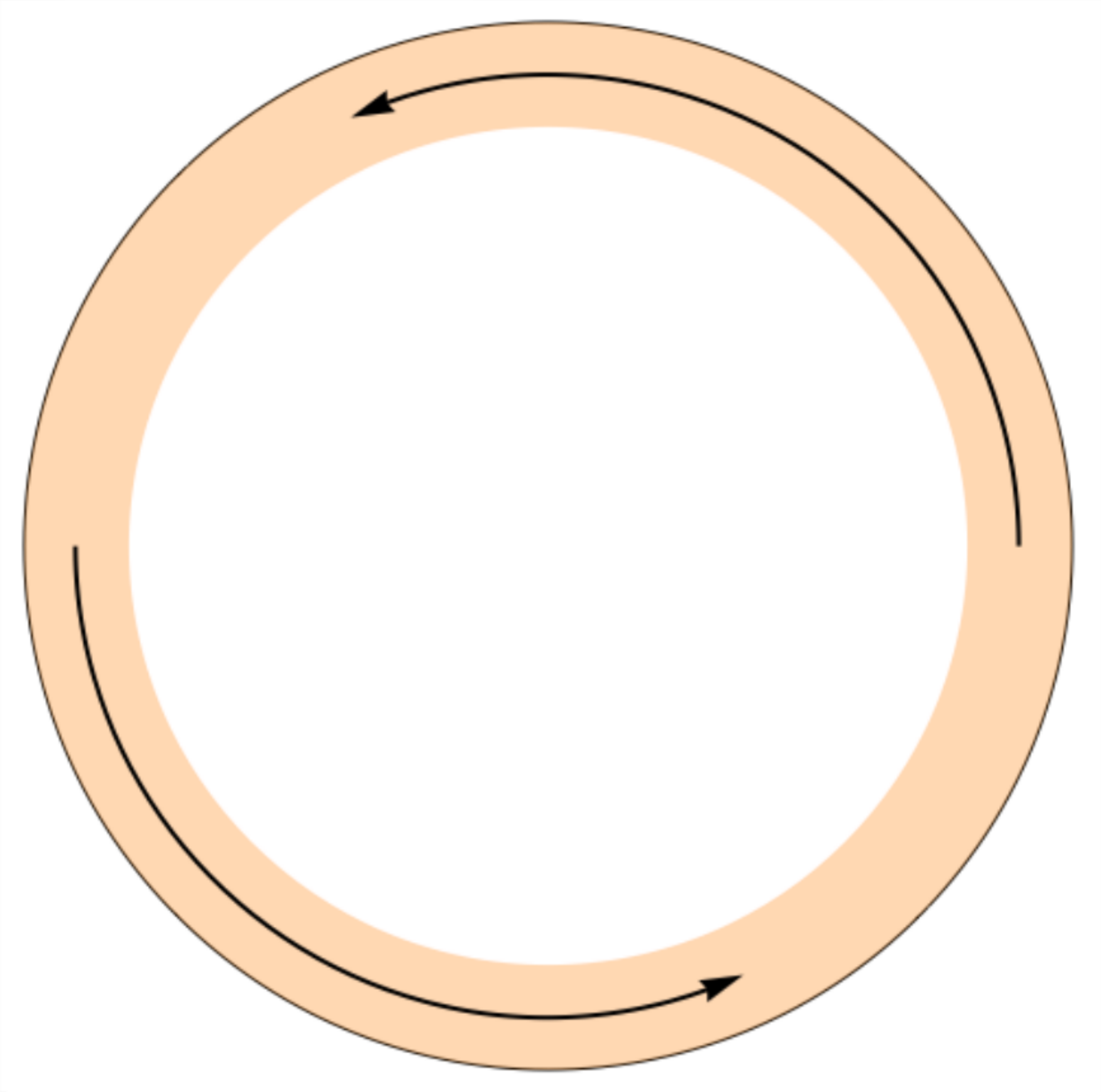
How?

$$x = (x_1, x_2, x_3, x_4, x_5, \ldots) \rightarrow (\sqrt{1 - ||x||^2}, x_1, x_2, x_3, x_4, \ldots)$$

$x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5$

Familiar?

If we could break the rules



Brouwer's Theorem in infinite dimensional space

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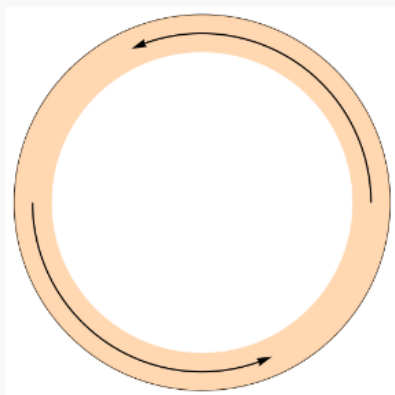

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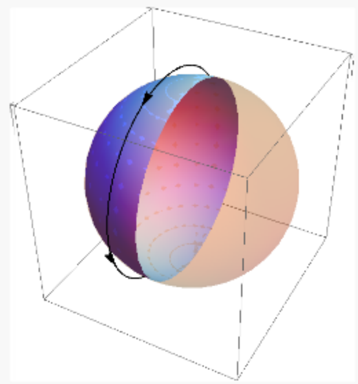

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ules

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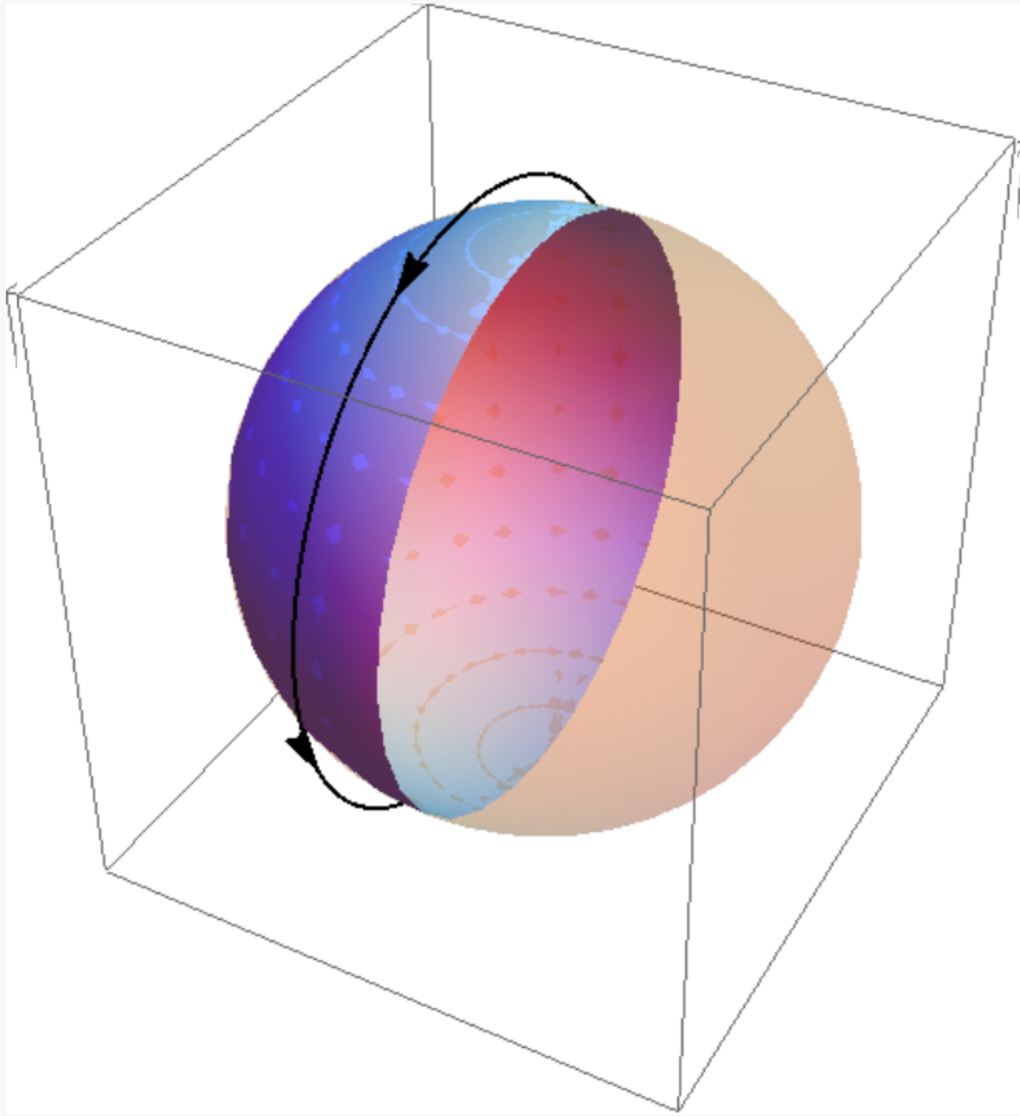

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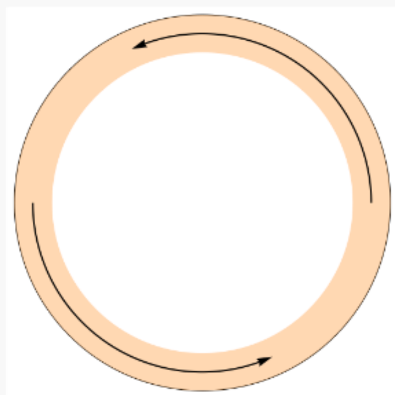

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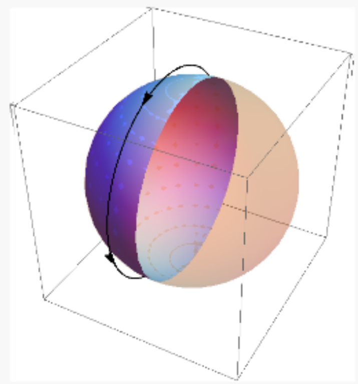

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Familiar?

Brouwer's Theorem in infinite dimensional space

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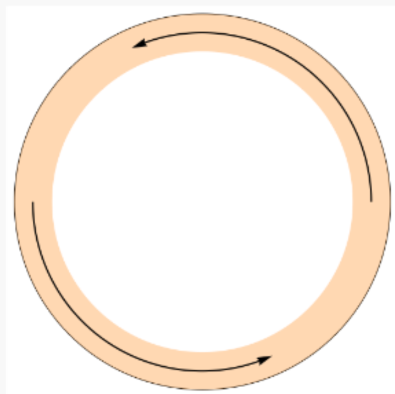

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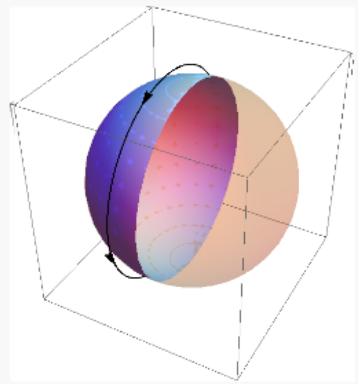

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Familiar?

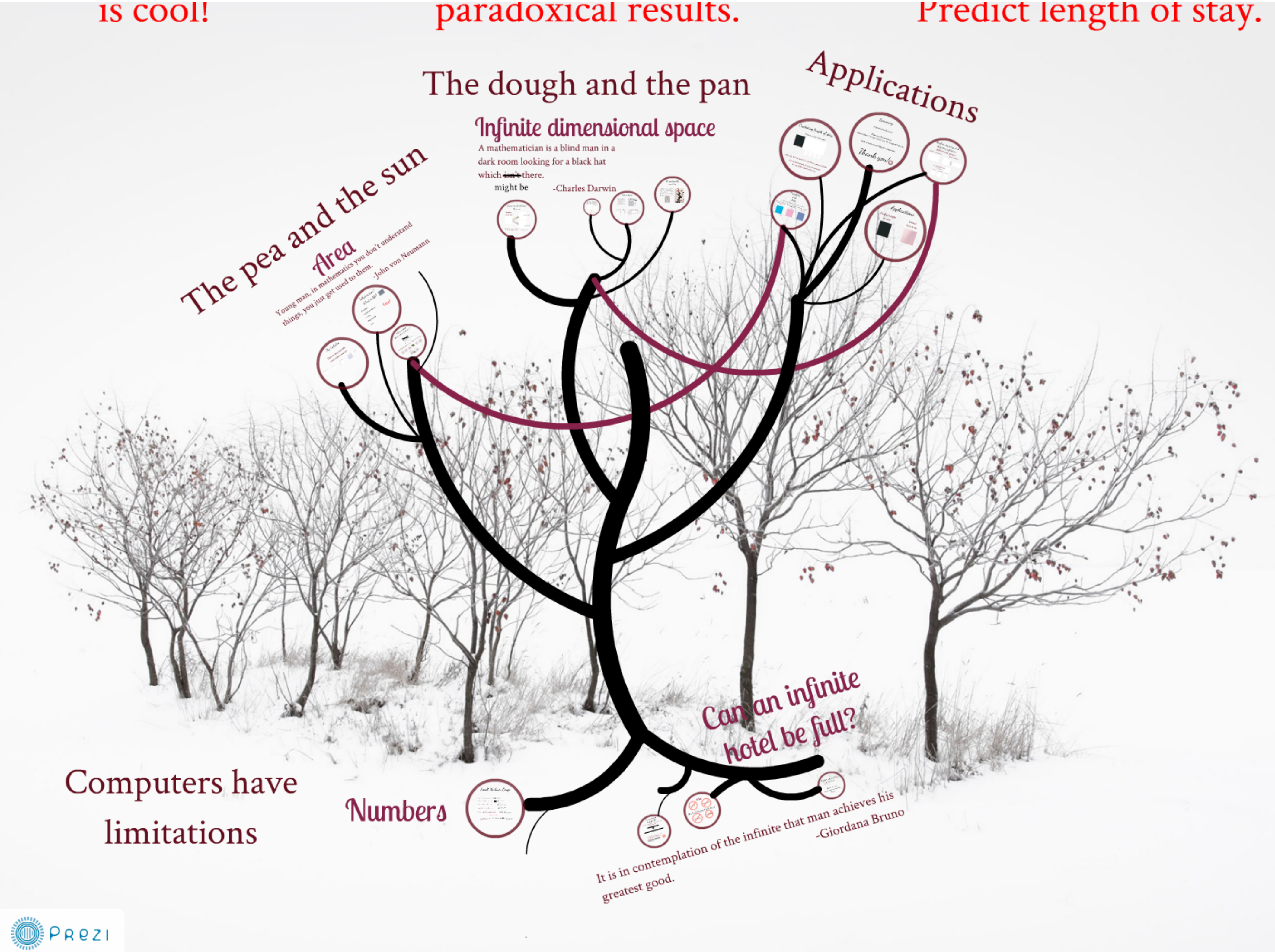
Infinite dimensional space

A mathematician is a blind man in a dark room looking for a black hat which ~~isn't~~ there.

might be

-Charles Darwin

Prezi



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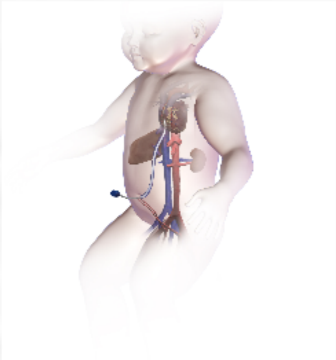
Numbers
Computers have limitations


Summary
Theoretical math is cool!
Three apparant paradoxes:
Hilbert's Hotel, The pea and the sun, The dough and the pan.
Predict length of stay. Help detect infections.
Thank you!
Machine learning and
detecting infection
IBM Artemis project
Prediction/Classification
Higher dimensions
How many dimensions
are enough?
Predicting length of stay
Back surgery for chronic pain
Although we can never be sure about a specific patient.
Given information about many patients,
we can make some predictions.
Probability
and
Area
1654 letter from Blaise Pascal to Pierre de Fermat
Applications
Predict length
of stay
Detect
infections
Prezi

Applications

Predict length of stay

Detect infections



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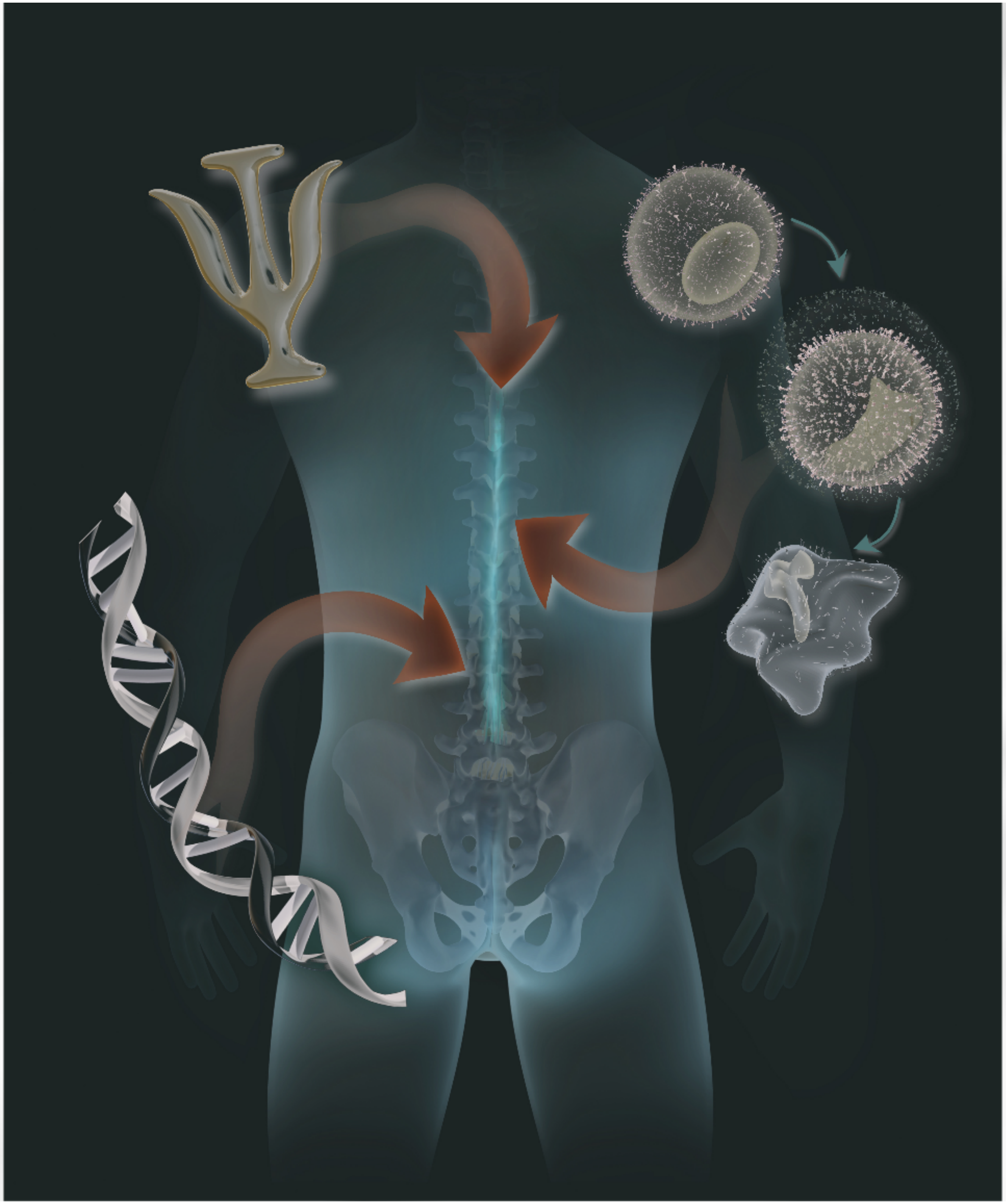
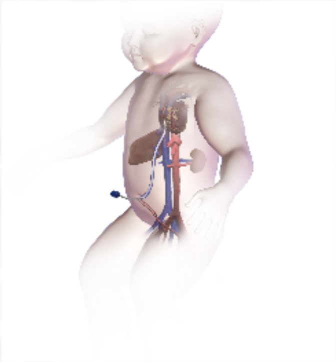


Applications

Predict length of stay

Detect infections

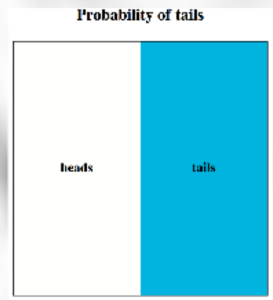


Probability and Area

1654 letter from Blaise Pascal to Pierre de Fermat

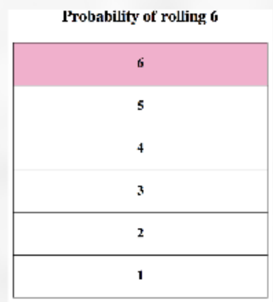
What is the probability that a fair coin will land tails?

1/2



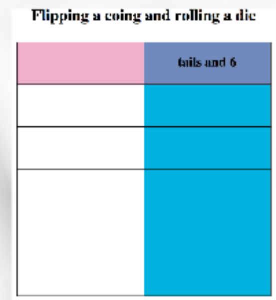
What is the probability that a fair die will land on 6?

1/6



What is the probability of both tails and a 6?

1/2*1/6=1/12



Area

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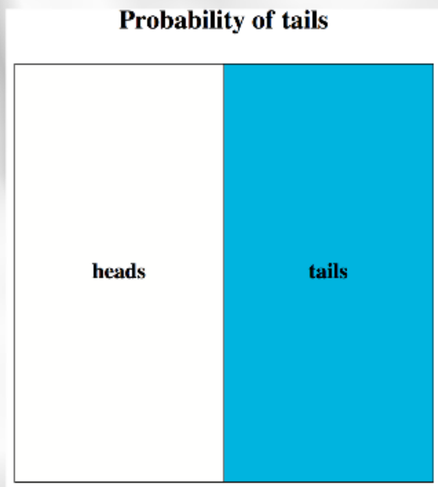

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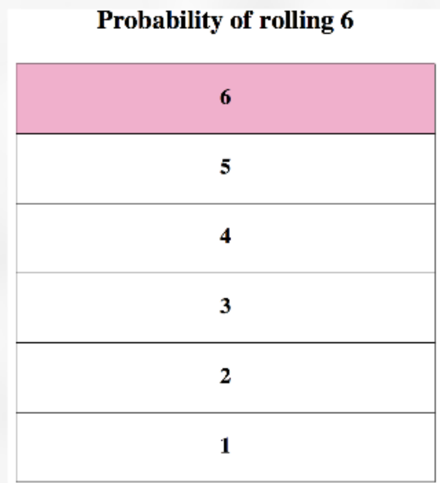

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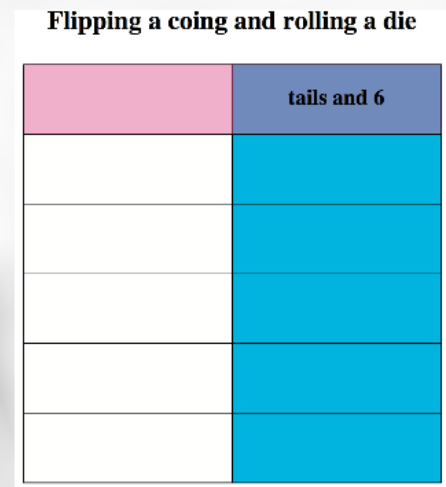

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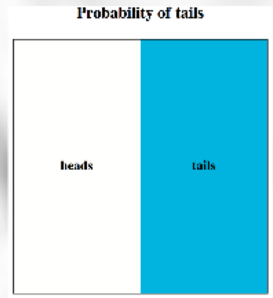

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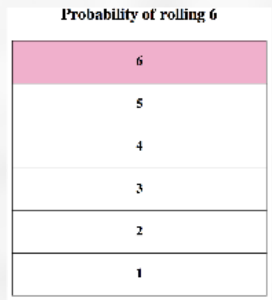

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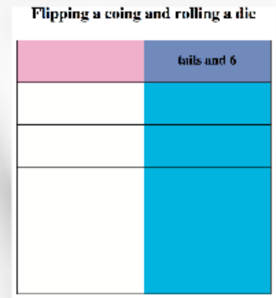
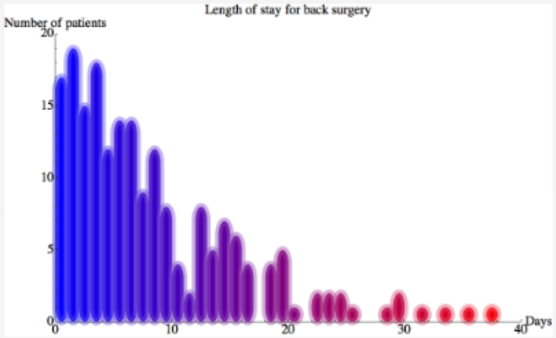


Hill

Predicting length of stay

Back surgery for chronic pain



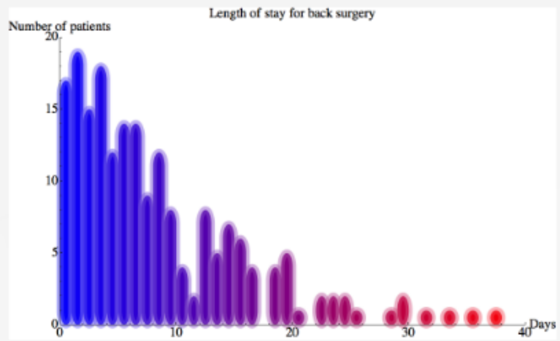
Although we can never be sure about a specific patient.

Given information about many patients,
we can make some predictions.

Hil

Predicting length of stay

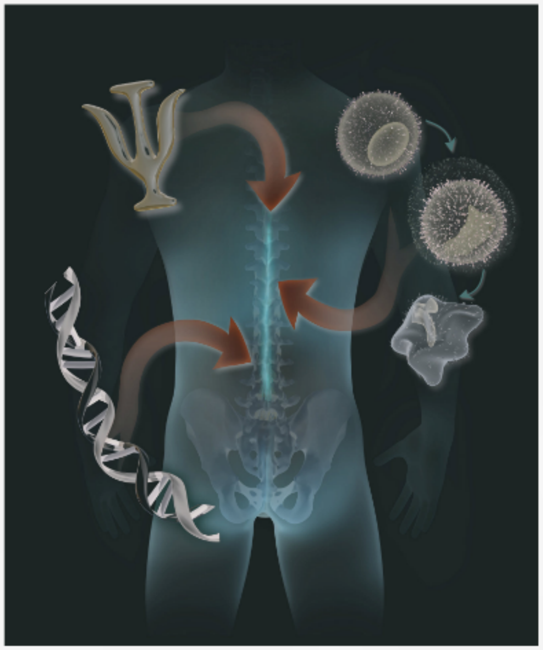
Back surgery for chronic pain

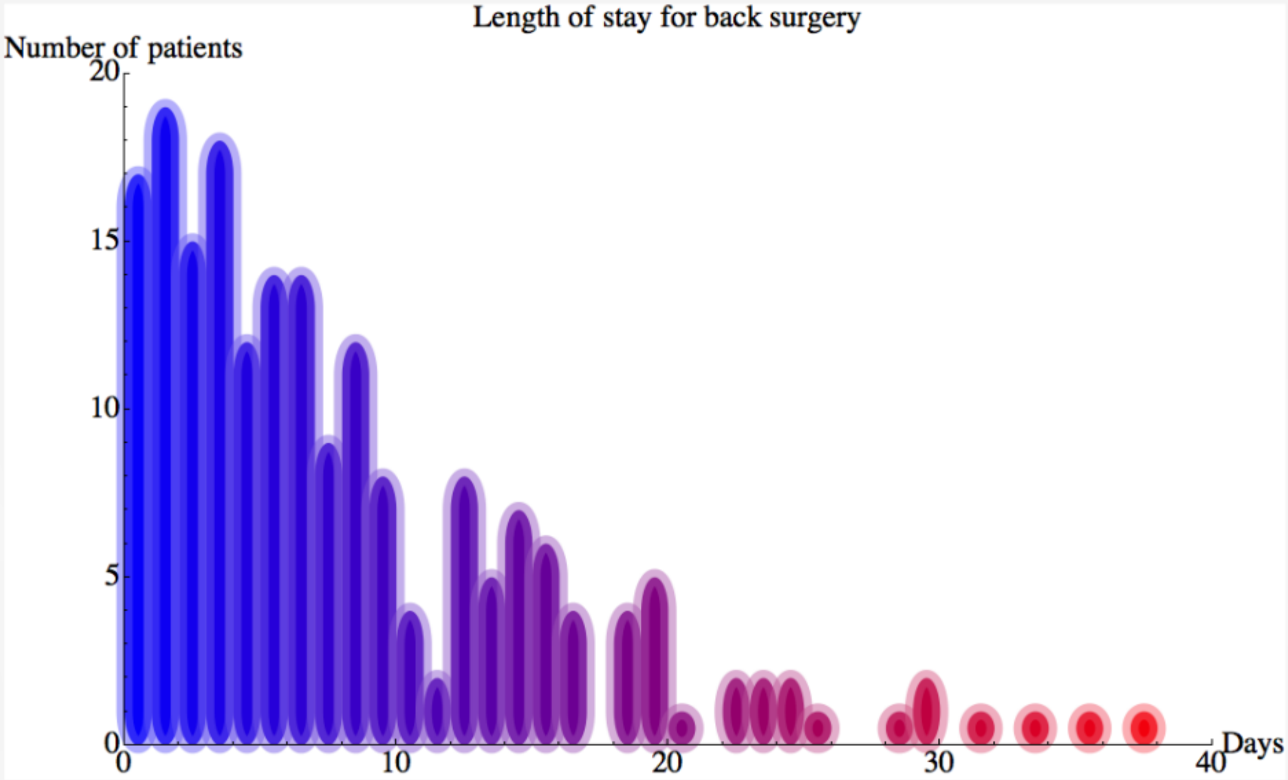


Although we can never be sure about a specific patient.

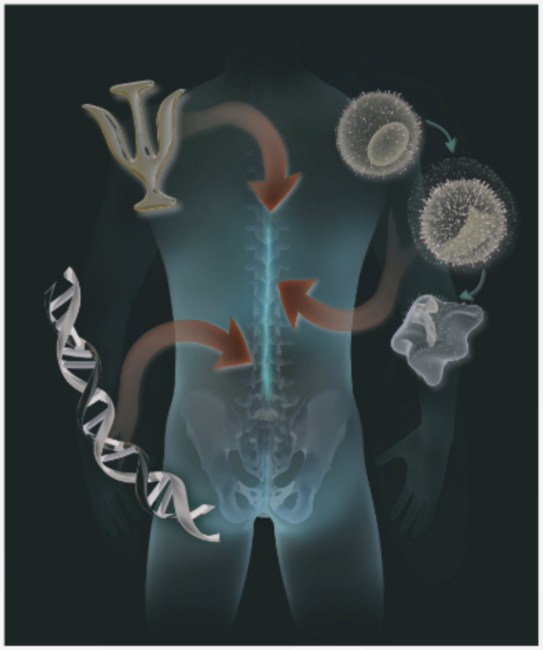
Given information about many patients,
we can make some predictions.

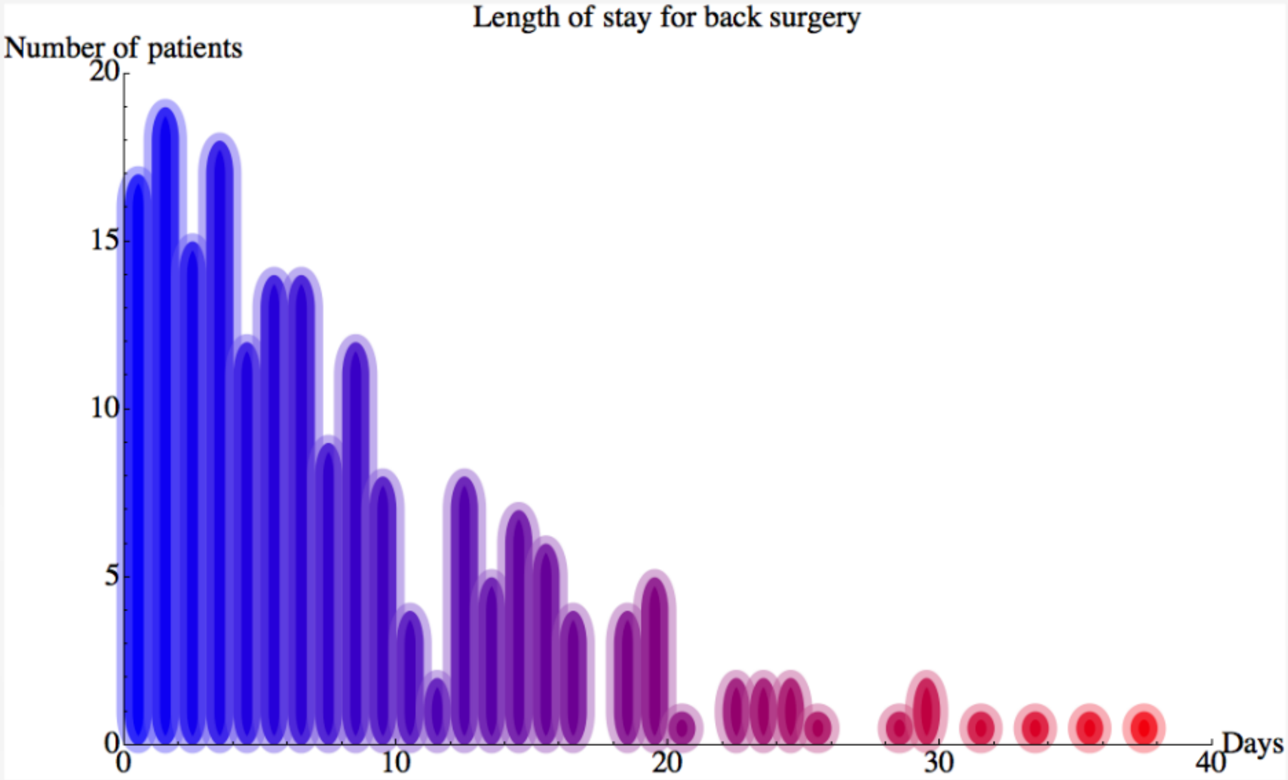
Back surgery for chronic pain





Back surgery for chronic pain

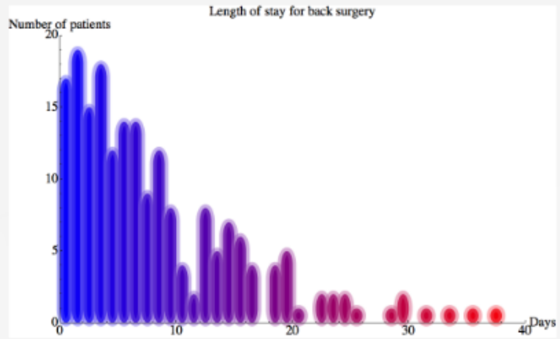




Hill

Predicting length of stay

Back surgery for chronic pain



Although we can never be sure about a specific patient.

Given information about many patients,
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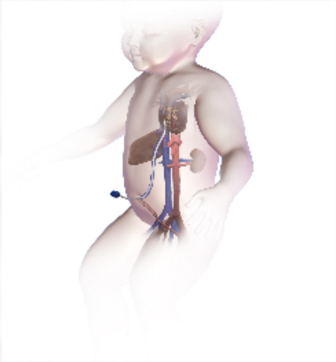
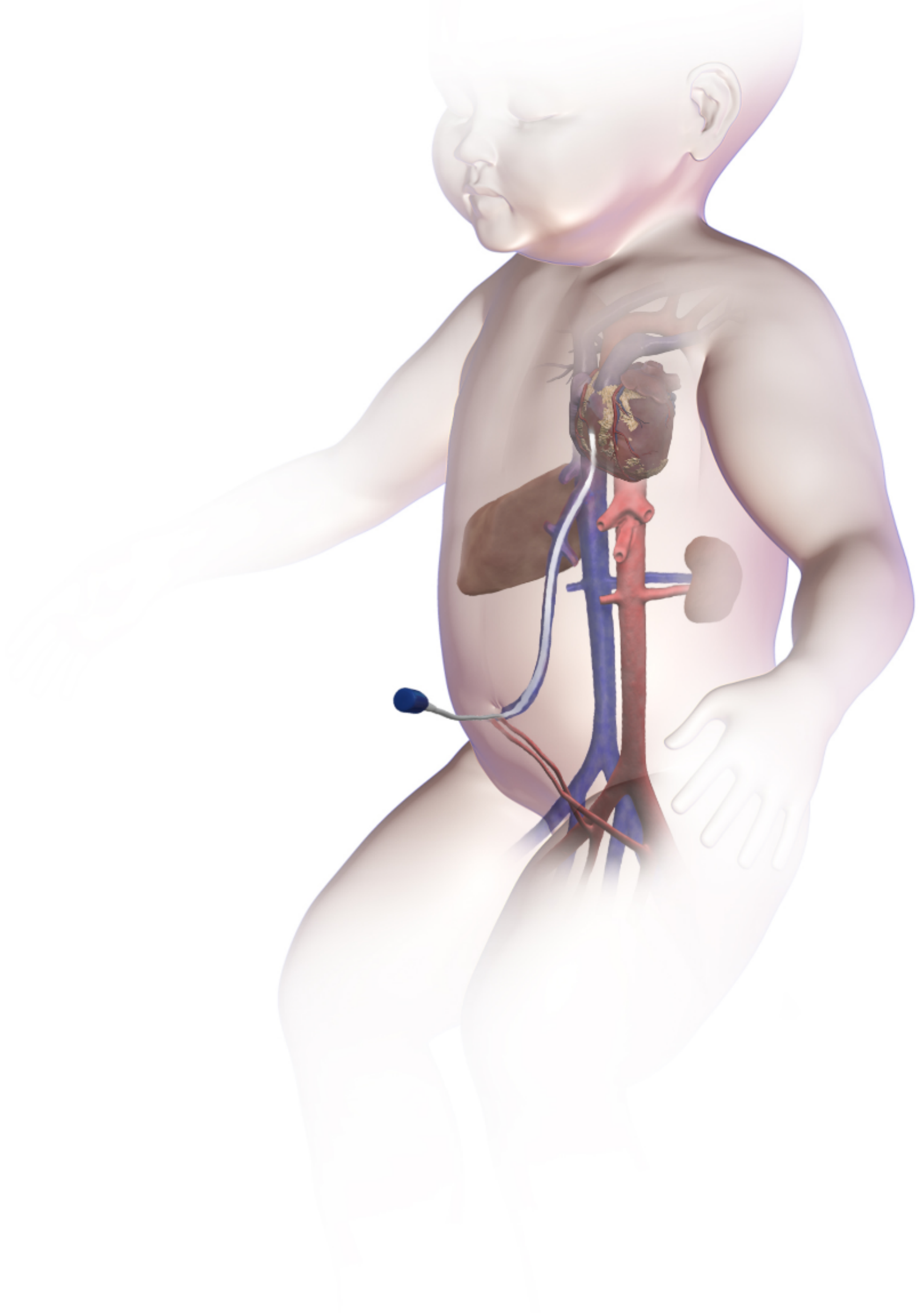
Applications

Predict length of stay

Detect infections

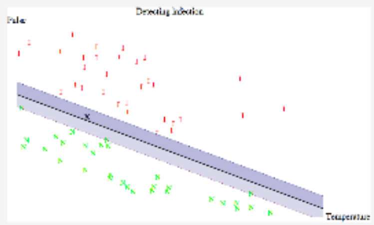




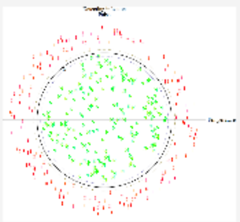
Machine learning and detecting infection

IBM Artemis project

Prediction/Classification

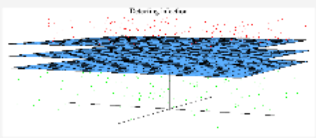


Higher dimensions

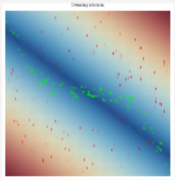


kernel

result



How many dimensions are enough?



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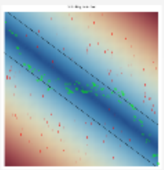
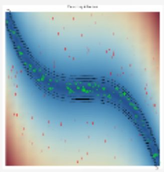
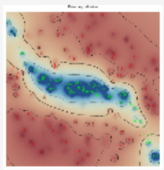


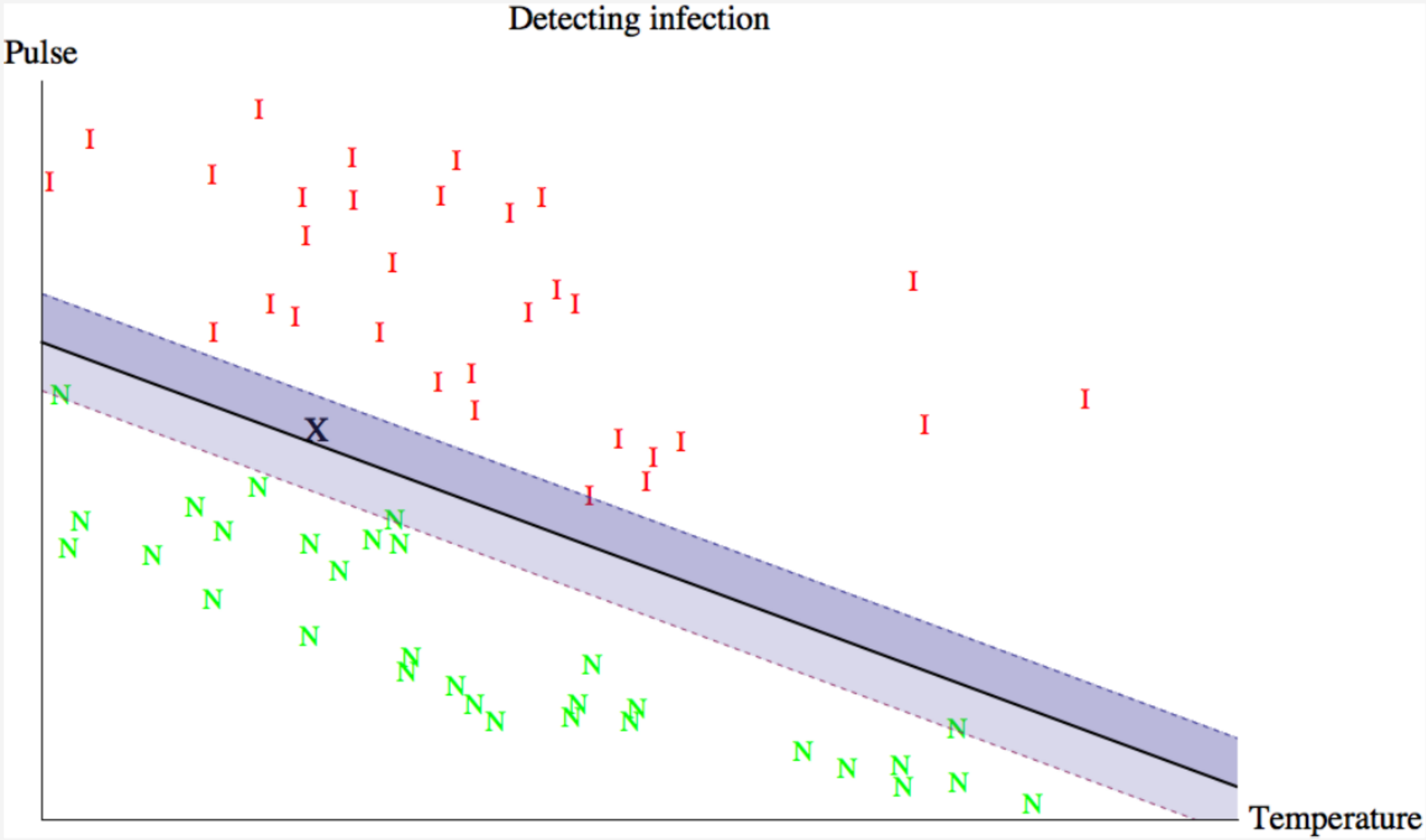
Infinitely many!



Too many?



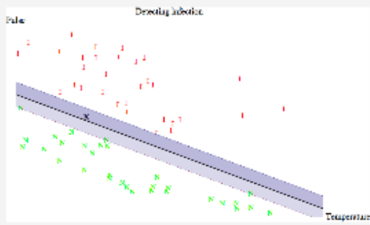
Prediction/Classification



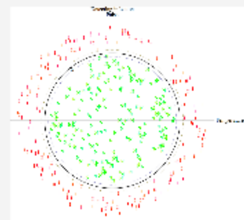
Machine learning and detecting infection

IBM Artemis project

Prediction/Classification

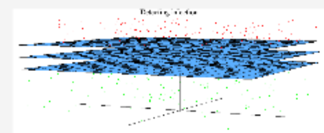


Higher dimensions



kernel →

result ←



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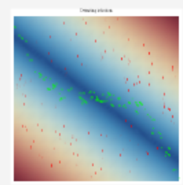

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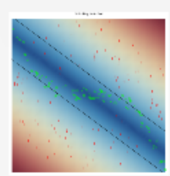

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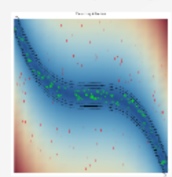

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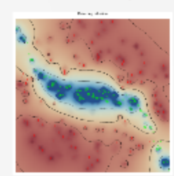
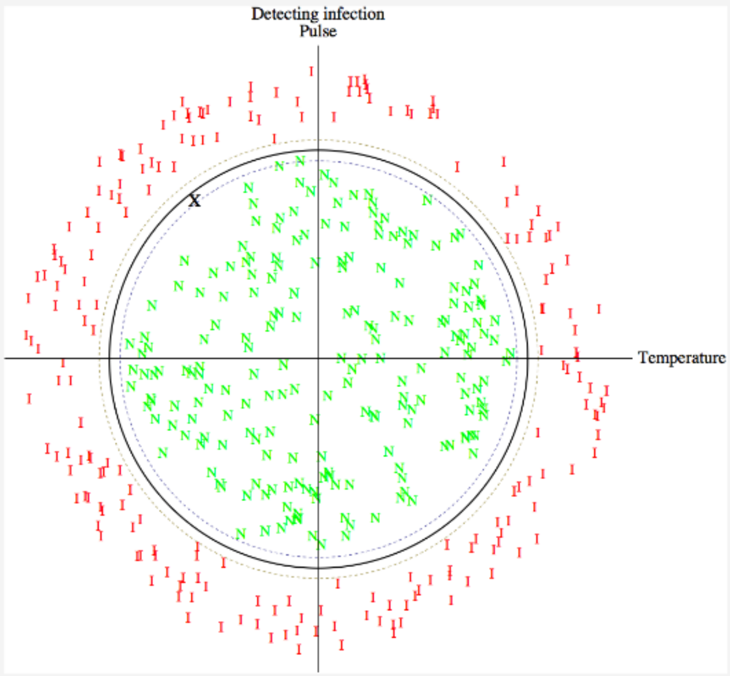


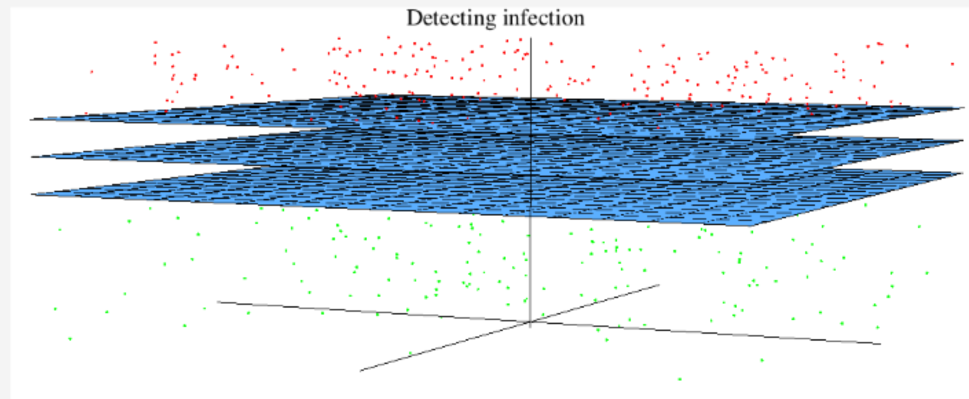
emis project

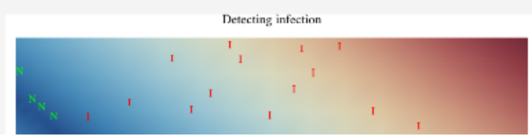
Higher dimensions



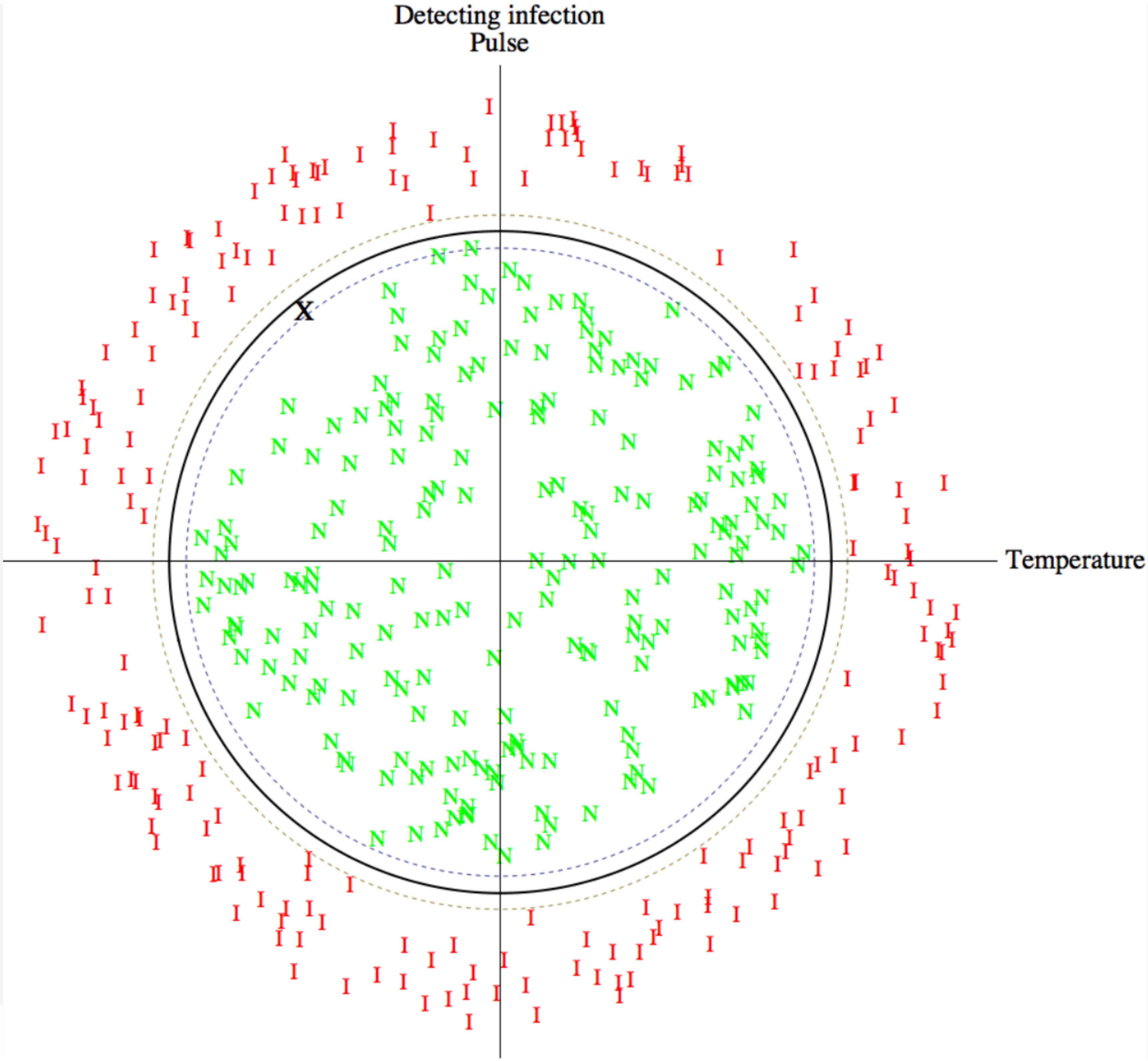
kernel

result





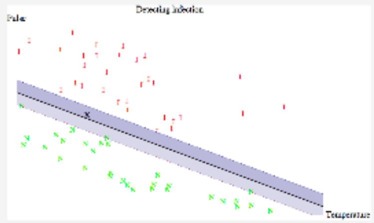
Prezi


Detecting infection
Pulse
Temperature
X
Prezi

Machine learning and detecting infection

IBM Artemis project

Prediction/Classification



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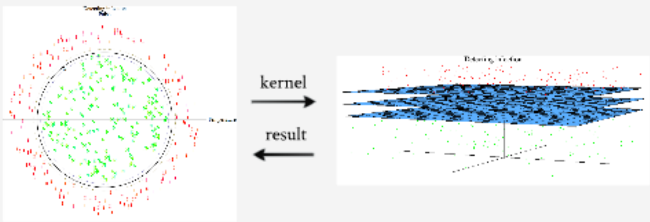

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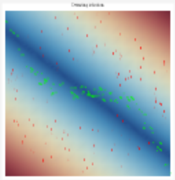

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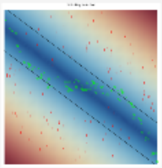
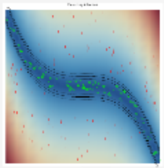


Infinitely many!



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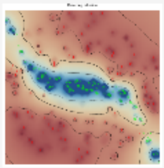
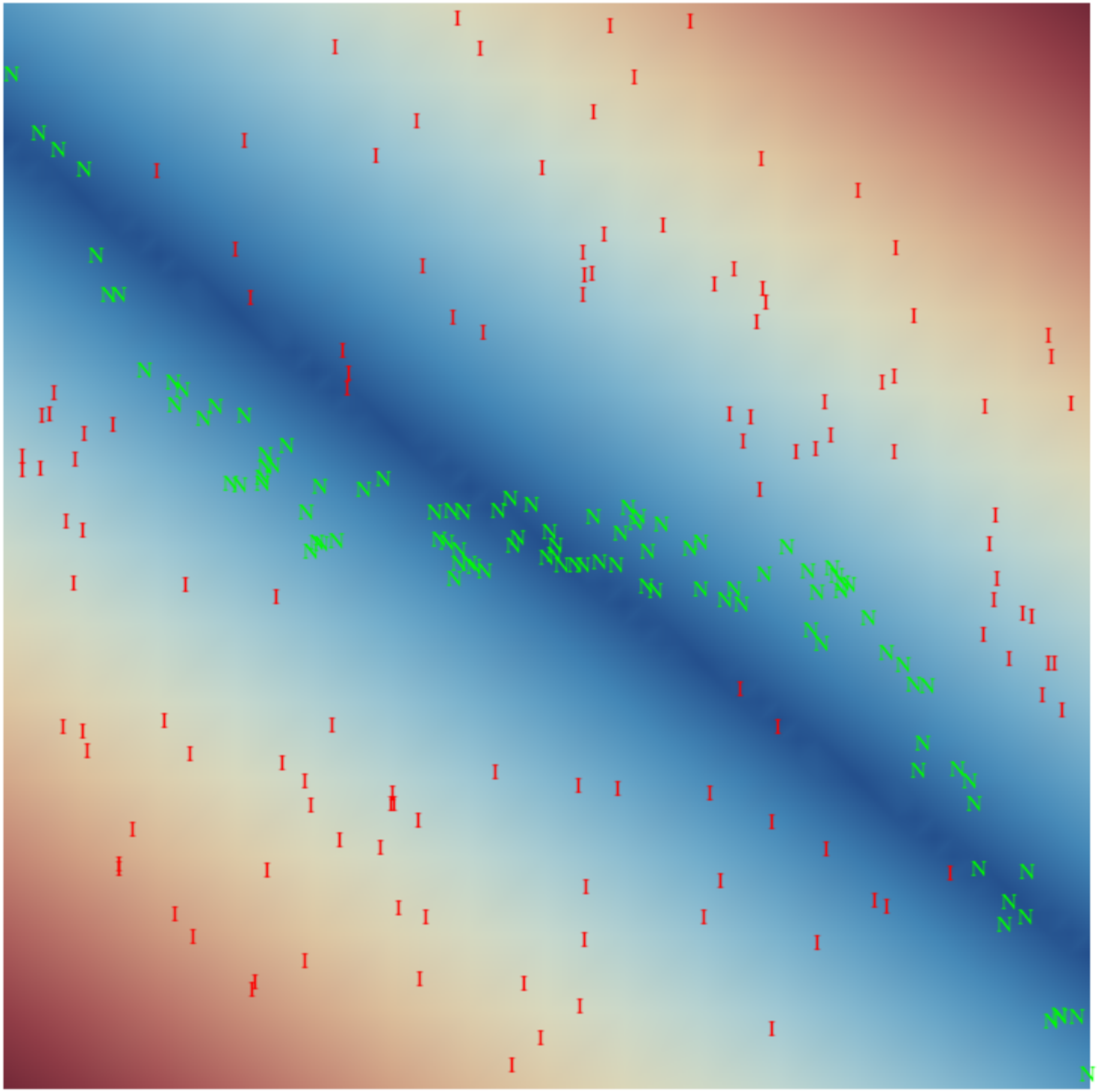


Detecting infection



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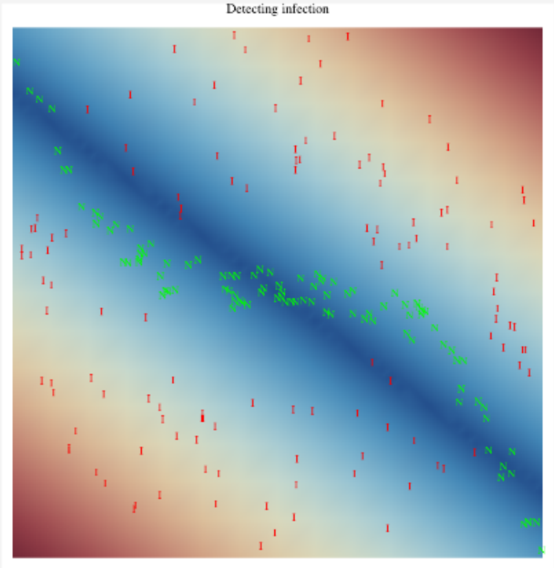

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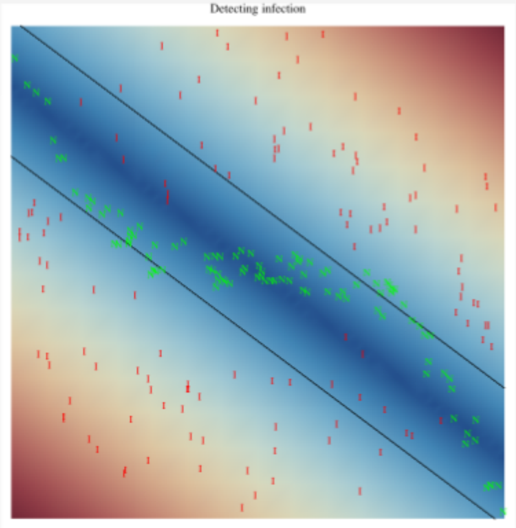

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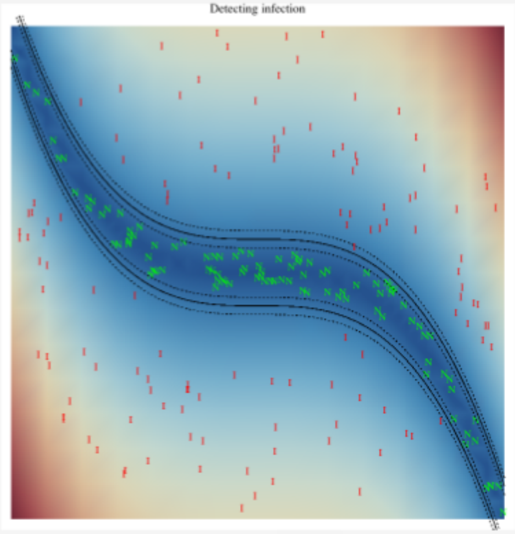

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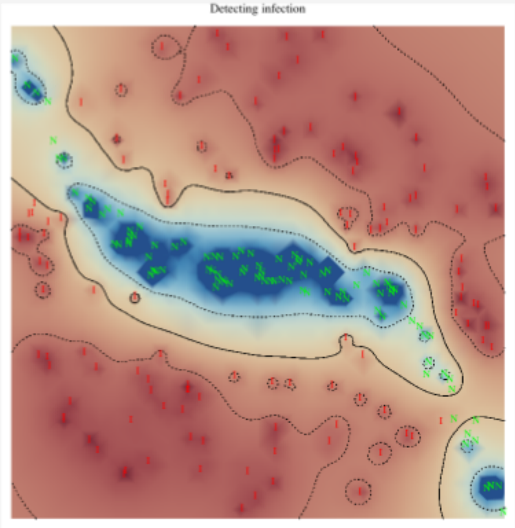
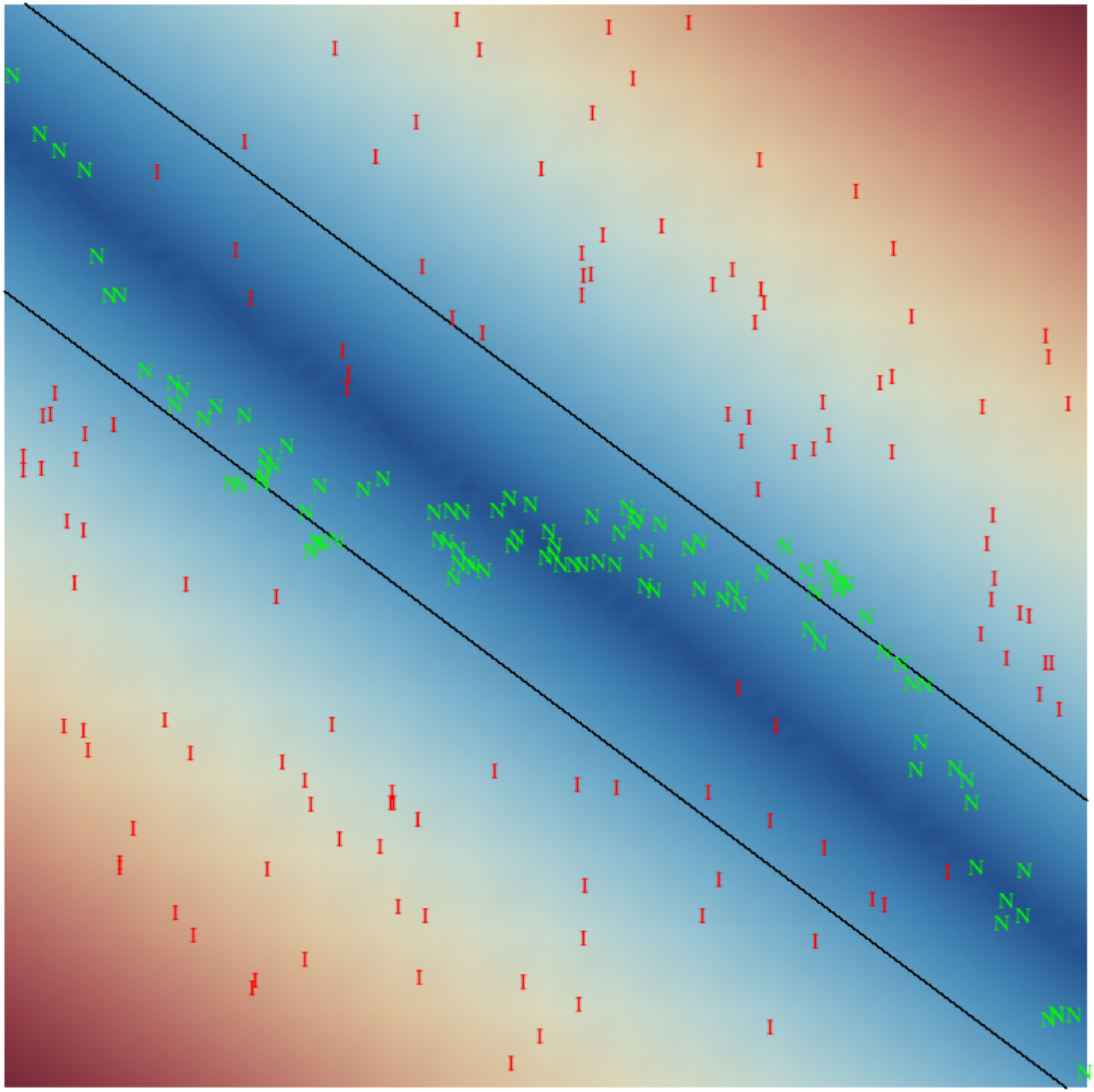


Detecting infection



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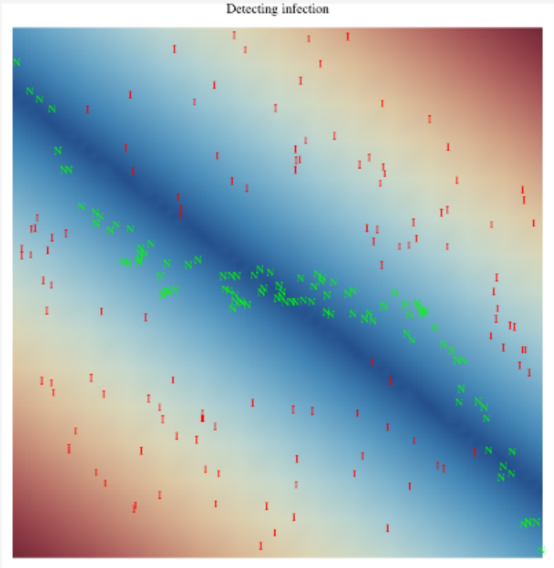

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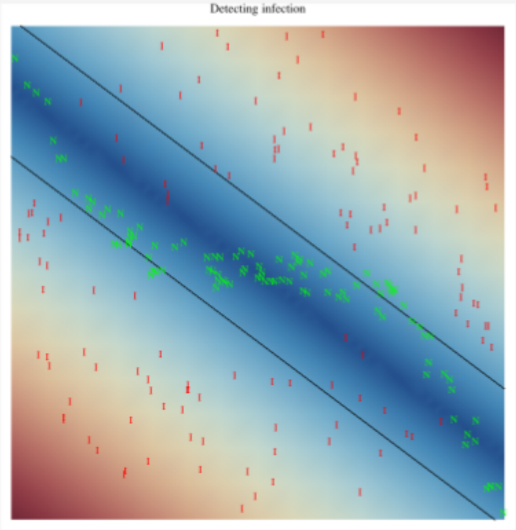
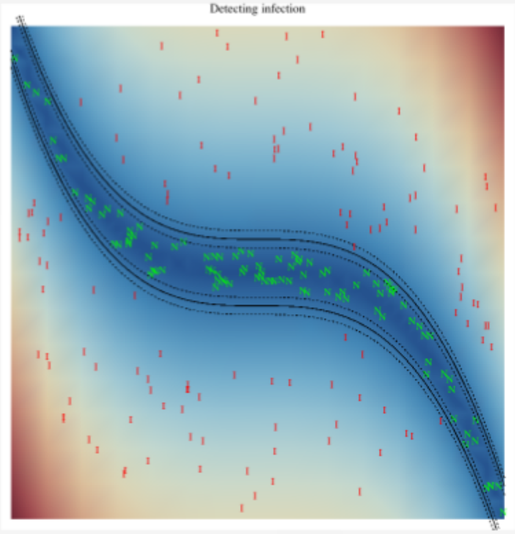
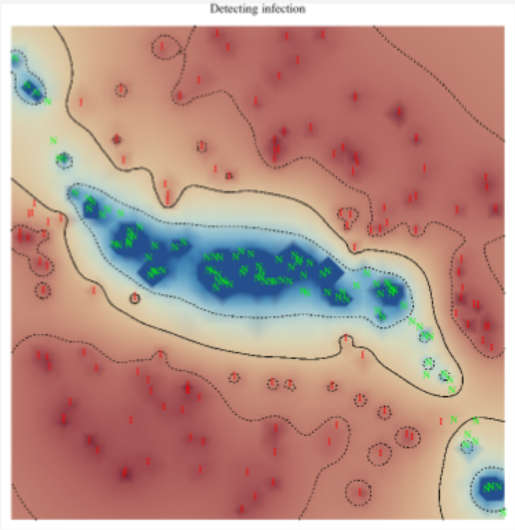
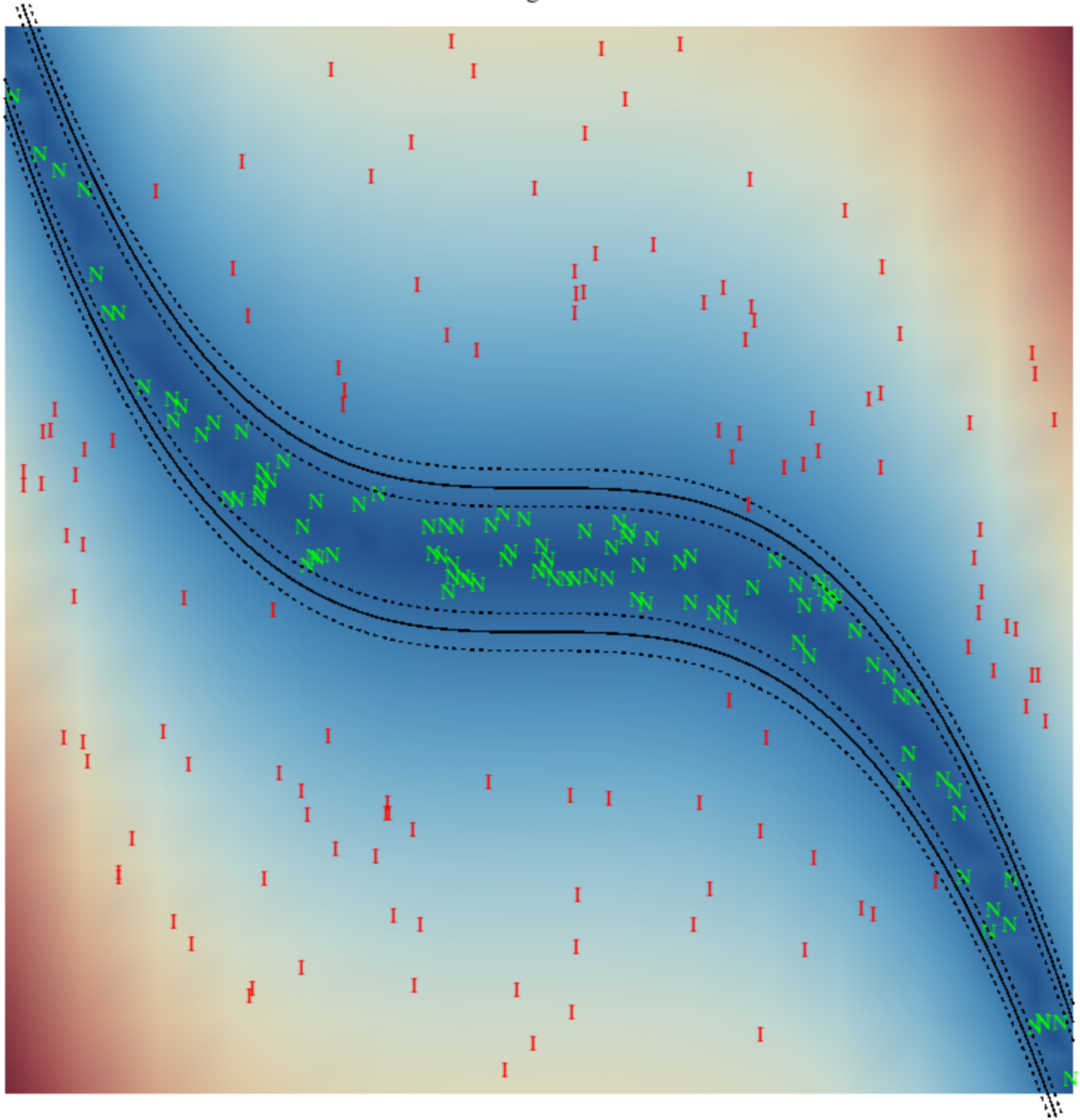






Detecting infection



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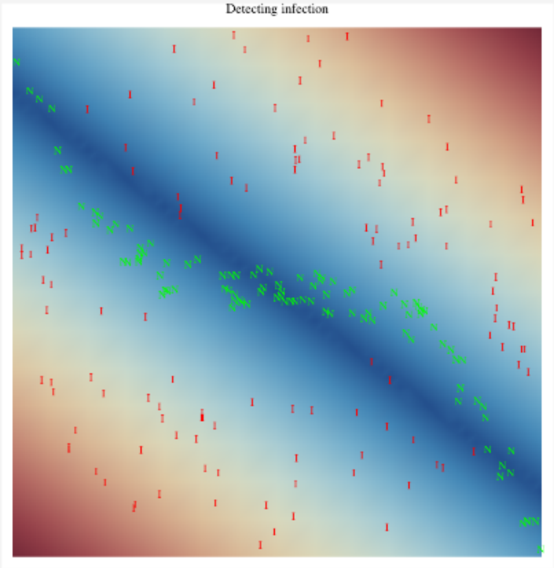

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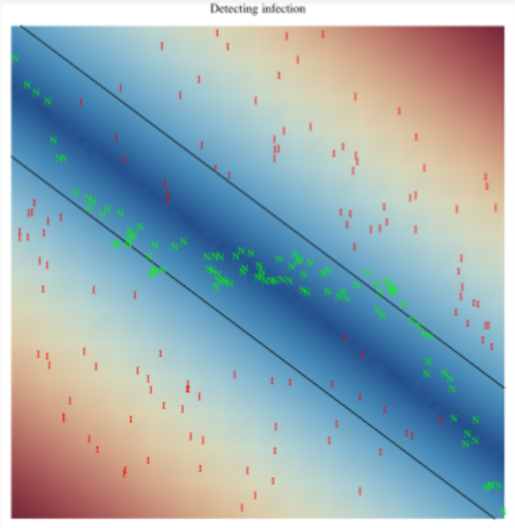

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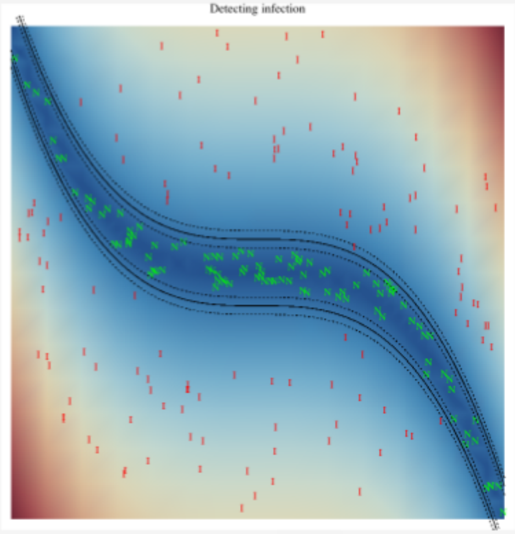

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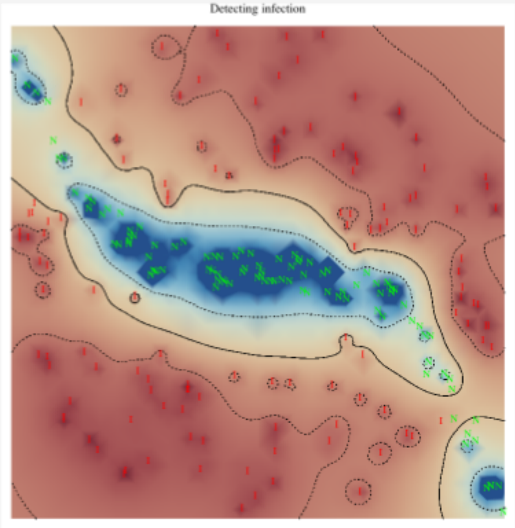
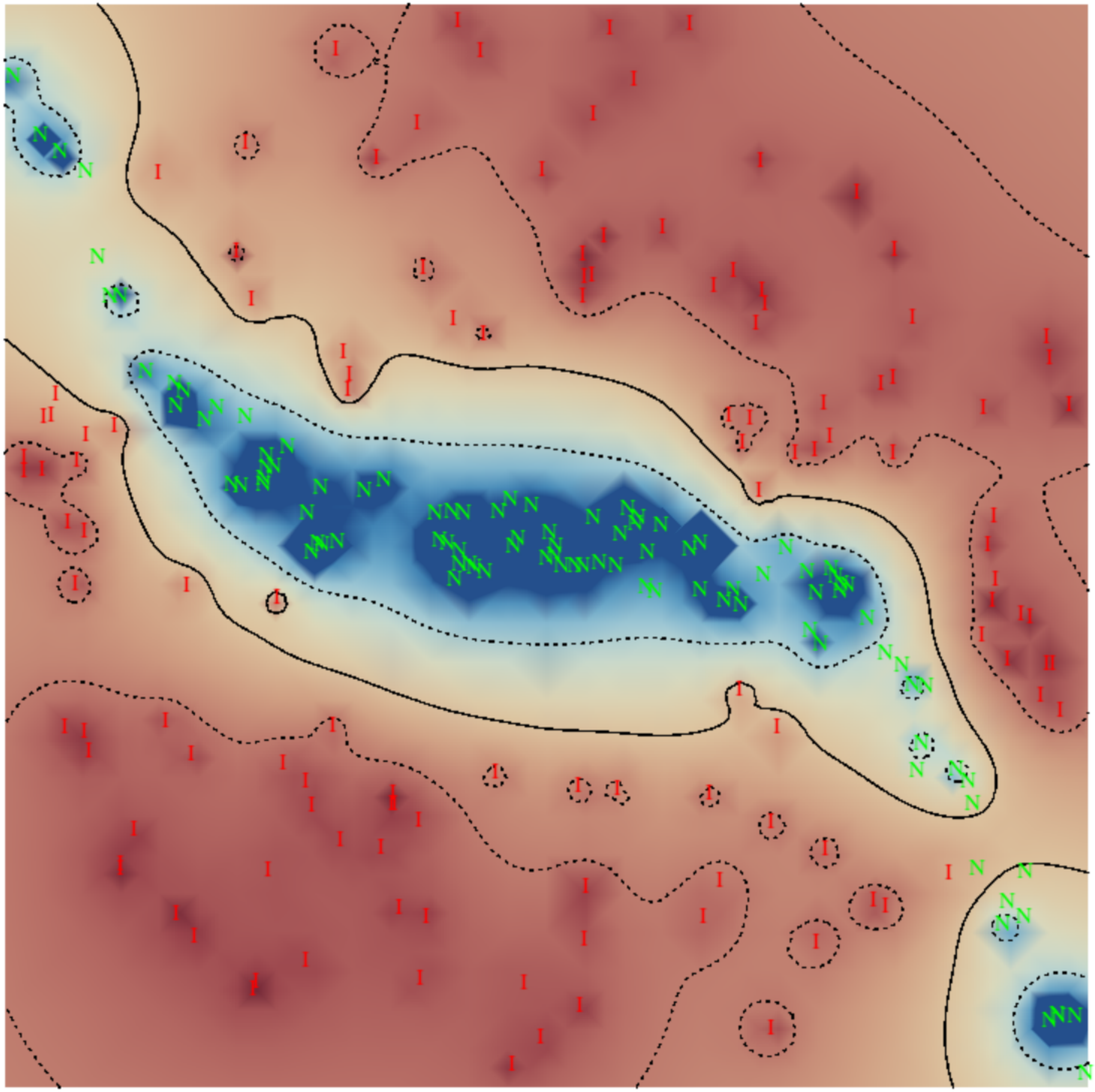


Detecting infection



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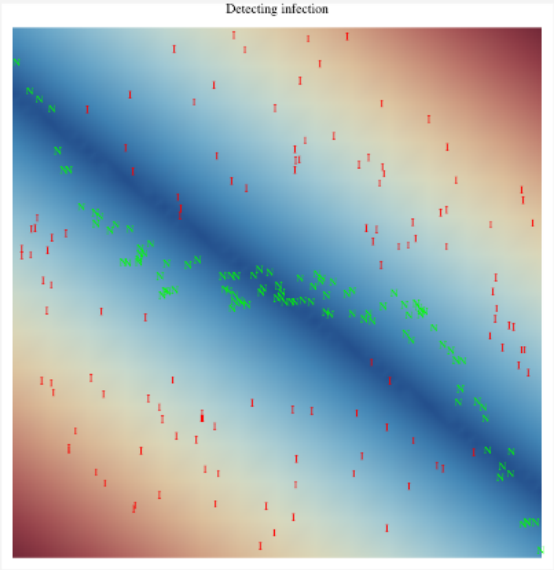

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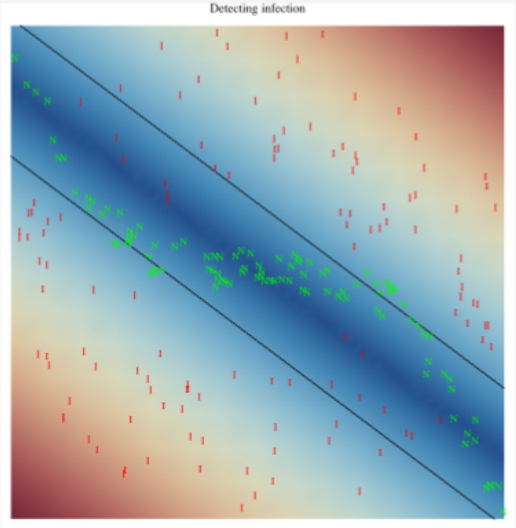

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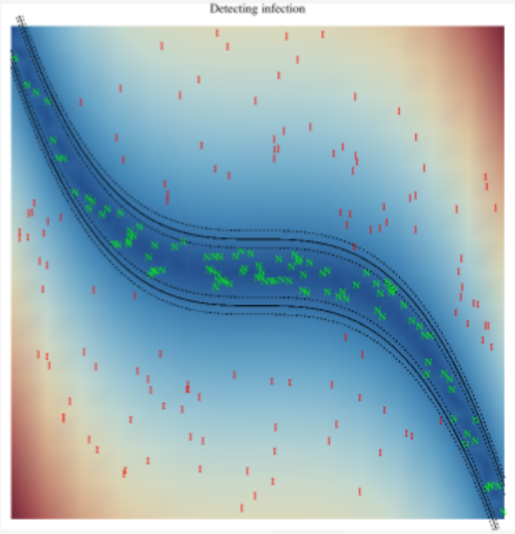

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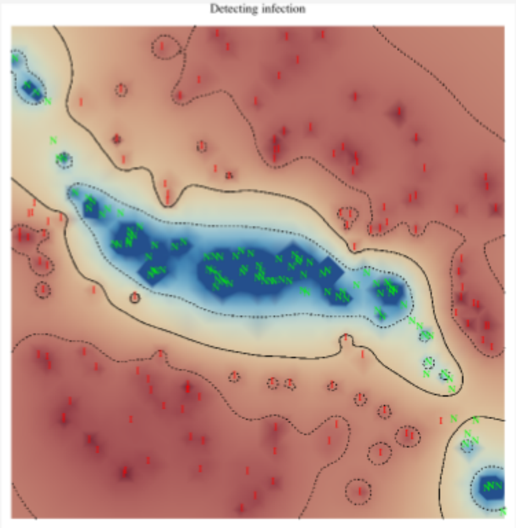
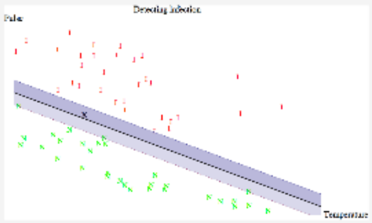


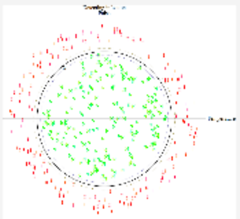
Machine learning and detecting infection

IBM Artemis project

Prediction/Classification

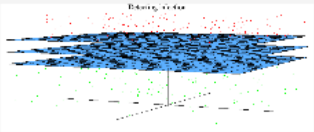


Higher dimensions



kernel →

← result



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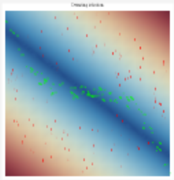

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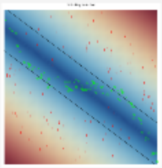

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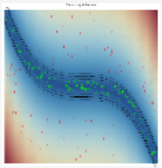

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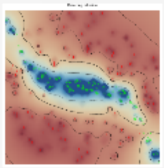


Summary

Theoretical math is cool!

Three apparant paradoxes:
Hilbert's Hotel, The pea and the sun, The dough and the pan.

Predict length of stay. Help detect infections.

Thank you!

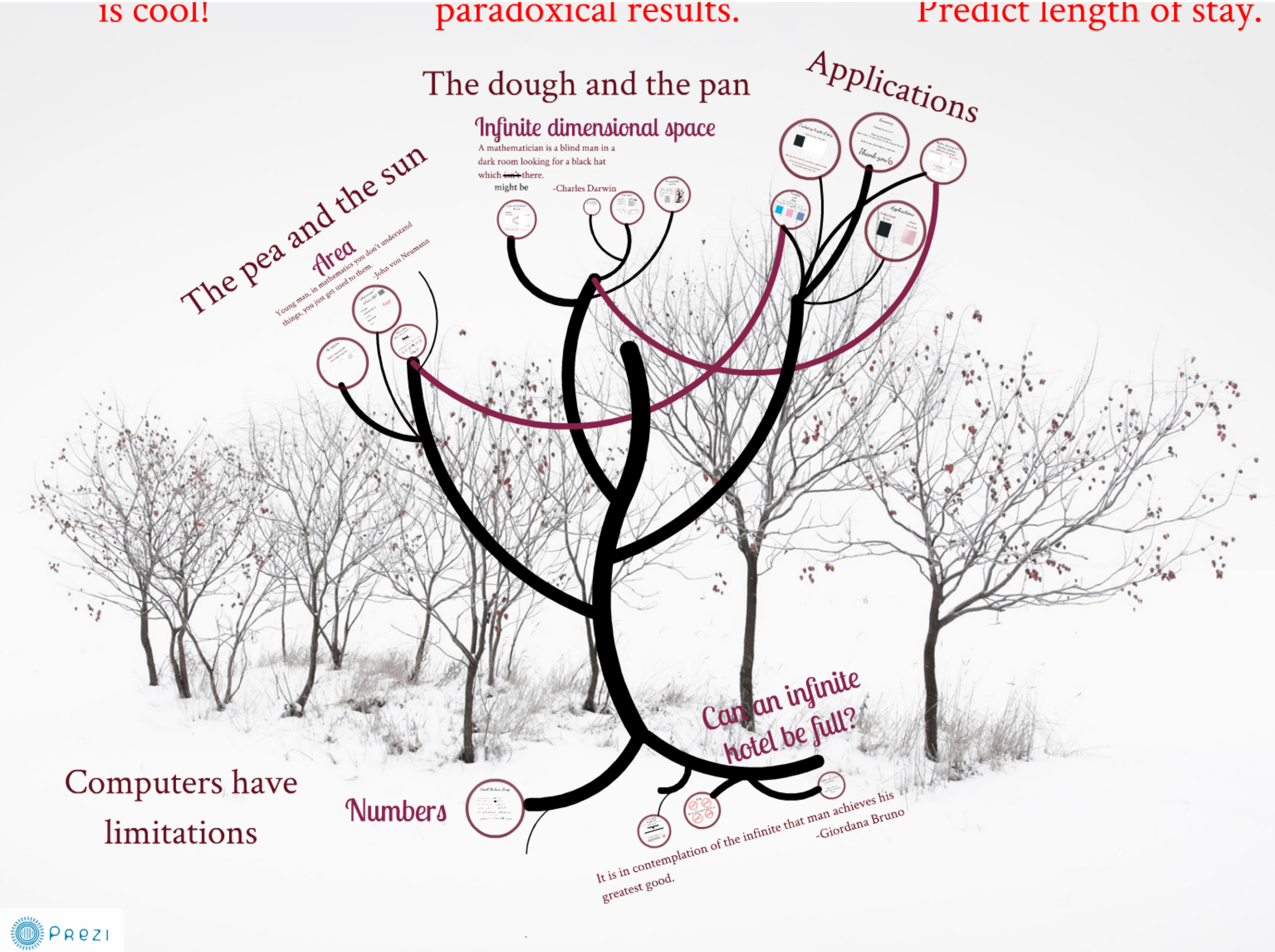
Thanks to:

Retsef Levi, Peter Dunn, Bethany Daily, Cecilia Zenteno
MIT and MGH

Alex Scheinker - mountain & tree
www.alexscheinker.com

Sam Rodriguez - medical illustrations
www.sampaintings.com

David Scheinker
dscheink@mit.edu


is cool!
paradoxical results.
Predict length of stay.
The dough and the pan
Applications
Infinite dimensional space
A mathematician is a blind man in a dark room looking for a black hat which ~~isn't~~ there.
might be
-Charles Darwin
The pea and the sun
Area
Young man, in mathematics you don't understand things, you just get used to them.
-John von Neumann
Can an infinite hotel be full?
It is in contemplation of the infinite that man achieves his greatest good.
-Giordana Bruno
Computers have limitations
Numbers

Can studying infinite dimensional space help improve health care?

Theoretical math is cool!

Three seemingly paradoxical results.

Detect infections. Predict length of stay.