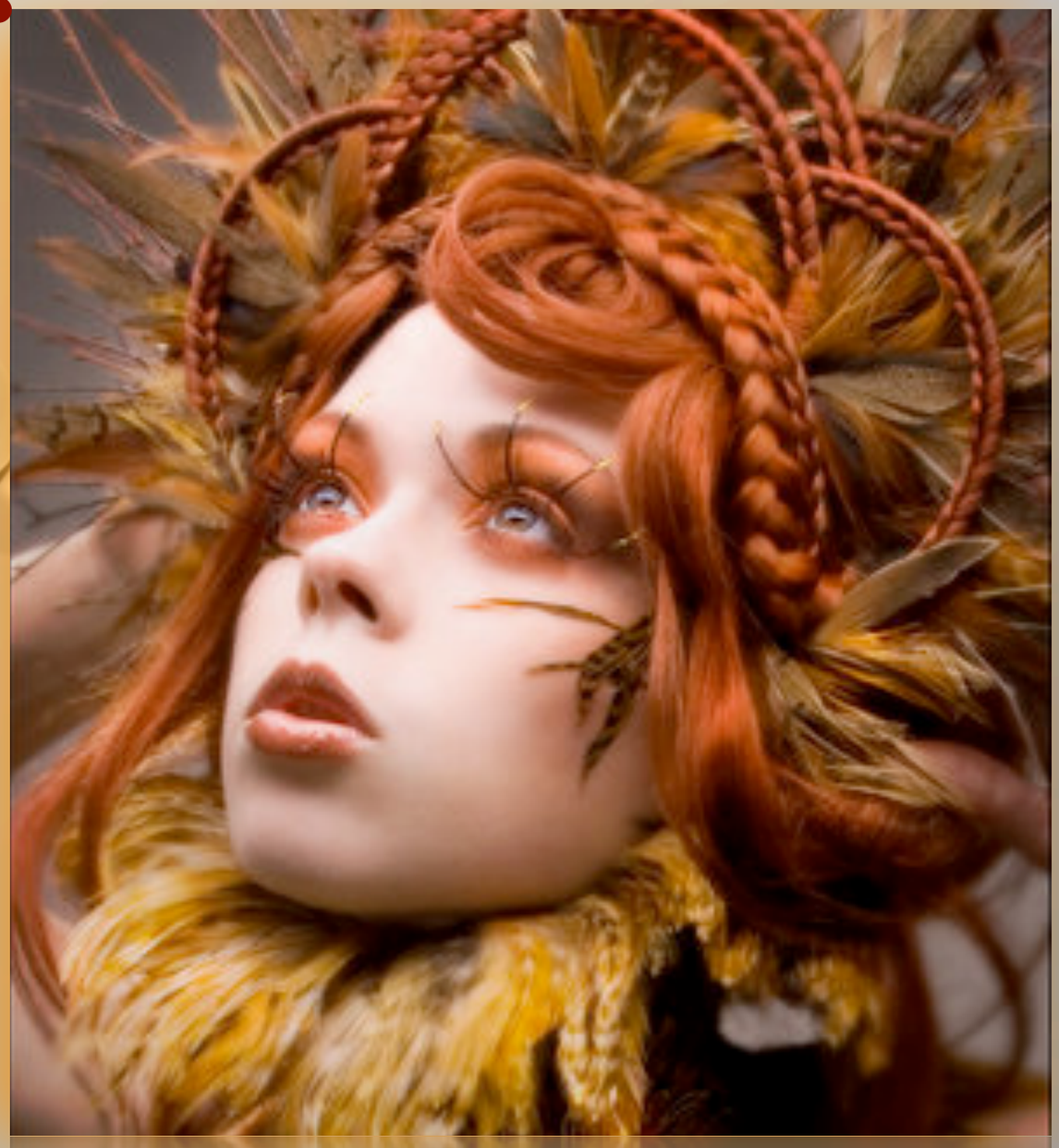
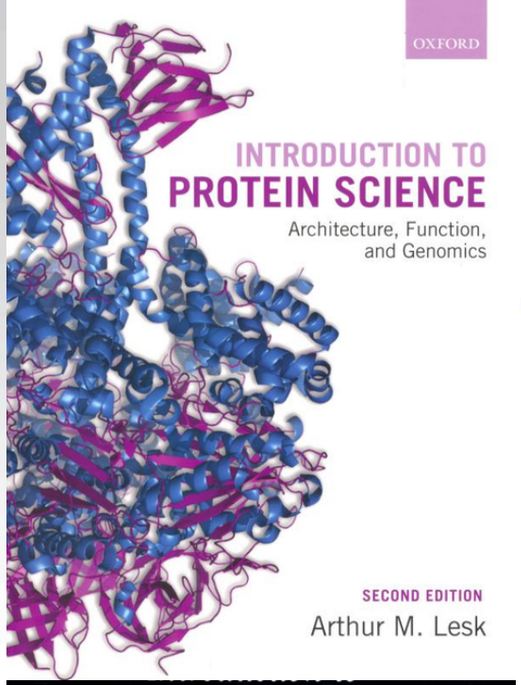
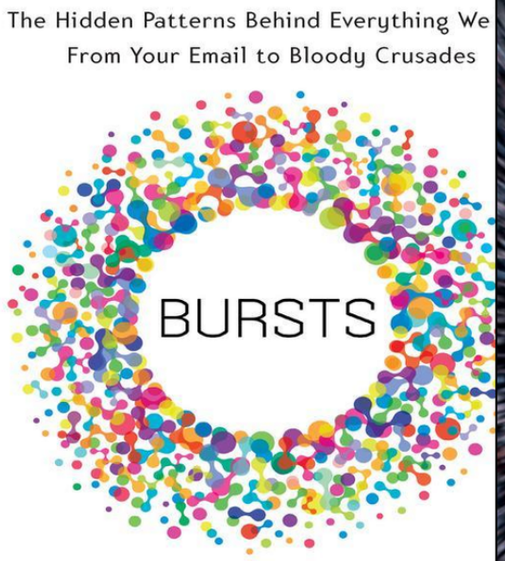
The Geometry of Networks

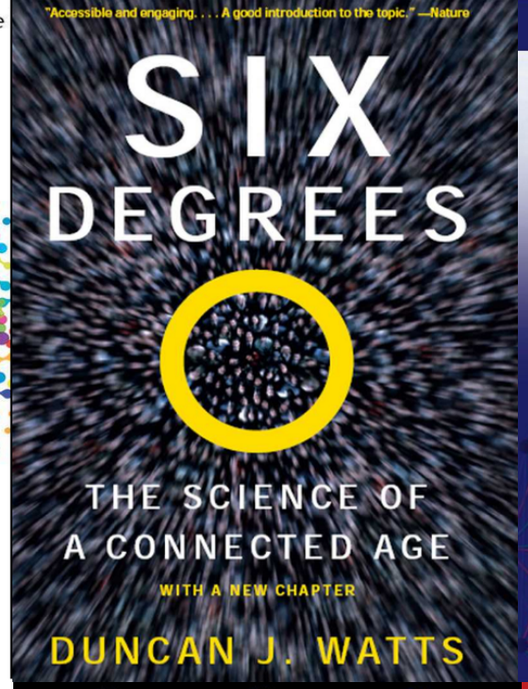
April 1, 2012

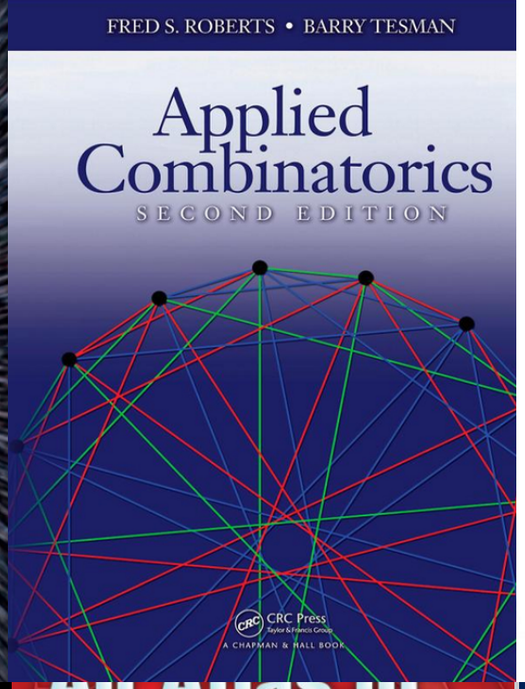
What is "hot" today in Math?

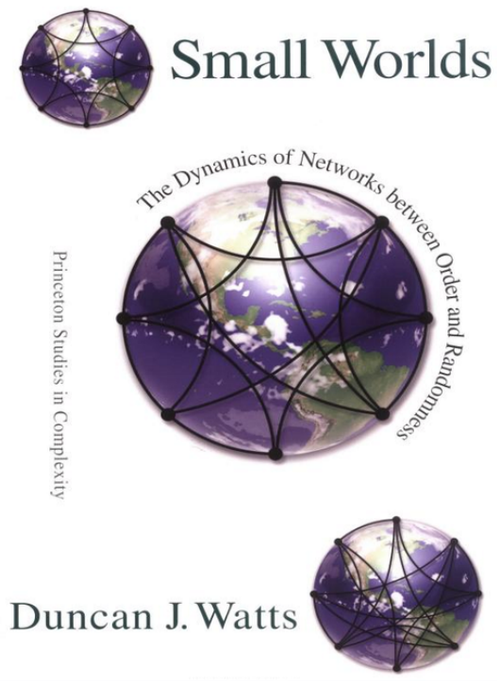


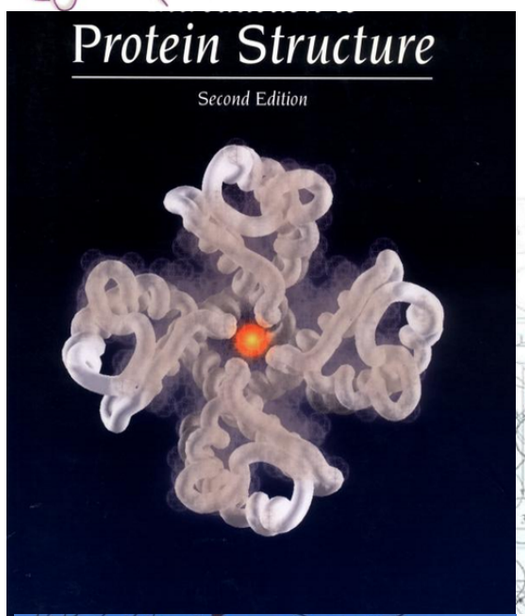

OXFORD
INTRODUCTION TO
PROTEIN SCIENCE
Architecture, Function, and Genomics
SECOND EDITION
Arthur M. Lesk


The Hidden Patterns Behind Everything We
From Your Email to Bloody Crusades
BURSTS
With A New Afterword
Albert-László Barabási
Author of LINKED


"Accessible and engaging. . . . A good introduction to the topic." —Nature
SIX
DEGREES
THE SCIENCE OF
A CONNECTED AGE
WITH A NEW CHAPTER
DUNCAN J. WATTS


FRED S. ROBERTS • BARRY TESMAN
Applied
Combinatorics
SECOND EDITION
CRC Press
A CHAPMAN & HALL BOOK


Small Worlds
The Dynamics of Networks between Order and Randomness
Princeton Studies in Complexity
Duncan J. Watts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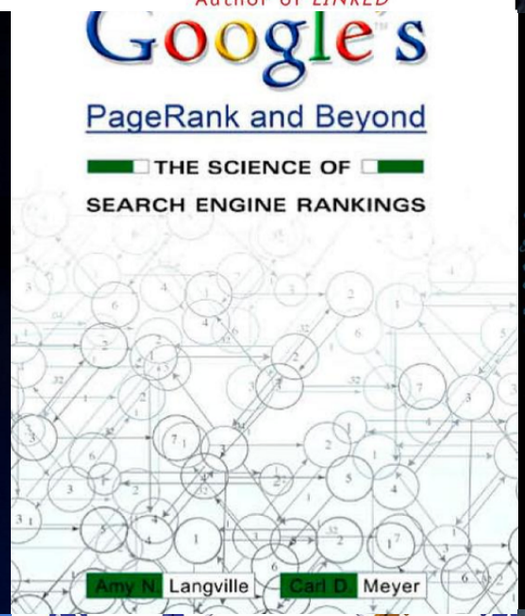
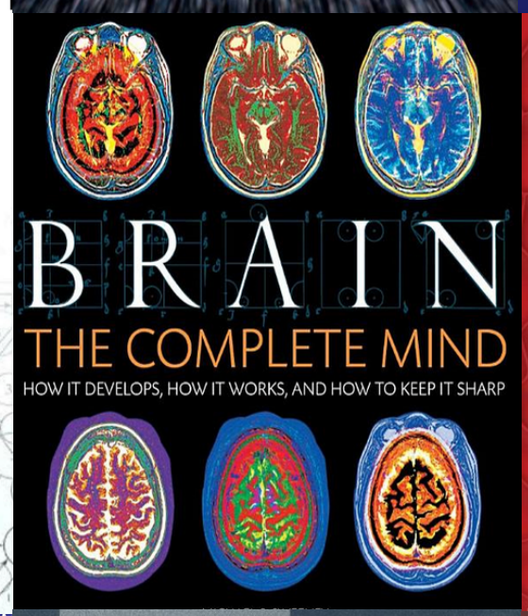
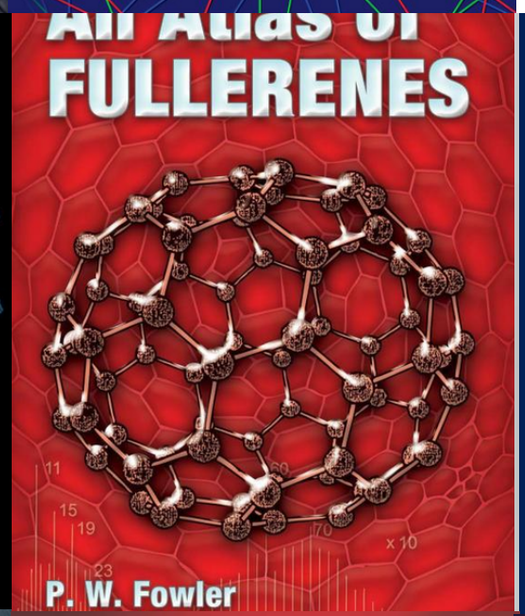
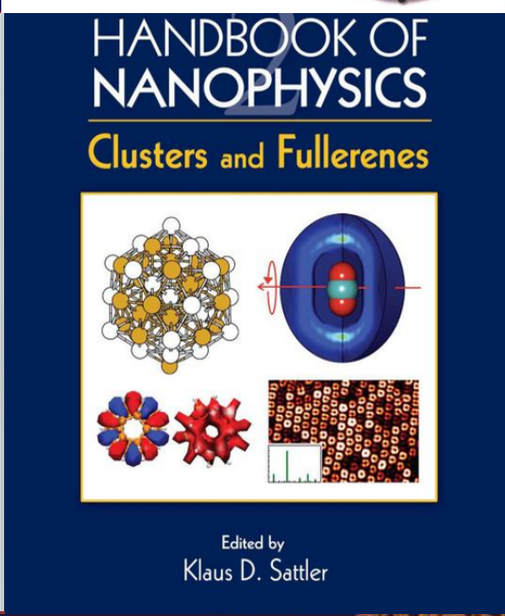

Google's
PageRank and Beyond
THE SCIENCE OF
SEARCH ENGINE RANKINGS
Amy N. Langville
Carl D. Meyer


BRAIN
THE COMPLETE MIND
HOW IT DEVELOPS, HOW IT WORKS, AND HOW TO KEEP IT SHARP


FULLERENES
P. W. Fowler


HANDBOOK OF
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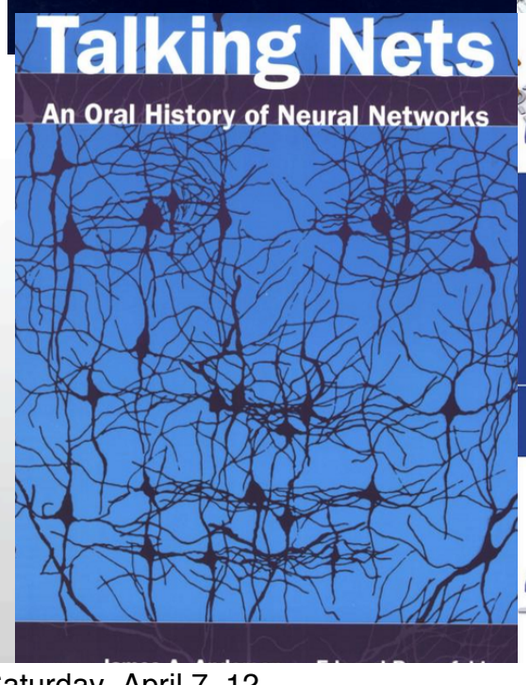
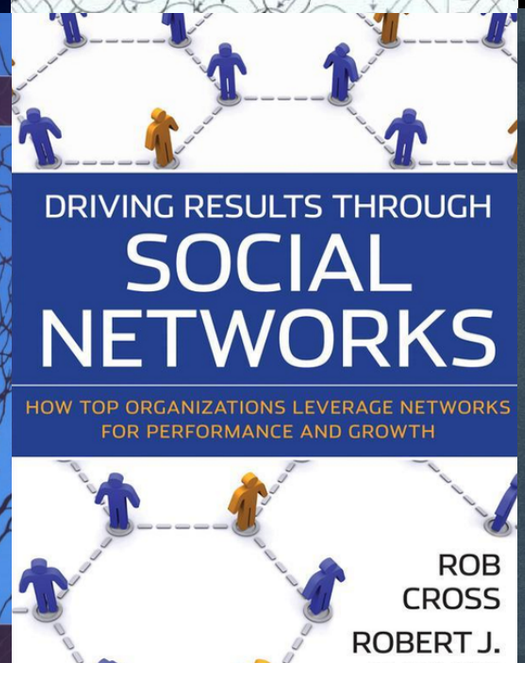
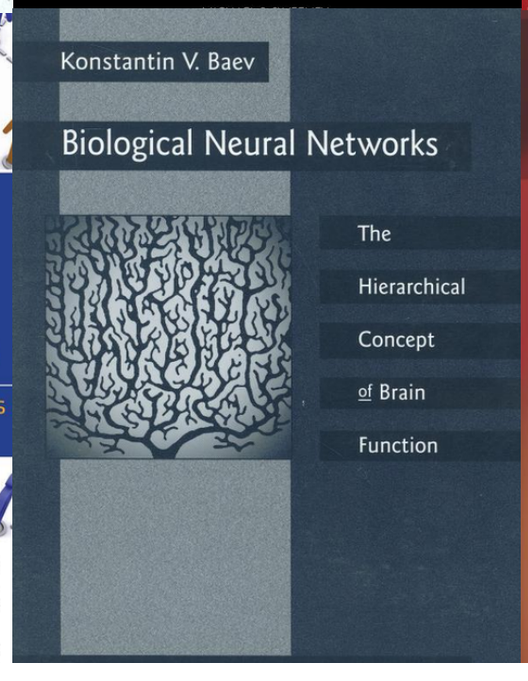
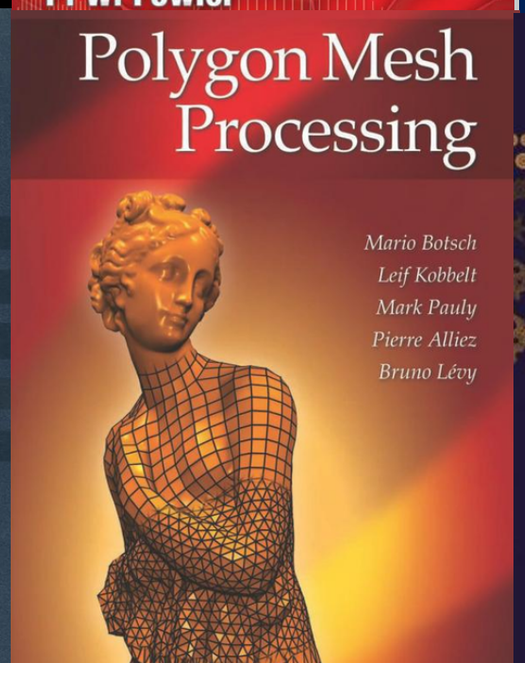
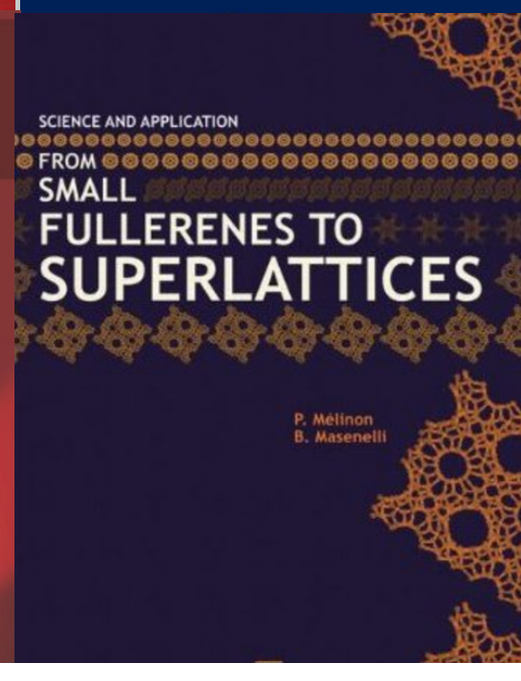
Edited by
Klaus D. Sattler

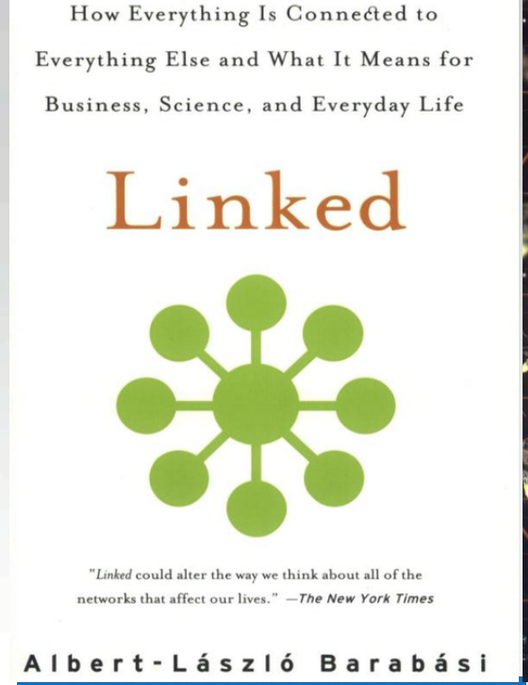

Talking Nets
An Oral History of Neural Networks

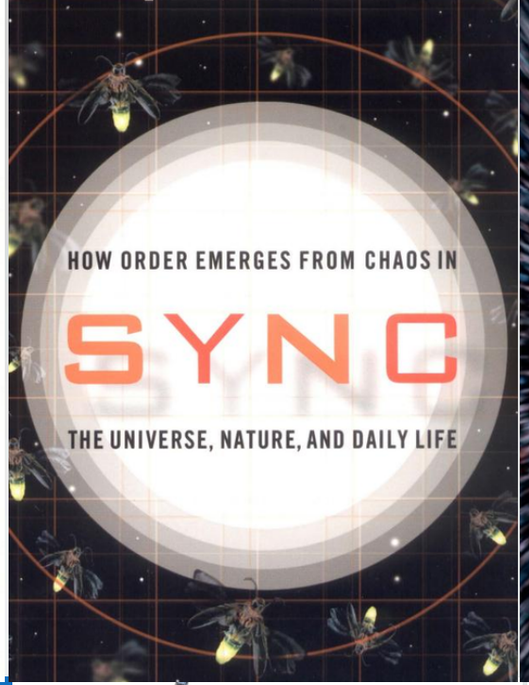

DRIVING RESULTS THROUGH
SOCIAL
NETWORKS
HOW TOP ORGANIZATIONS LEVERAGE NETWORKS
FOR PERFORMANCE AND GROWTH
ROB
CROSS
ROBERT J.

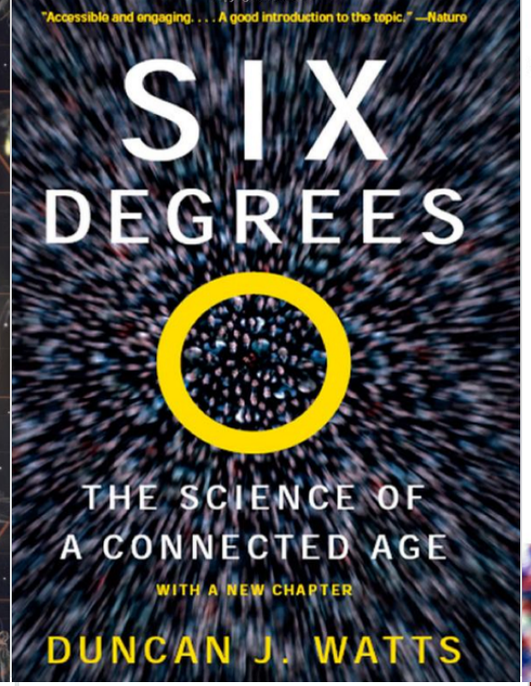

Konstantin V. Baev
Biological Neural Networks
The
Hierarchical
Concept
of Brain
Function


Polygon Mesh
Processing
Mario Botsch
Leif Kobbelt
Mark Pauly
Pierre Alliez
Bruno Lévy


SCIENCE AND APPLICATION
FROM
SMALL
FULLERENES TO
SUPERLATTICES
P. Mélinon
B. Masenelli


How Everything Is Connected to
Everything Else and What It Means for
Business, Science, and Everyday Life
Linked
"Linked could alter the way we think about all of the networks that affect our lives." —The New York Times
Albert-László Barabási


HOW ORDER EMERGES FROM CHAOS IN
SYNC
THE UNIVERSE, NATURE, AND DAILY LIFE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THE SCIENCE OF A CONNECTED AGE
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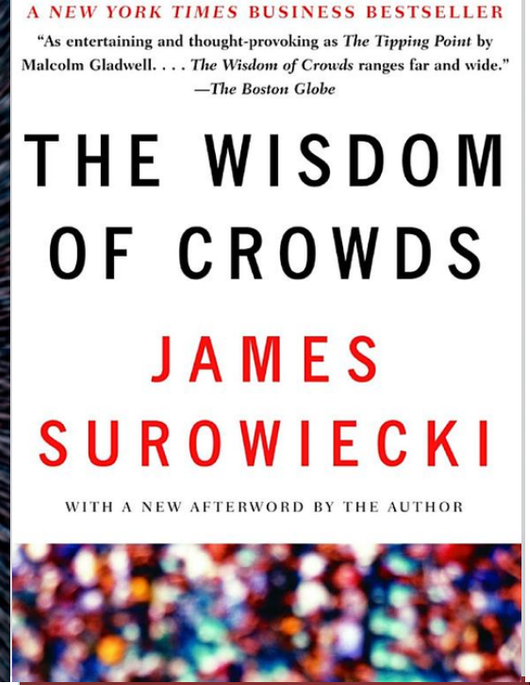
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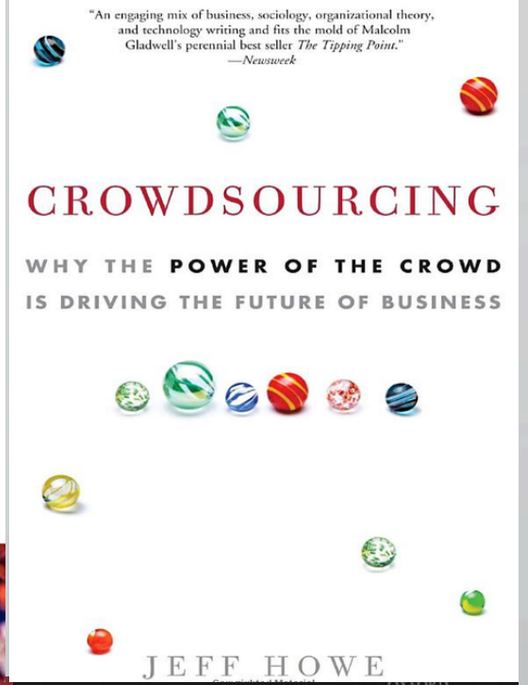
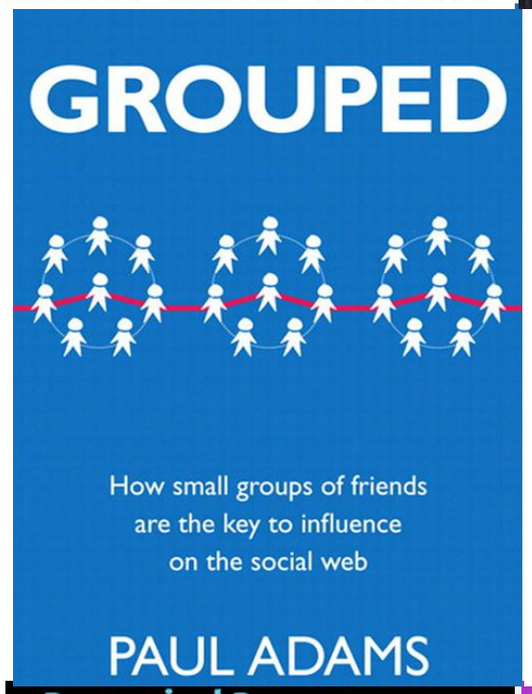
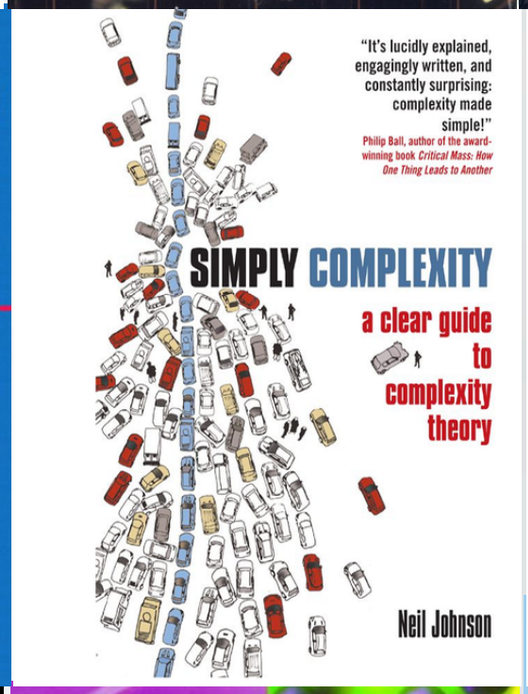
JAMES SUROWIECKI
WITH A NEW AFTERWORD BY THE AUTHOR


"An engaging mix of business, sociology, organizational theory, and technology writing and fits the mold of Malcolm Gladwell's perennial best seller The Tipping Point." —Newsweek
CROWDSOURCING
WHY THE POWER OF THE CROWD IS DRIVING THE FUTURE OF BUSINESS
JEFF HOWE


GROUPED
How small groups of friends are the key to influence on the social web
PAUL ADAMS


"It's lucidly explained, engagingly written, and constantly surprising: complexity made simple!" Philip Ball, author of the award-winning book Critical Mass: How One Thing Leads to Another
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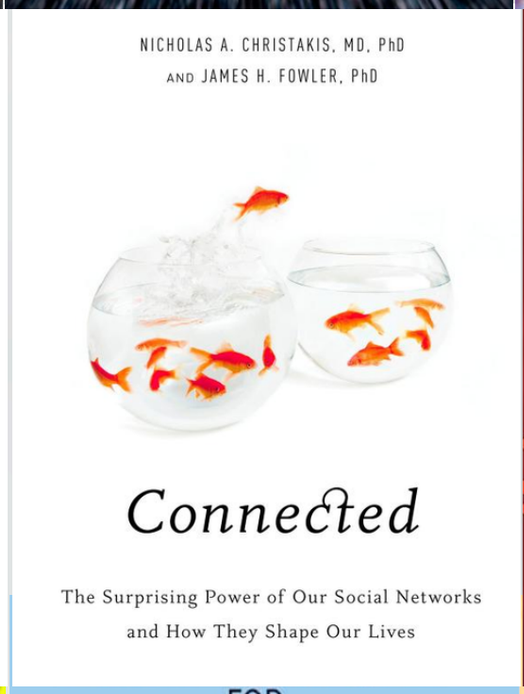
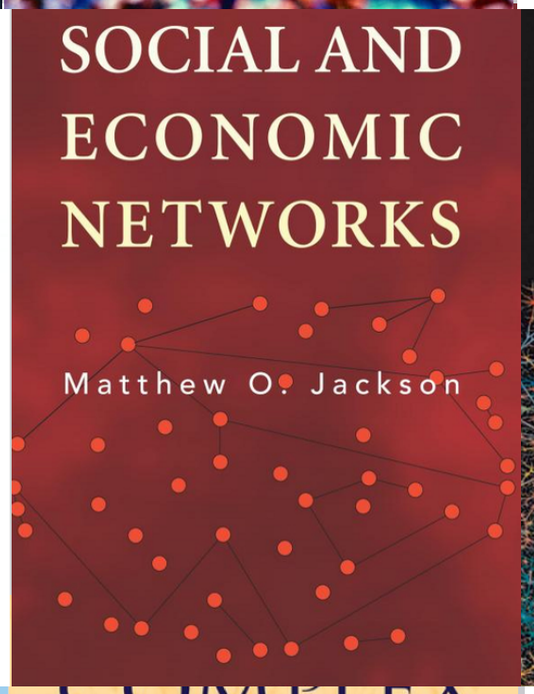
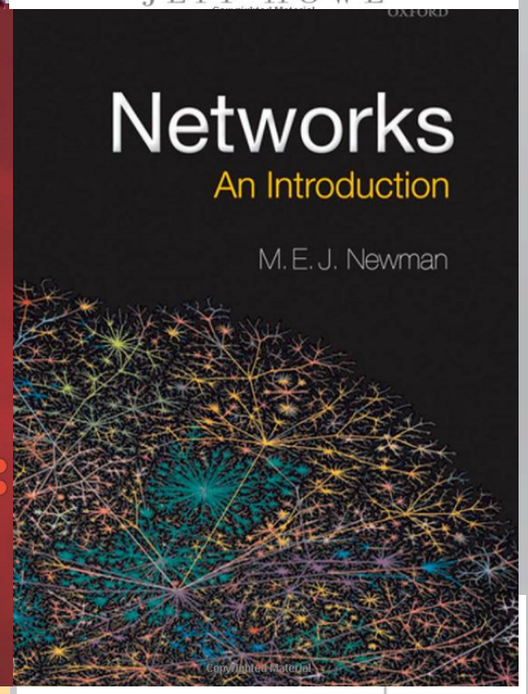
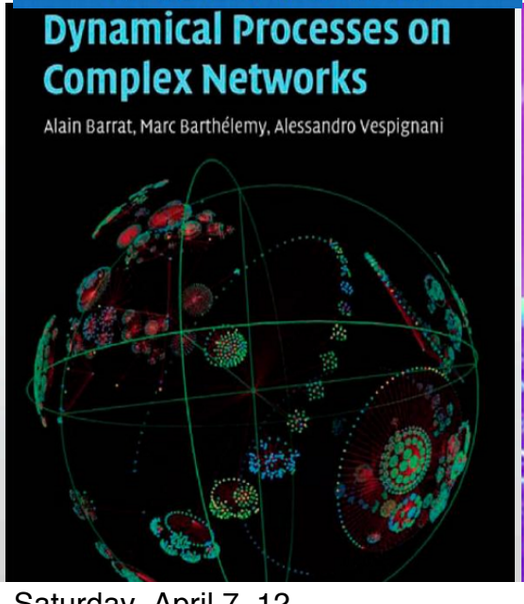
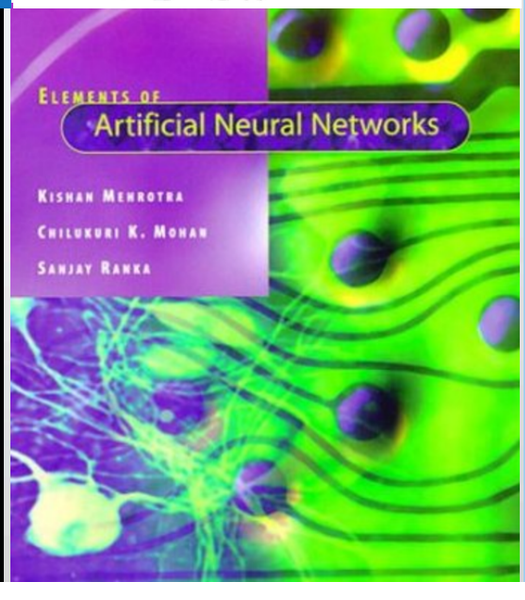
a clear guide to complexity theory
Neil Johnson

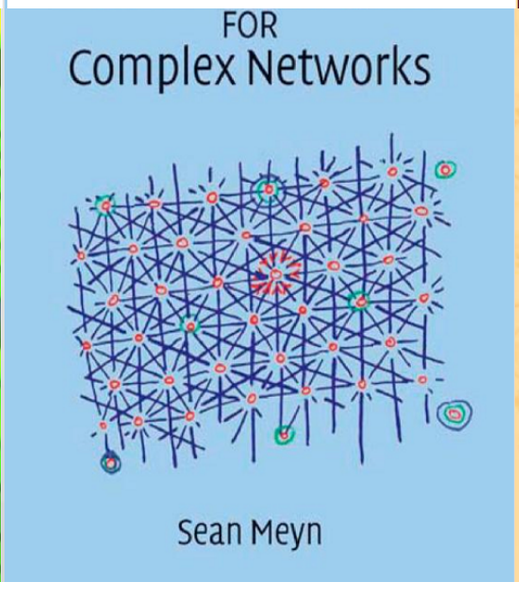

NICHOLAS A. CHRISTAKIS, MD, PhD
AND JAMES H. FOWLER, PhD
Connected
The Surprising Power of Our Social Networks and How They Shape Our Lives

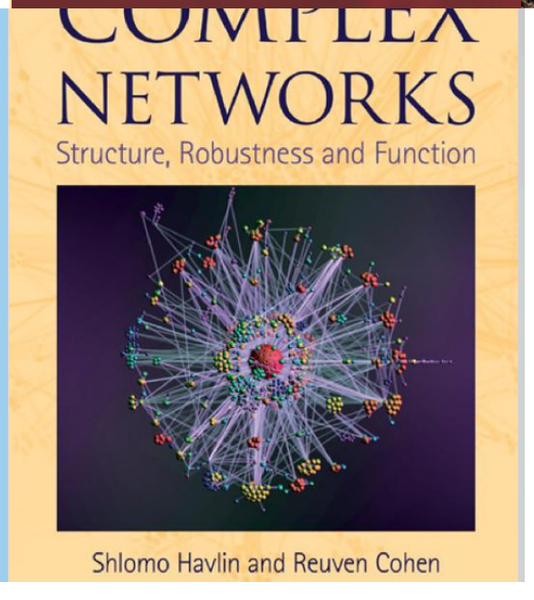

SOCIAL AND ECONOMIC NETWORKS
Matthew O. Jackson

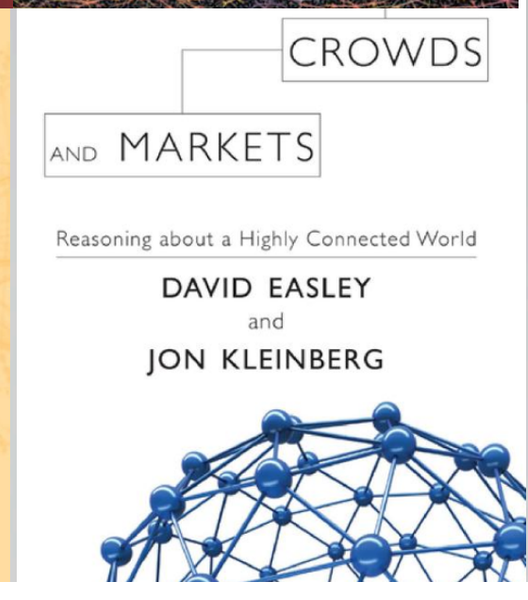

Networks
An Introduction
M.E.J. Newman


Dynamical Processes on Complex Networks
Alain Barrat, Marc Barthélemy, Alessandro Vespignani


ELEMENTS OF
Artificial Neural Networks
KISHAN MEHROTRA
CHILUKURI K. MOHAN
SANJAY RANKA


FOR
Complex Networks
Sean Meyn


COMPLEX NETWORKS
Structure, Robustness and Function
Shlomo Havlin and Reuven Cohen

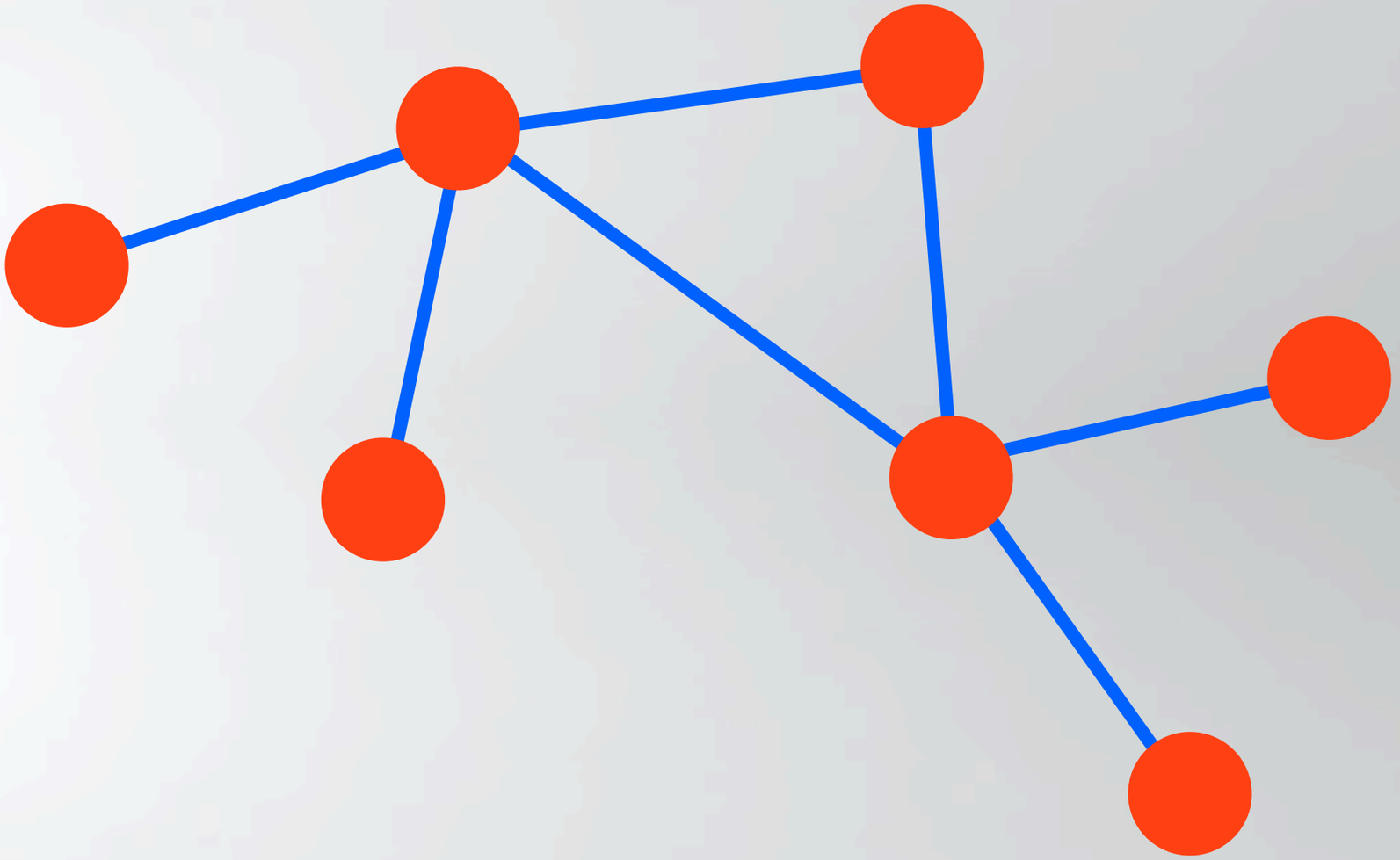

CROWDS
AND MARKETS
Reasoning about a Highly Connected World
DAVID EASLEY
and
JON KLEINBERG

Geometry on Networks

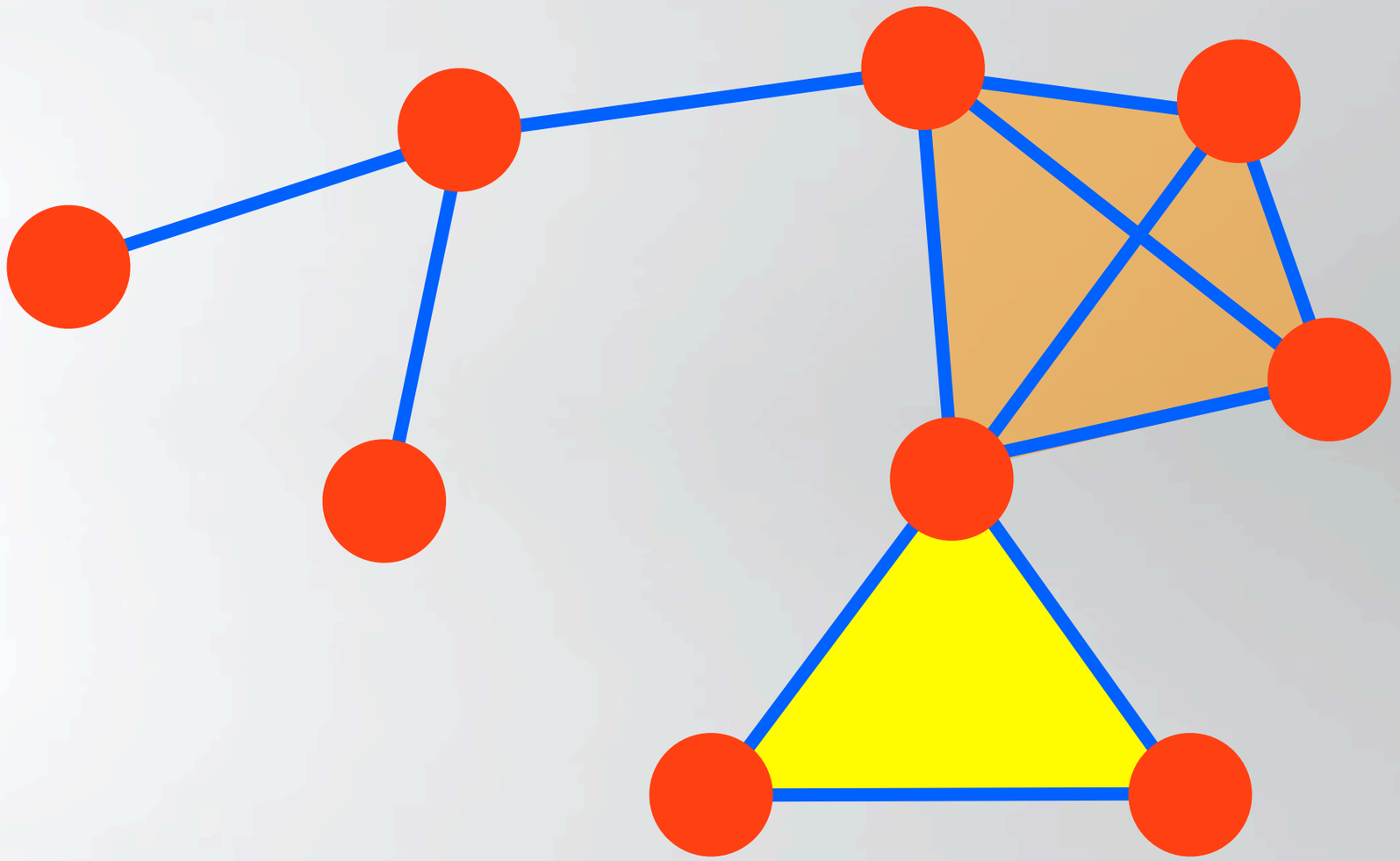
Graphs

Vertices

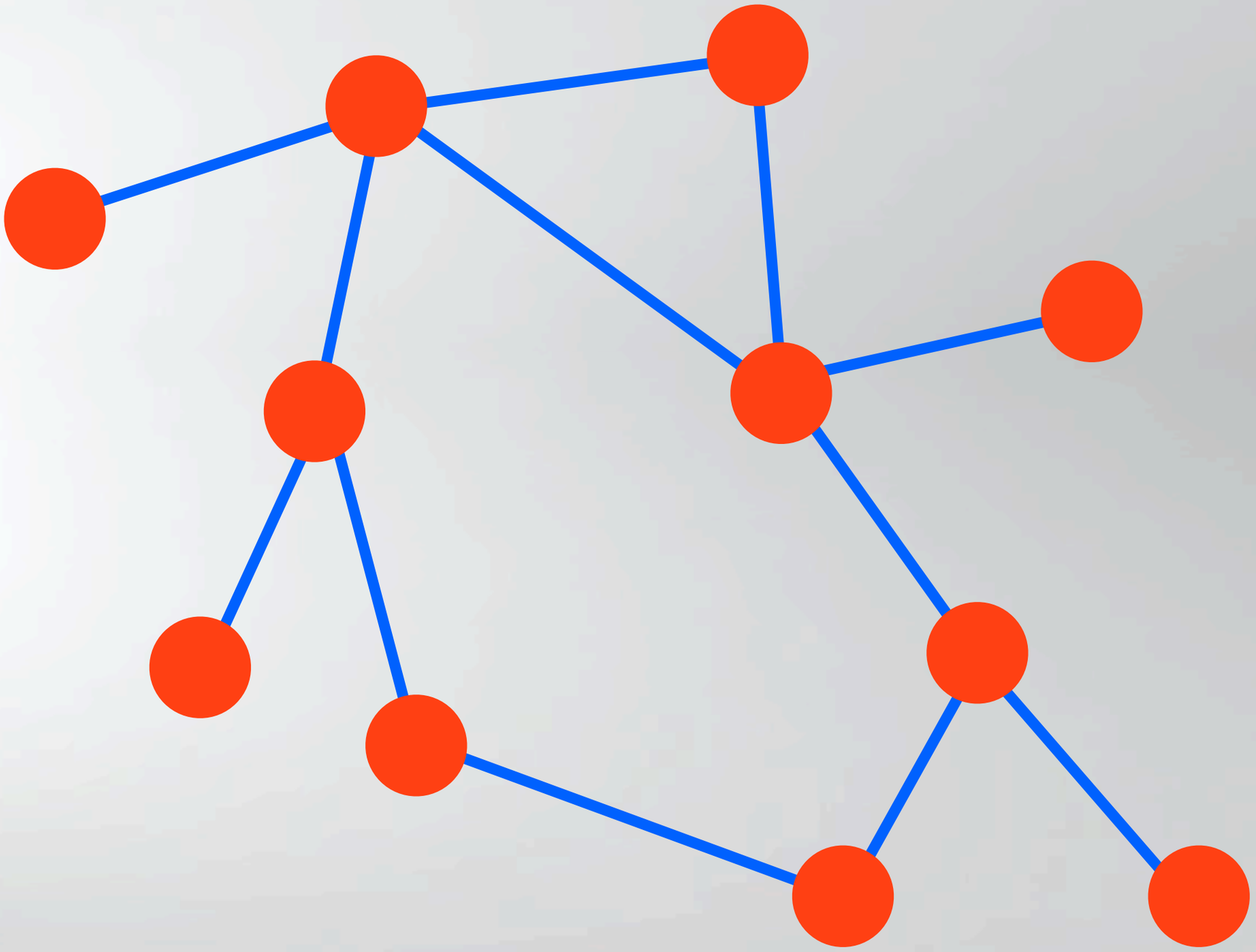
Edges



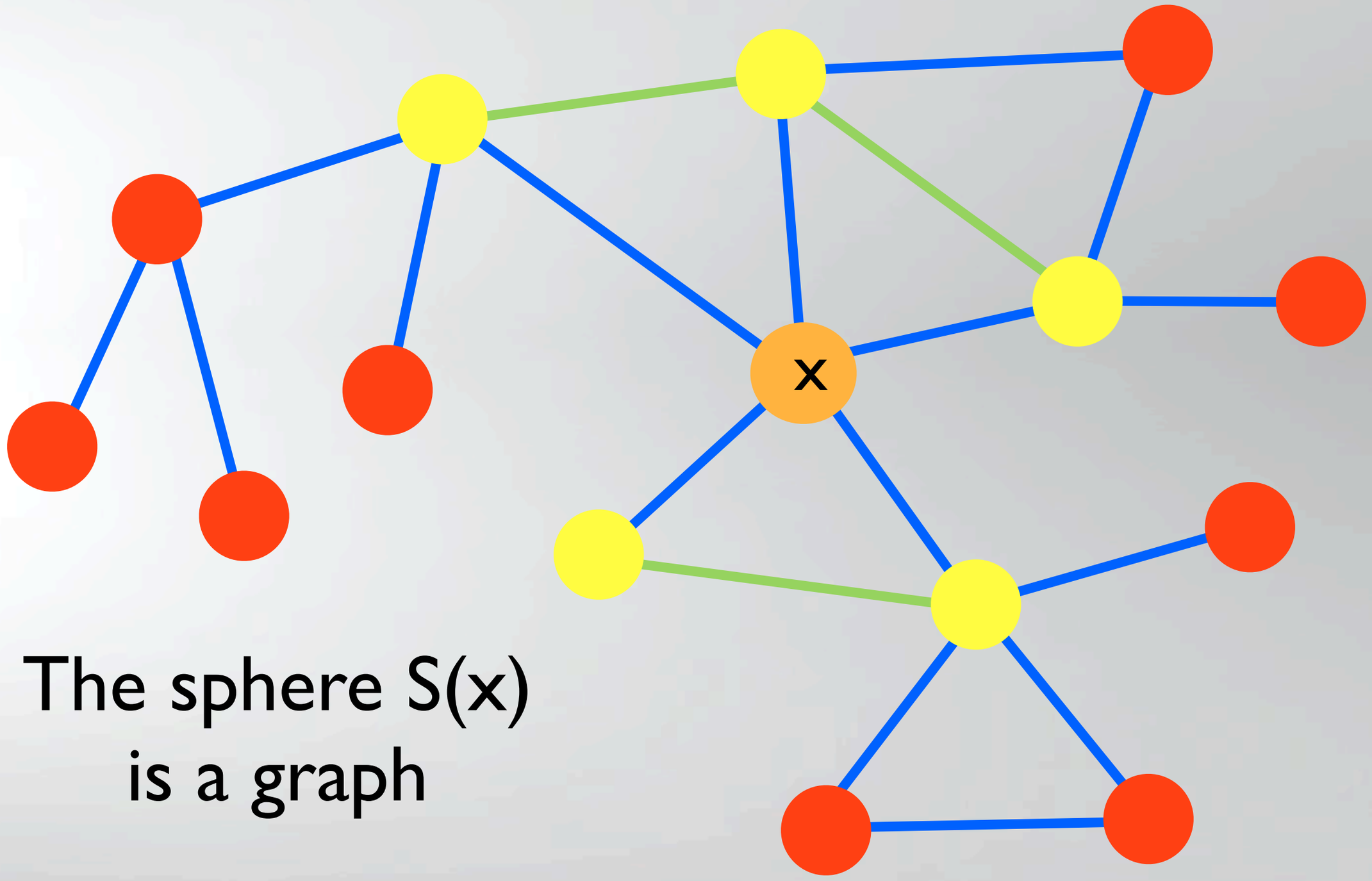
Cliques



Diameter

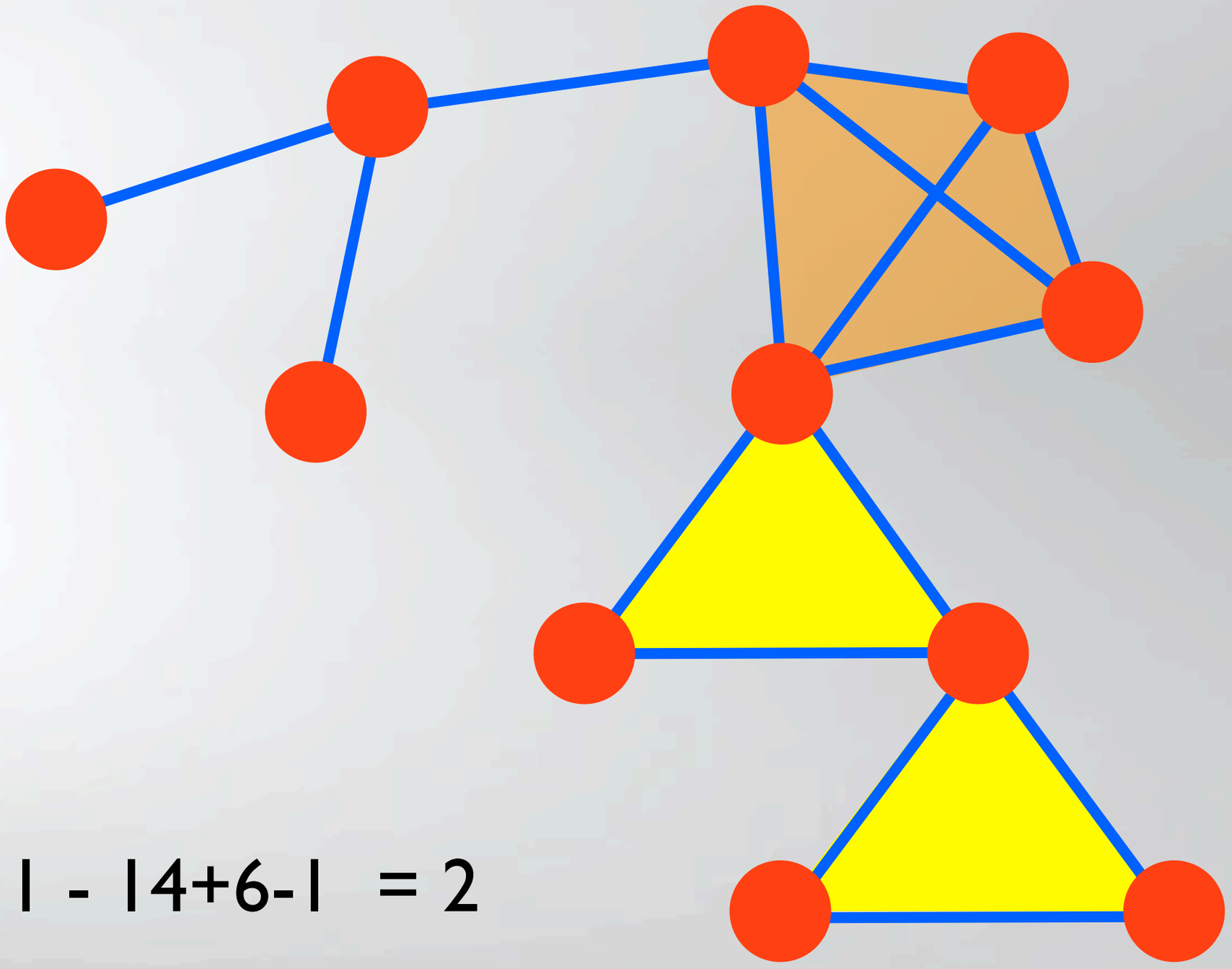


Spheres



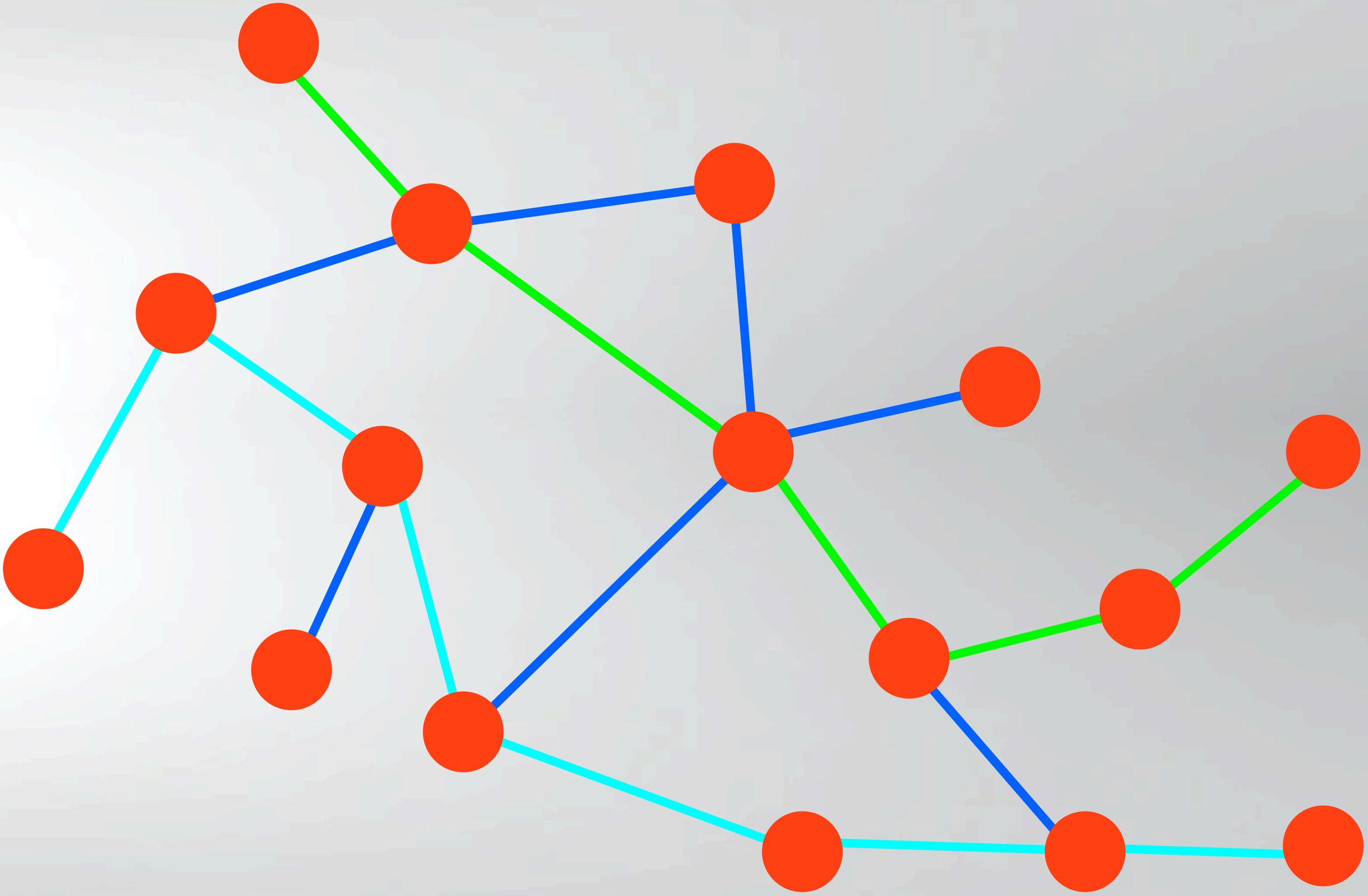
The sphere S(x)
is a graph

Euler Characteristic

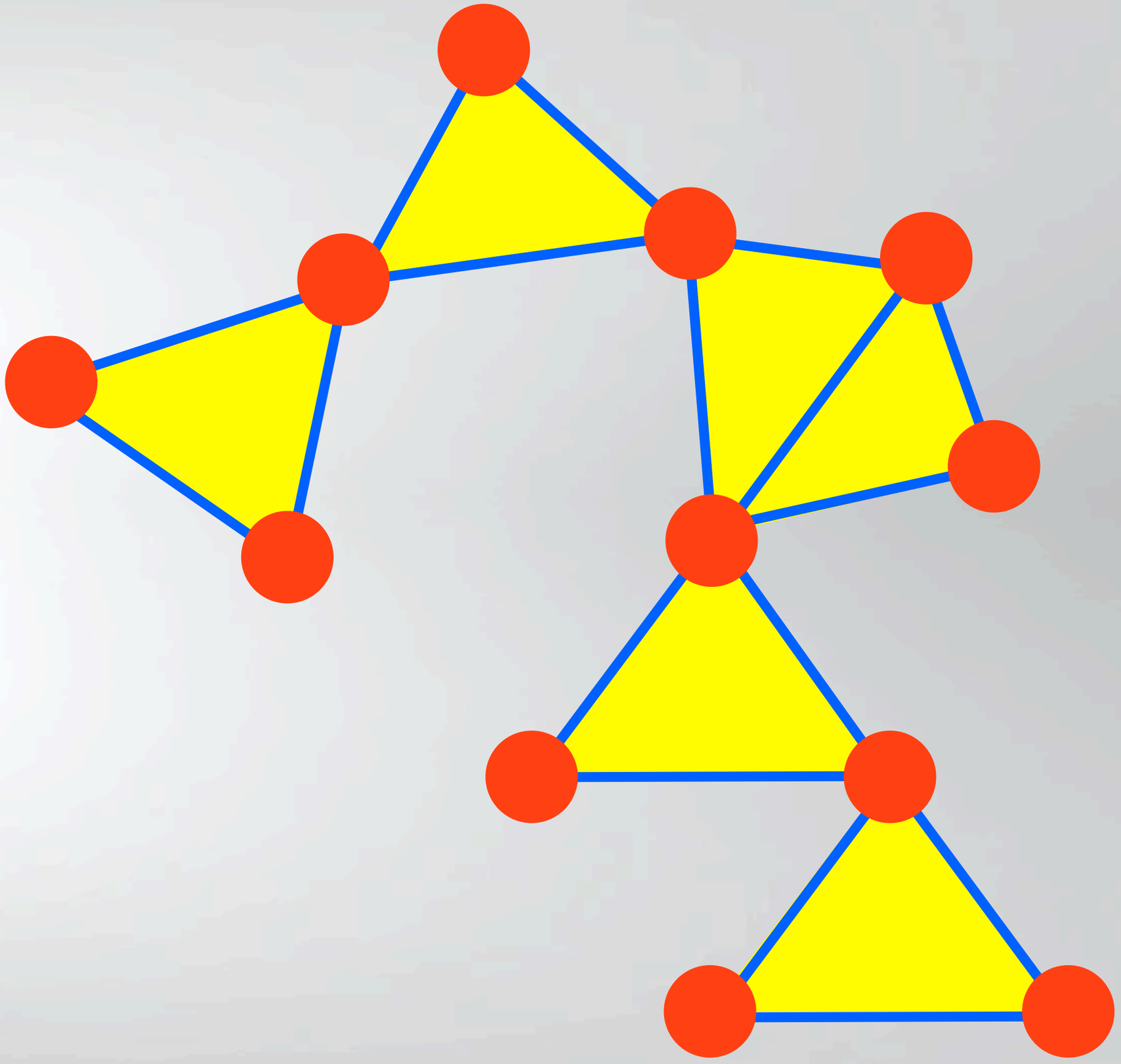


11 - 14+6-1 = 2

Parallel Lines



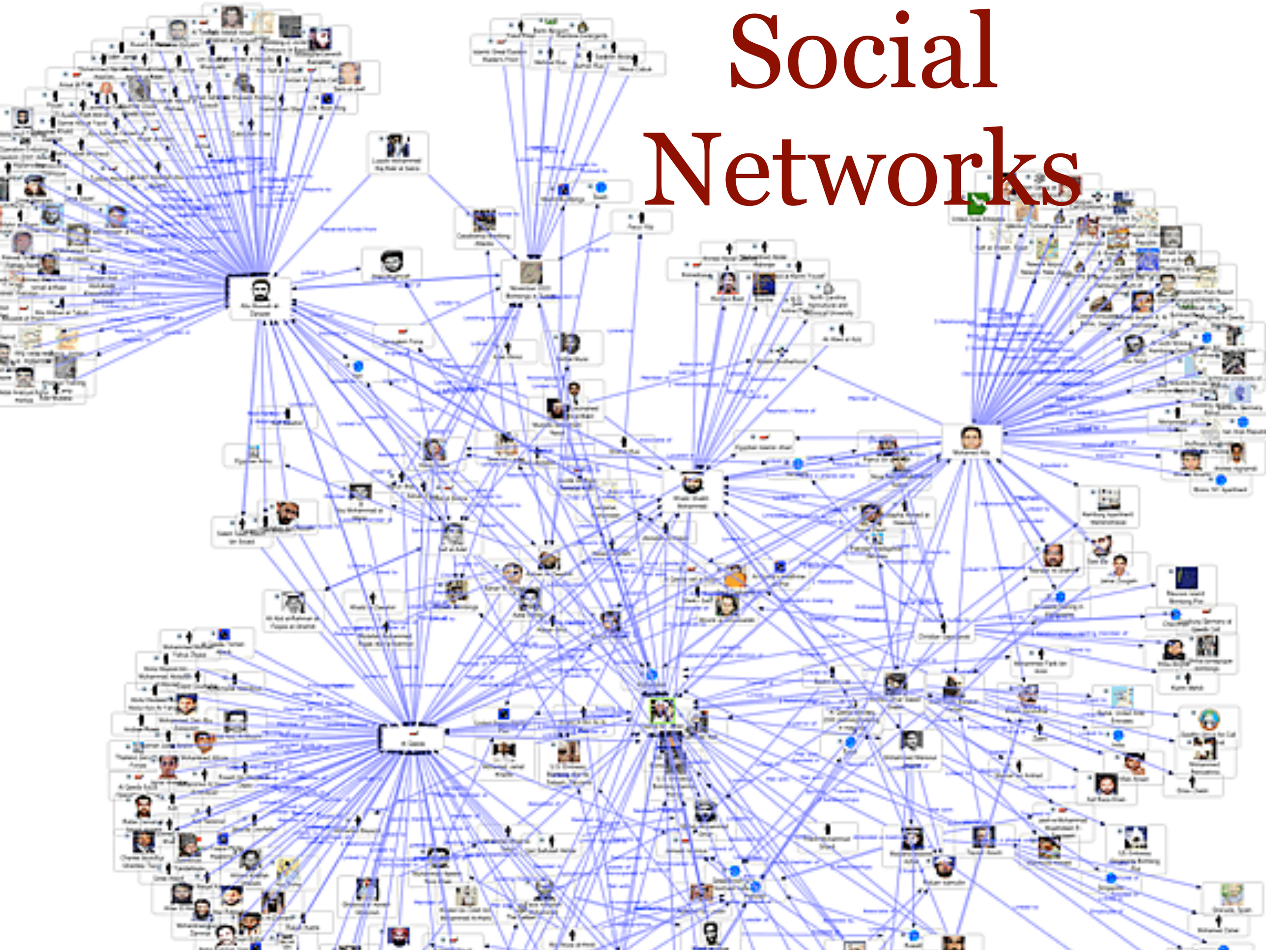
Area



Examples of Networks

Transportation

Social Networks



Social networks

Duncan Watts

in "Six Degrees"

"In the world of networks, sociologists, economists, mathematicians, computer scientists, biologists, engineers and physicists all have something to offer each other and much to learn."

Sociology

Sociologist: Morris Zeldich

1969 Zeldich: rhetorical question:

Can you really study an army in a laboratory?

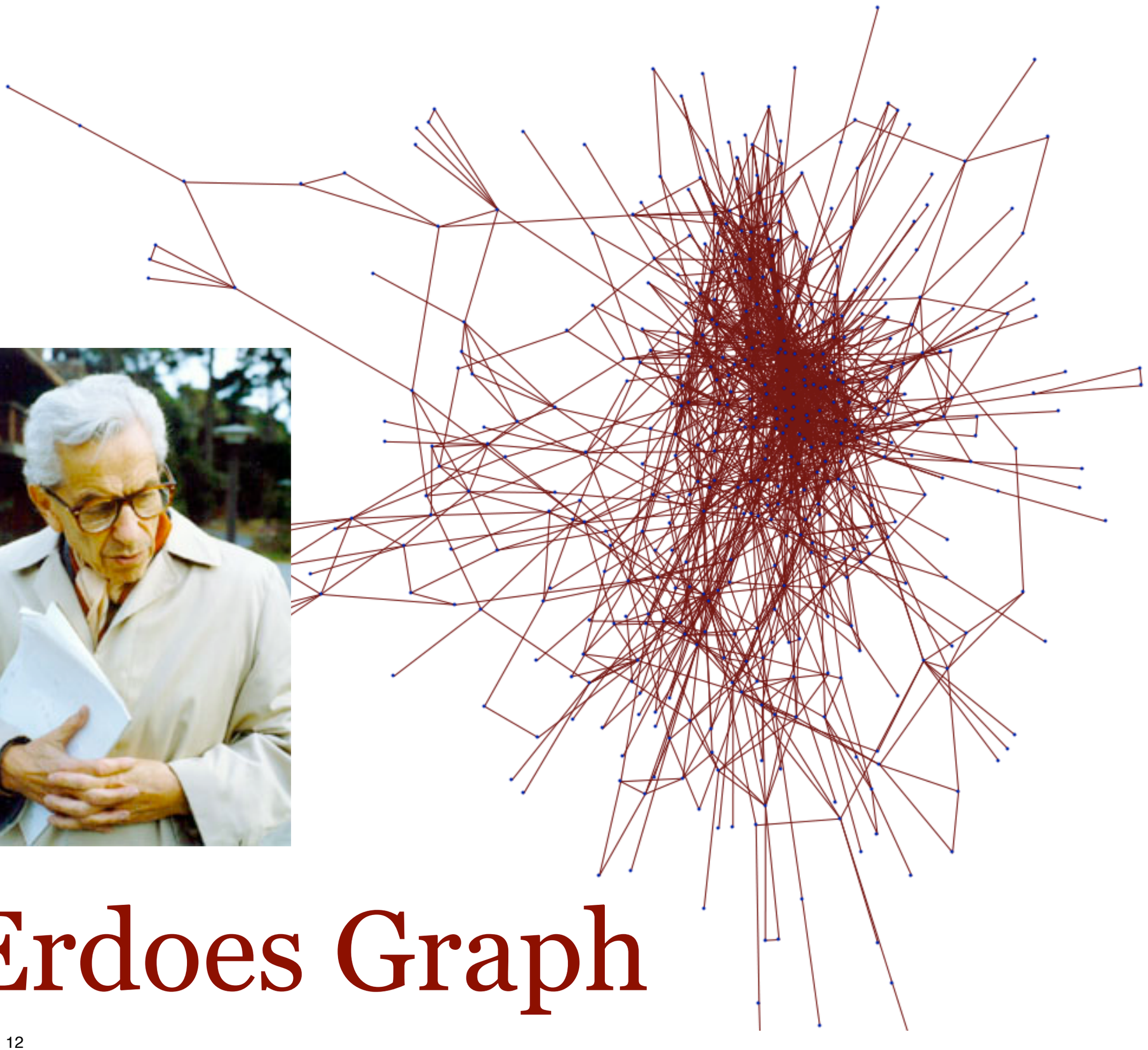
2011: Christakis:

"Nearly half a century later, the answer appears to be yes."

The Trouble With Common Sense,

Nicholas Christakis,

NYT June 24, 2011



Erdoes Graph

Genealogy

King George III — Queen Charlotte

King George IV; Prince Frederick; King WilliamVI; Princess Charlotte; Prince Edward; Princess Victoria; Princess Augusta; Princess Elizabeth; Prince Ernest; Prince Augustus; Prince Adolphus; Princess Mary; Princess Sophia; Prince Octavius; Prince Alfred; Princess Amelia

Queen Victoria — Prince Consort Albert

Princess Victoria; King (Albert) Edward VII — Princess Alexandra; Princess Alice; Prince Alfred; Princess Helena; Princess Louise; Prince Arthur; Prince Leopold; Princess Beatrice

Prince Albert Victor; King George V — Princess consort Mary of Teck; Princess Louise; Princess Victoria; Princess Maud; Prince Alexander

Prince Edward VIII; King George VI — Queen Elizabeth; Princess Mary; Prince Henry; Prince George; Prince John

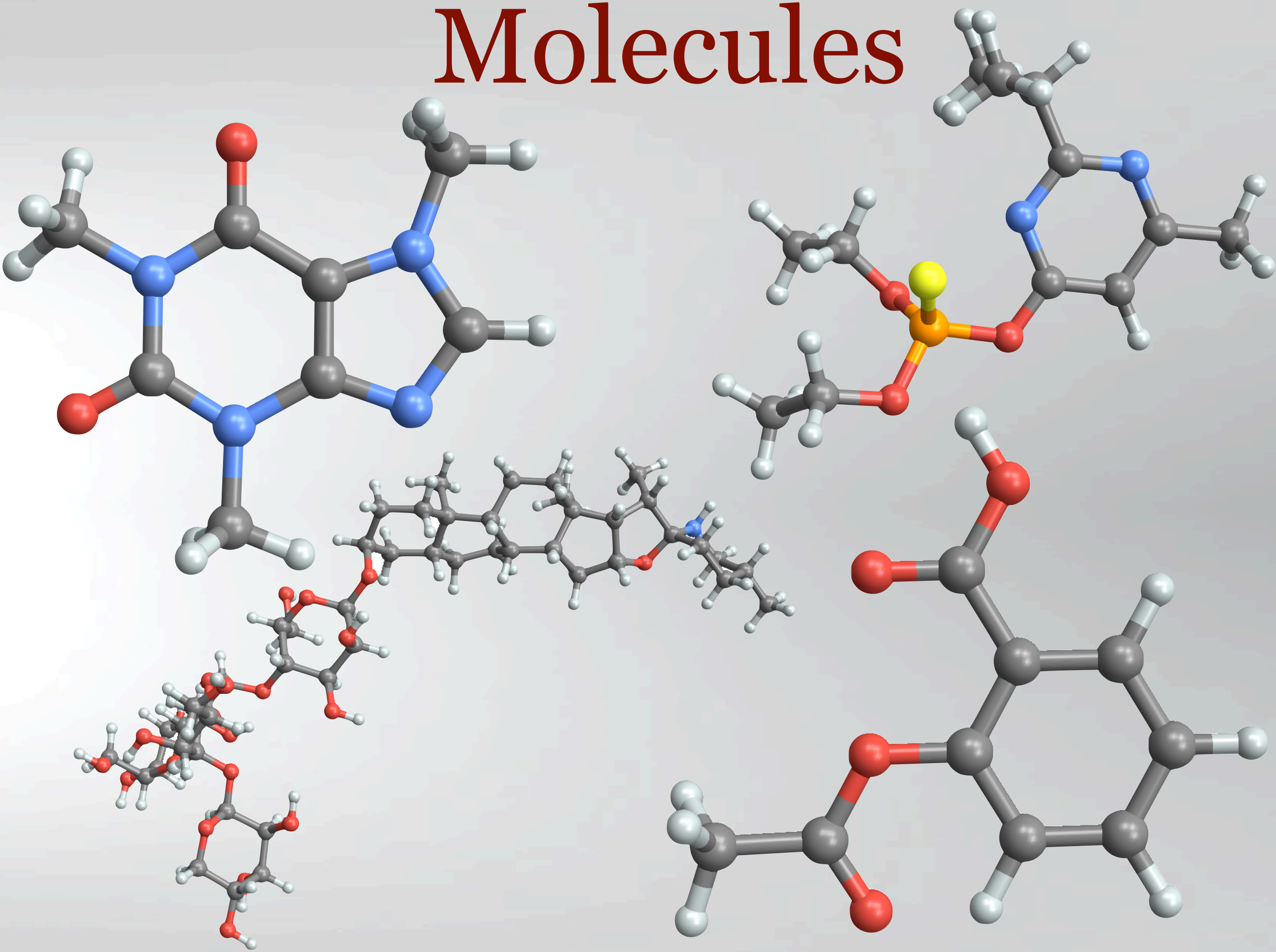
Queen Elizabeth II — Prince consort Philip; Princess Margaret

Prince Charles — Princess Diana; Princess Anne; Prince Andrew; Prince Edward

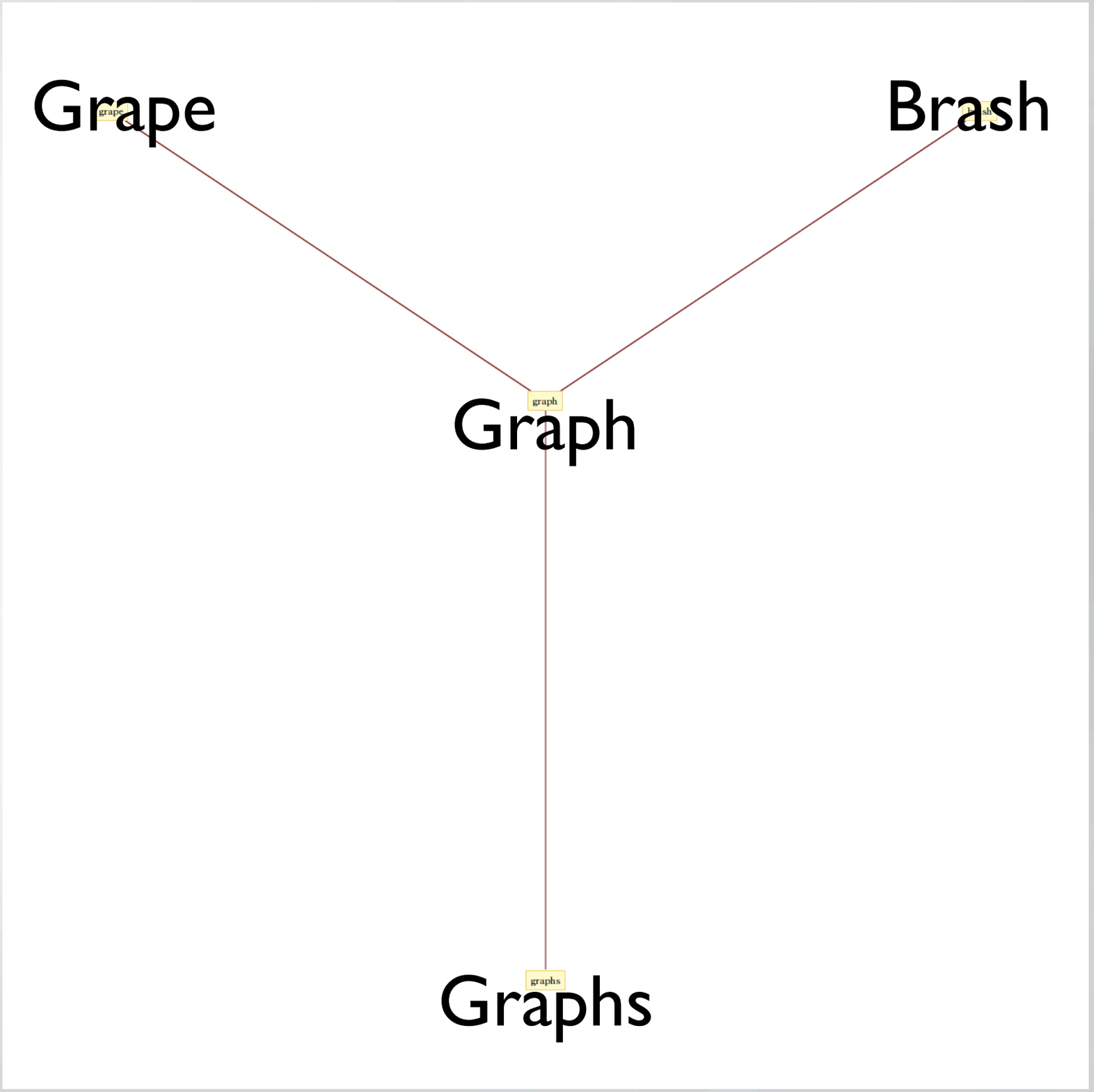
Prince William; Prince Henry

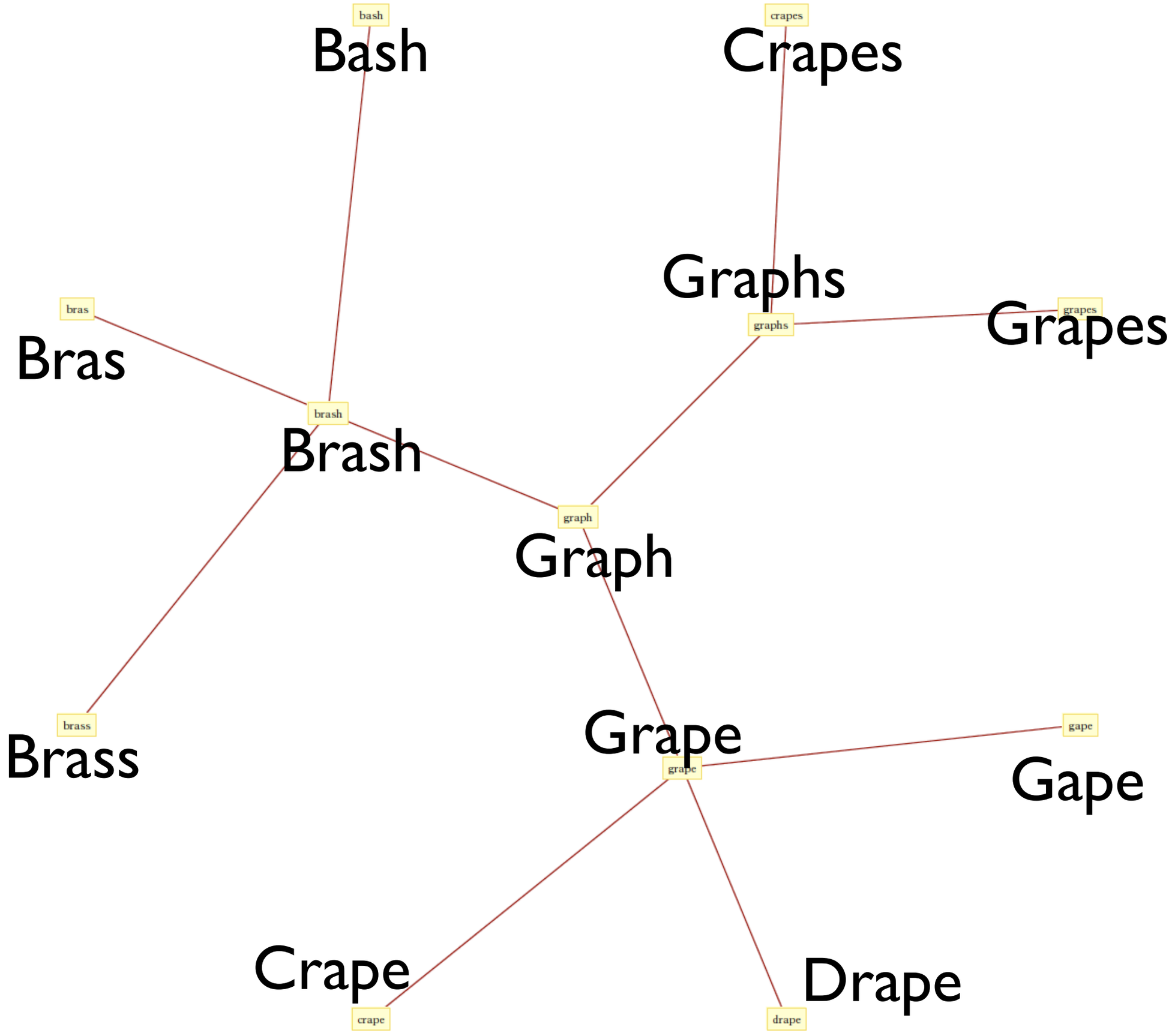
* names in red ruled during Jane Austen's life

Molecules



Word changes




bash
Bash
crapes
Crapes
Graphs
graphs
grapes
Grapes
bras
Bras
brash
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graph
Graph
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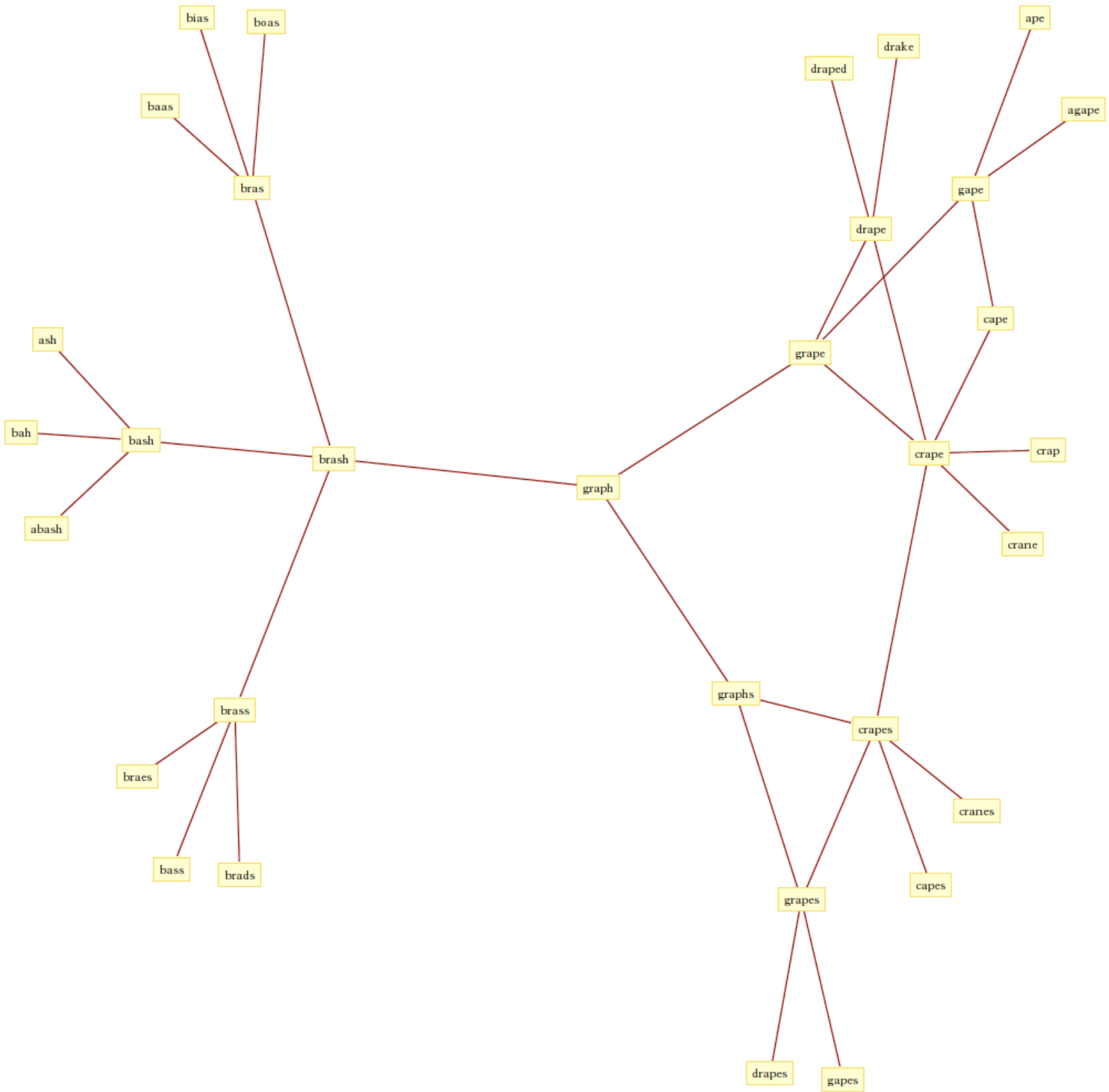
Brass
Grape
grape
gape
Gape
Crape
crape
Drape
drape
distance 2


bias
boas
baas
bras
ash
bah
bash
brash
abash
brass
braes
bass
brads
graph
draped
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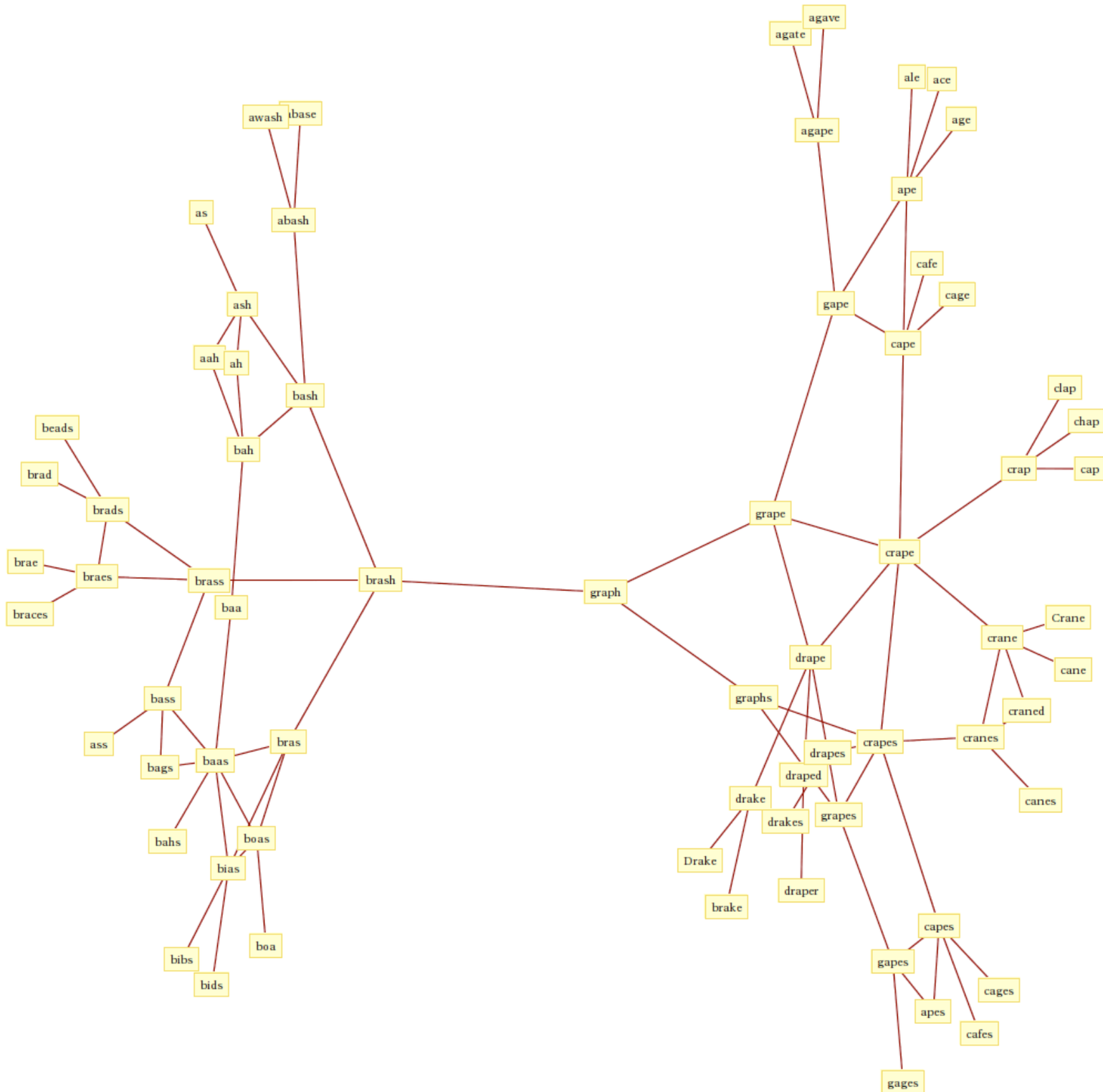
ape
agape
gape
drape
cape
grape
crap
crape
crane
graphs
crapes
cranes
capes
grapes
drapes
gapes

distance 3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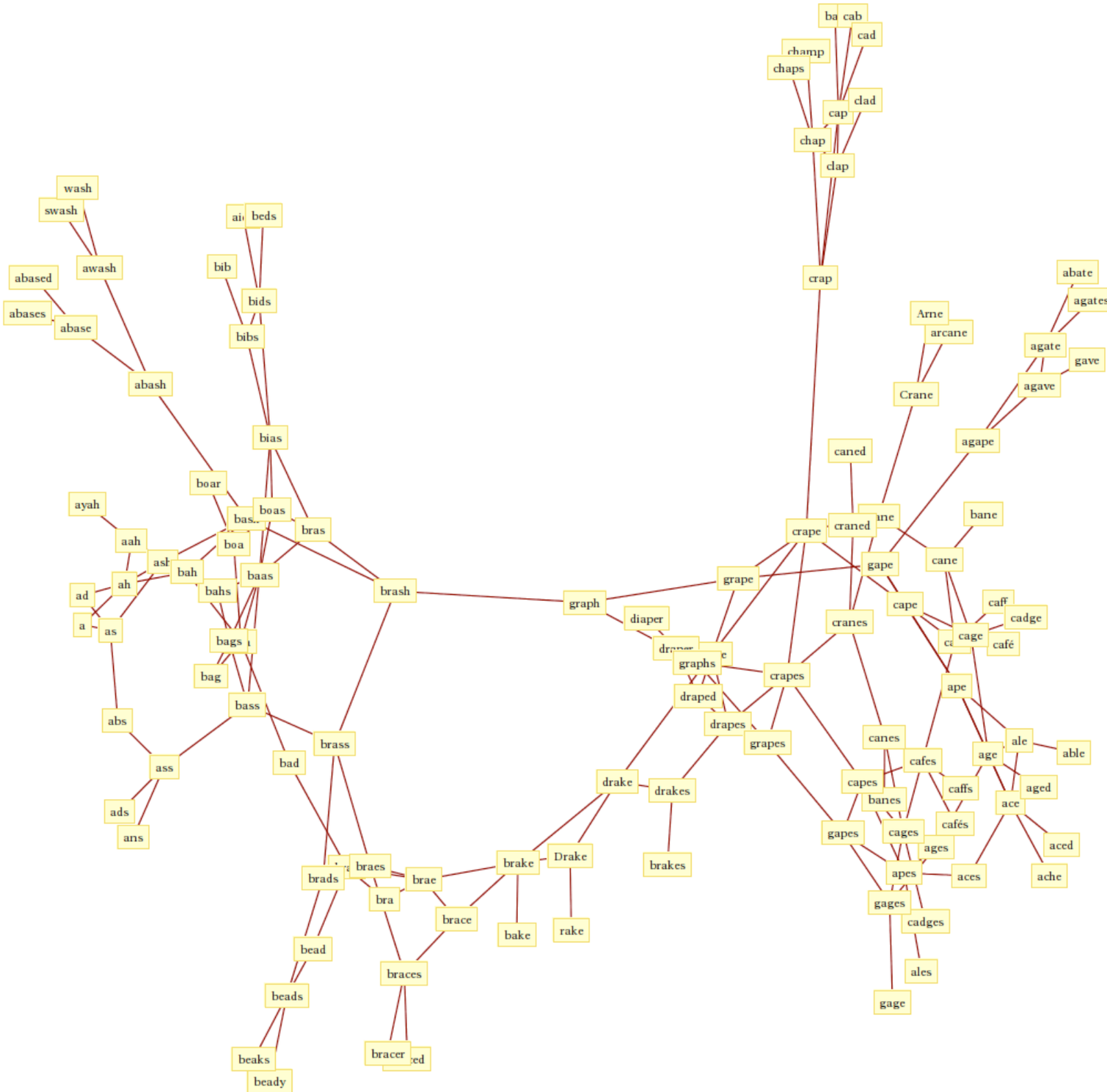
as
abash
ash
aah
ah
bash
beads
bah
brad
brads
brae
braes
brass
brash
braces
baa
bass
ass
bags
baas
bras
bahs
boas
bias
bibs
bids
boa
agave
agate
agape
ale
ace
age
ape
cafe
cage
gape
cape
clap
chap
crap
cap
grape
crape
graph
Crane
crane
cane
drape
graphs
craned
crapes
cranes
drapes
draped
canes
drake
drakes
grapes
Drake
draper
brake
capes
gapes
cages
apes
cafes
gages

distance 4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abash
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bids
bibs
bias
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boas
bras
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aah
boa
bah
baas
bahs
ah
ad
a
as
bags
bag
bass
abs
ass
ads
ans
brass
bad
brash
graph
diaper
graphs
draped
drapes
grapes
drake
drakes
brakes
brake
Drake
brae
braes
brads
bra
brace
bake
rake
bead
beads
beaks
beady
braces
bracer
cab
cad
champ
chaps
clad
cap
chap
clap
crap
abate
agates
Arne
arcane
agate
gave
agave
Crane
agape
caned
crape
craned
bane
gape
cane
grape
cape
caff
cadge
cranes
cage
café
crapes
ape
canes
ale
able
cafes
age
capes
caffs
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cafés
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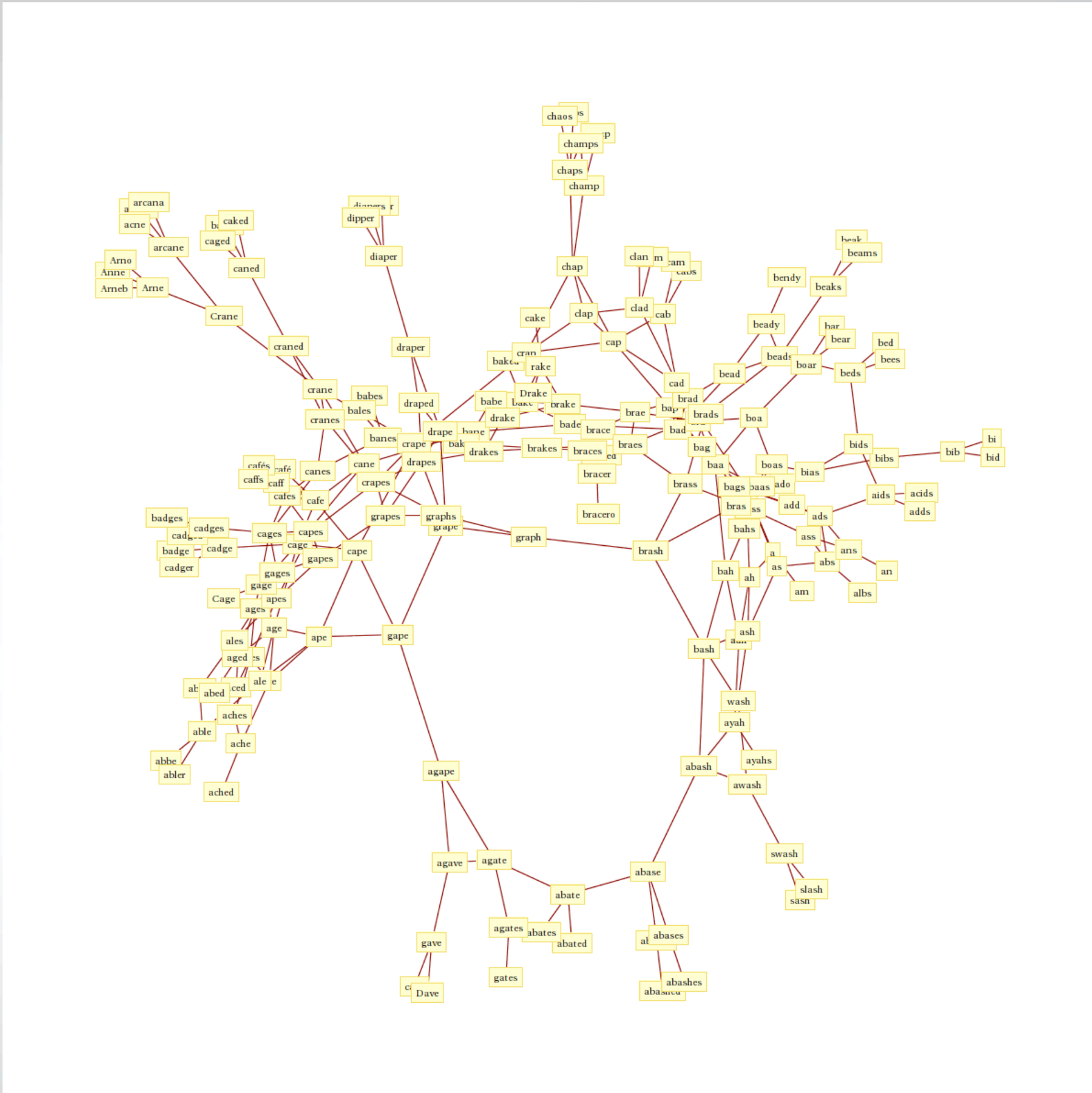
apes
aces
ache
gages
cadges
ales
gage

distance 5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champ
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arcane
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caned
Arno
Anne
Arneb
Arne
Crane
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babes
bales
banes
cane
canes
cafés
caffs
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drapes
drape
draped
draper
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dipper
chap
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clap
clad
cab
cap
rake
Drake
babe
drake
brake
brae
brace
bade
drakes
brakes
braces
braes
bracer
bracero
graph
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grapes
cape
gape
ape
gapes
cages
capes
cadges
badges
badge
cadge
cadger
gages
gage
Cage
apes
ages
age
ales
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able
ache
abbe
abler
ached
agape
agave
agate
gave
Dave
agates
gates
abate
abated
abase
abases
abashes
abash
awash
swash
slash
ayah
ayahs
wash
bash
ash
brash
bah
ah
as
am
abs
albs
ans
an
ass
ads
add
aids
acids
adds
bids
bibs
bib
bi
bid
bias
boas
bag
baa
brass
bags
bras
bahs
brad
brads
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bendy
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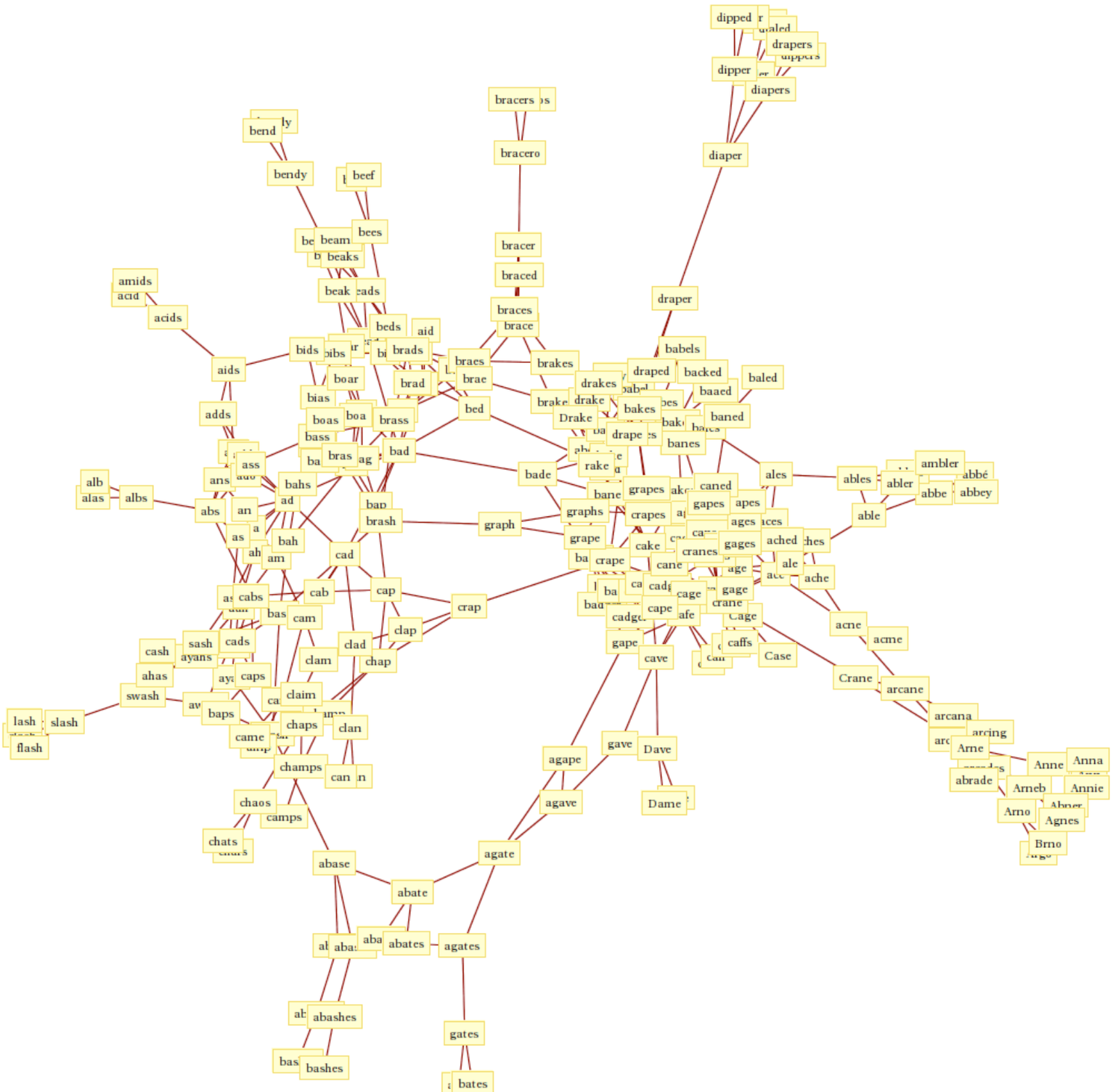
beams
bar
ado

distance 6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bend
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beef
bees
beam
beaks
beak
amids
acid
acids
beds
aid
bids
brads
brae
brakes
draped
backed
baled
aids
boar
brad
drakes
baaed
bias
bed
drake
bakes
baned
adds
boas
brass
Drake
drape
banes
bass
bad
bras
ass
rake
bade
ales
ambler
abbé
ables
abler
abbe
abbey
alb
alas
albs
bahs
grapes
caned
abs
an
bap
graphs
crapes
gapes
apes
able
brash
graph
ages
as
bah
grape
cake
cranes
gages
ached
ches
am
cad
crape
cane
ale
ache
cabs
cab
cap
crap
cage
gage
bas
cam
cape
crane
Cage
acne
acme
clap
cash
sash
cads
clad
gape
caffs
Case
ayans
clam
chap
cave
ahas
caps
Crane
arcane
swash
claim
arcana
lash
slash
baps
chaps
clan
arcing
flash
came
gave
Dave
Arne
Anne
Anna
agape
abrade
Arneb
Annie
champs
agave
Dame
Arno
Agnes
chaos
camps
Brno
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abate
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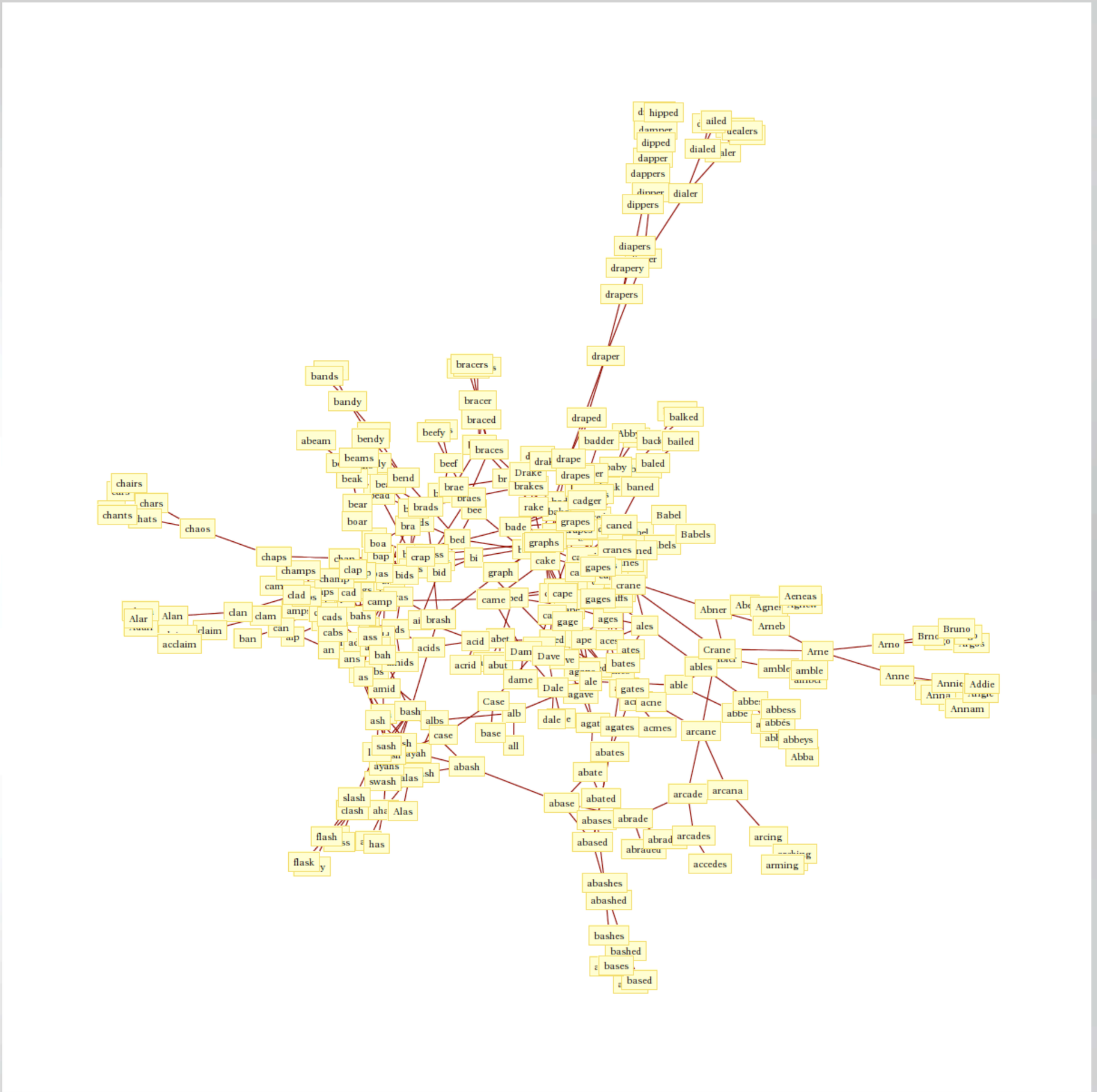
agates
abashes
gates
bashes
bates

distance 7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ailed
dipped
dialed
dapper
dappers
dialer
dippers
diapers
drapery
drapers
draper
bracers
bands
bandy
bracer
braced
draped
balked
abeam
bendy
beefy
braces
badder
bailed
beams
beef
drape
baled
beak
bend
Drake
drapes
chairs
brae
brakes
baned
chars
bear
brads
cadger
chants
boar
rake
Babel
chaos
bade
grapes
caned
Babels
boa
bed
graphs
chaps
bap
crap
cranes
bi
cake
gapes
champs
clap
bids
bid
graph
crane
clad
cad
camp
came
cape
gages
Aeneas
Alar
Alan
clan
clam
cads
bahs
brash
gage
ages
Abner
Arneb
claim
ban
cabs
ass
acid
ales
Bruno
acclaim
acids
Dave
Crane
Arne
Arno
bah
bates
ables
amble
Anne
amid
dame
Dale
ale
gates
able
Annie
Addie
Annam
Case
alb
abbess
bash
ash
albs
dale
agates
acmes
arcane
abbés
case
base
all
abbeys
sash
abates
Abba
abash
abate
swash
arcade
arcana
slash
abase
abated
Alas
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arcades
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flask
accedes
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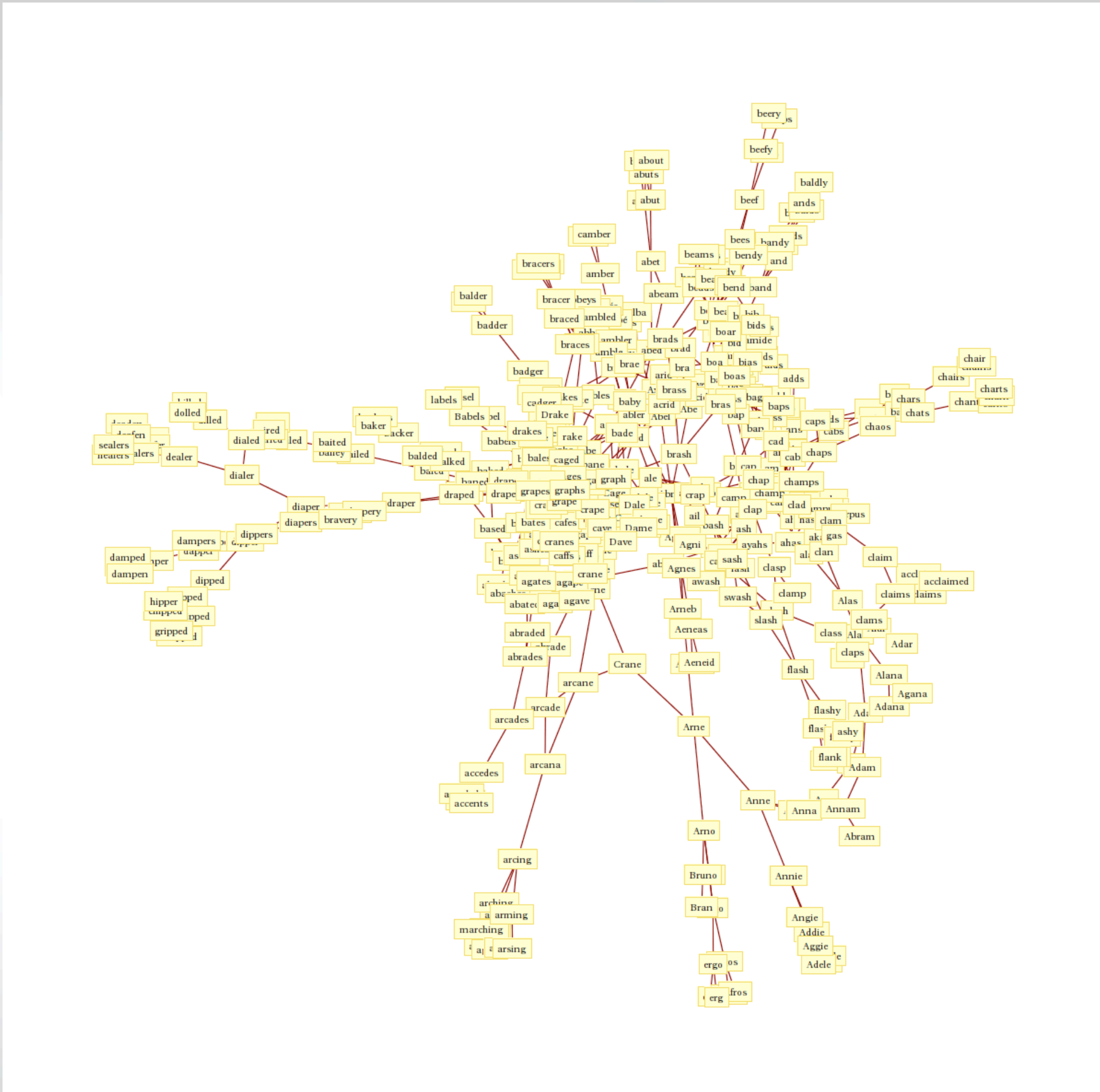
abashes
abashed
bashes
bashed
bases
based

distance 8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about
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abut
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beef
ands
camber
bees
bandy
bracers
amber
abet
beams
bendy
and
balder
abeam
bend
band
bracer
beys
braced
ambled
bids
badder
braces
brads
boar
amide
chair
badger
brae
bra
boas
bias
adds
chairs
charts
labels
sel
baby
brass
bras
baps
chars
chats
dolled
Babels
Drake
abler
acrid
Abe
Abel
caps
chaos
baker
drakes
rake
bade
cad
sealers
dealer
dialed
baited
balded
caged
brash
chaps
dialer
graph
chap
champs
draped
drape
grapes
graphs
crap
diaper
draper
grape
Dale
clap
clad
diapers
bravery
based
bates
cafes
Dame
ash
clam
dippers
cranes
Dave
Agni
ayahs
gas
damped
caffs
sash
clan
claim
dampen
crane
Agnes
clasp
acclaimed
dipped
agates
awash
claims
hipper
agave
swash
clamp
Alas
gripped
Arneb
slash
clams
abraded
Aeneas
class
Adar
abrades
Crane
Aeneid
claps
flash
Alana
arcane
Agana
arcade
flashy
Adana
arcades
Arne
ashy
flank
Adam
accedes
arcana
accents
Anne
Anna
Annam
Abram
Arno
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Bruno
Annie
arming
Bran
Angie
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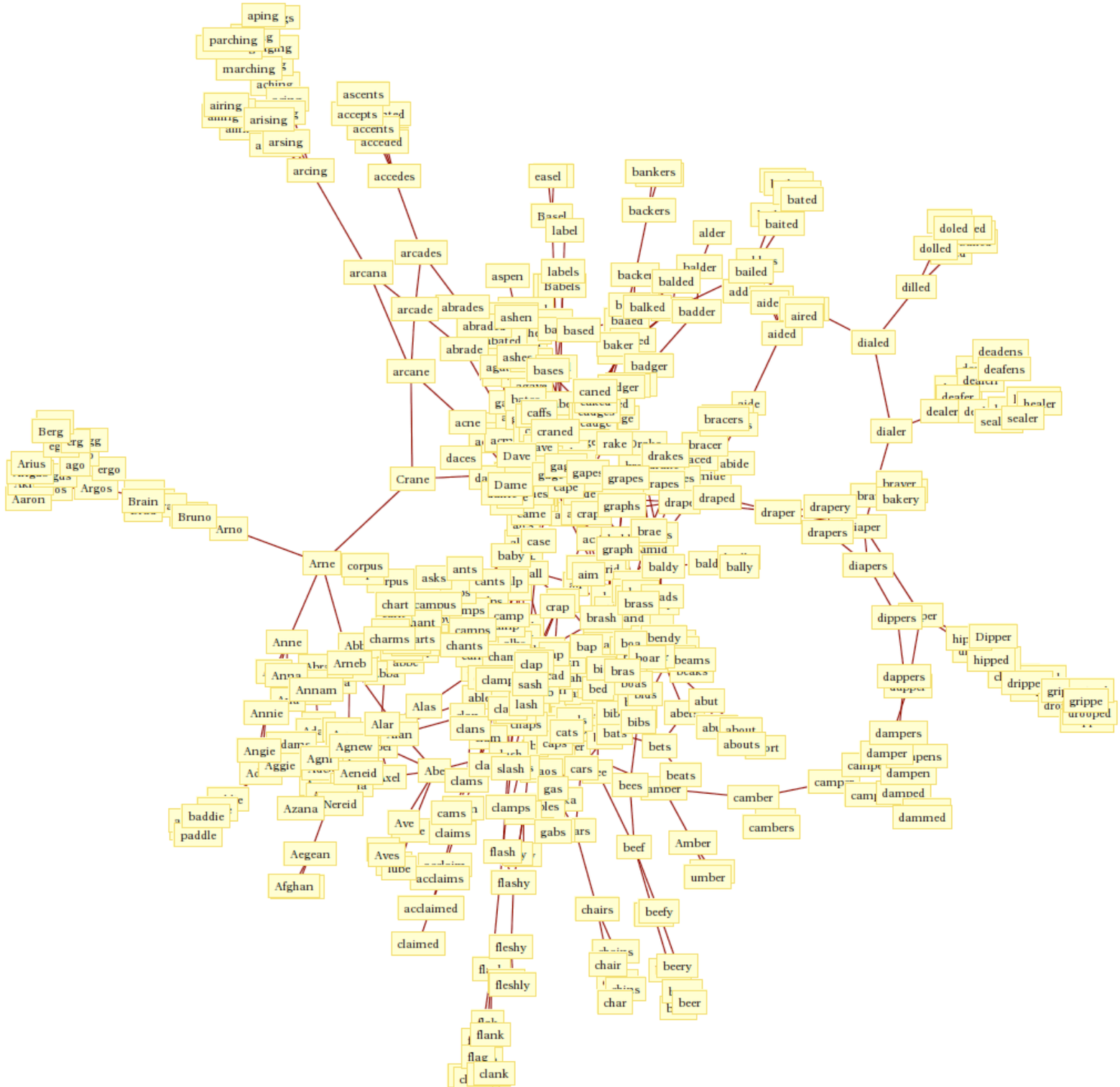
Addie
arsing
Aggie
ergo
Adele
erg

distance 9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abrades
abrade
arcane
Crane
Arne
corpus
Anne
Annam
Annie
Angie
Aggie
Alar
Alas
Aegean
Afghan
Azana
Nereid
baddie
paddle
Aves
Ave
Aeneid
Agnew
Arneb
Berg
Arius
Aaron
Argos
Brain
Bruno
Arno
easel
label
aspen
labels
ashen
based
bases
caned
caffs
craned
acne
daces
Dave
Dame
case
baby
ants
asks
chart
charms
chants
clap
sash
lash
clans
clams
cams
claims
acclaims
acclaimed
claimed
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flashy
fleshy
fleshly
flank
clank
bankers
backers
alder
balded
balked
badder
baker
badger
bracers
bracer
drakes
abide
grapes
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drapery
drapers
braver
bakery
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dippers
Dipper
hipped
dappers
dampers
damper
dampen
damped
dammed
camber
cambers
bated
baited
bailed
aided
aired
dialed
dilled
dolled
doled
deadens
deafens
dealer
sealer
dialer
baldy
bally
brass
brash
bendy
beams
bras
bed
bibs
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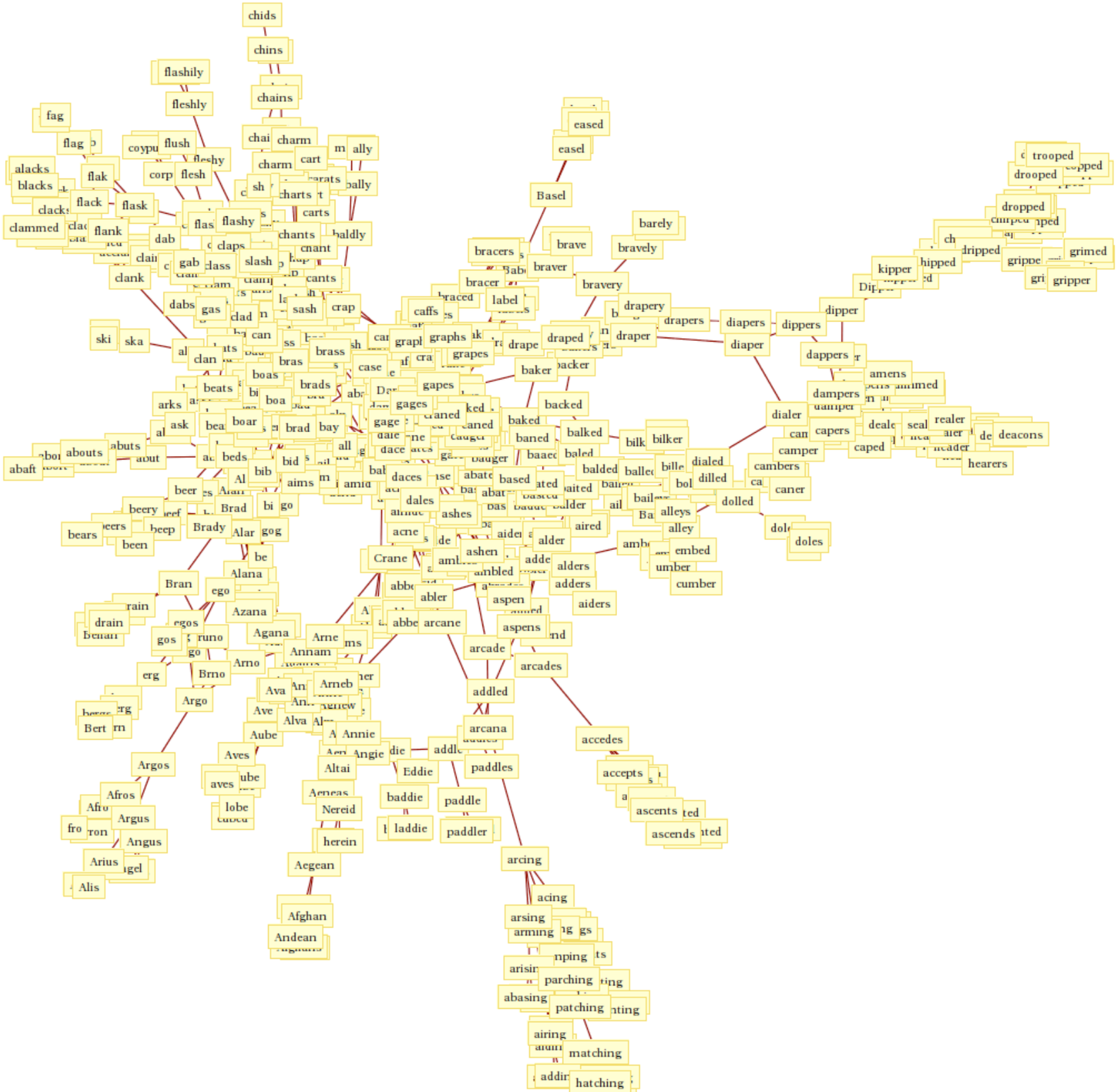
char
beer

distance 10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blacks
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flack
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flashy
dab
claps
gab
class
slash
clank
cants
dabs
gas
sash
crap
ski
ska
brass
boas
beats
brads
boa
arks
ask
boar
brad
bay
abuts
about
abaft
beds
bid
bib
aims
beer
beery
beep
been
bears
Brad
Brady
Alar
gog
be
Alana
Bran
ego
Azana
drain
egos
gos
Agana
Arne
Annam
Arno
erg
Brno
Argo
Ava
Arneb
Ave
Alva
Bert
Aube
Annie
Aves
Argos
Angie
Altai
aves
Eddie
Afros
lobe
Aeneas
Nereid
Argus
Angus
herein
Arius
Aegean
Alis
Afghan
Andean
Crane
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grapes
case
gapes
gages
daces
dales
ashes
acne
ashen
abler
arcane
abbe
eased
easel
Basel
barely
bravely
bracers
brave
braver
bracer
bravery
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draped
drape
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baked
balked
bilker
dialed
dilled
based
aired
alder
alleys
alley
dolled
alders
adders
aiders
embed
cumber
aspen
aspens
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arcades
addled
arcana
paddles
paddle
paddler
laddie
baddie
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acing
arsing
arming
parching
abasing
patching
airing
matching
hatching
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accepts
ascents
ascends
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diaper
dippers
dipper
kipper
hipped
dripped
grimed
gripper
trooped
drooped
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realer
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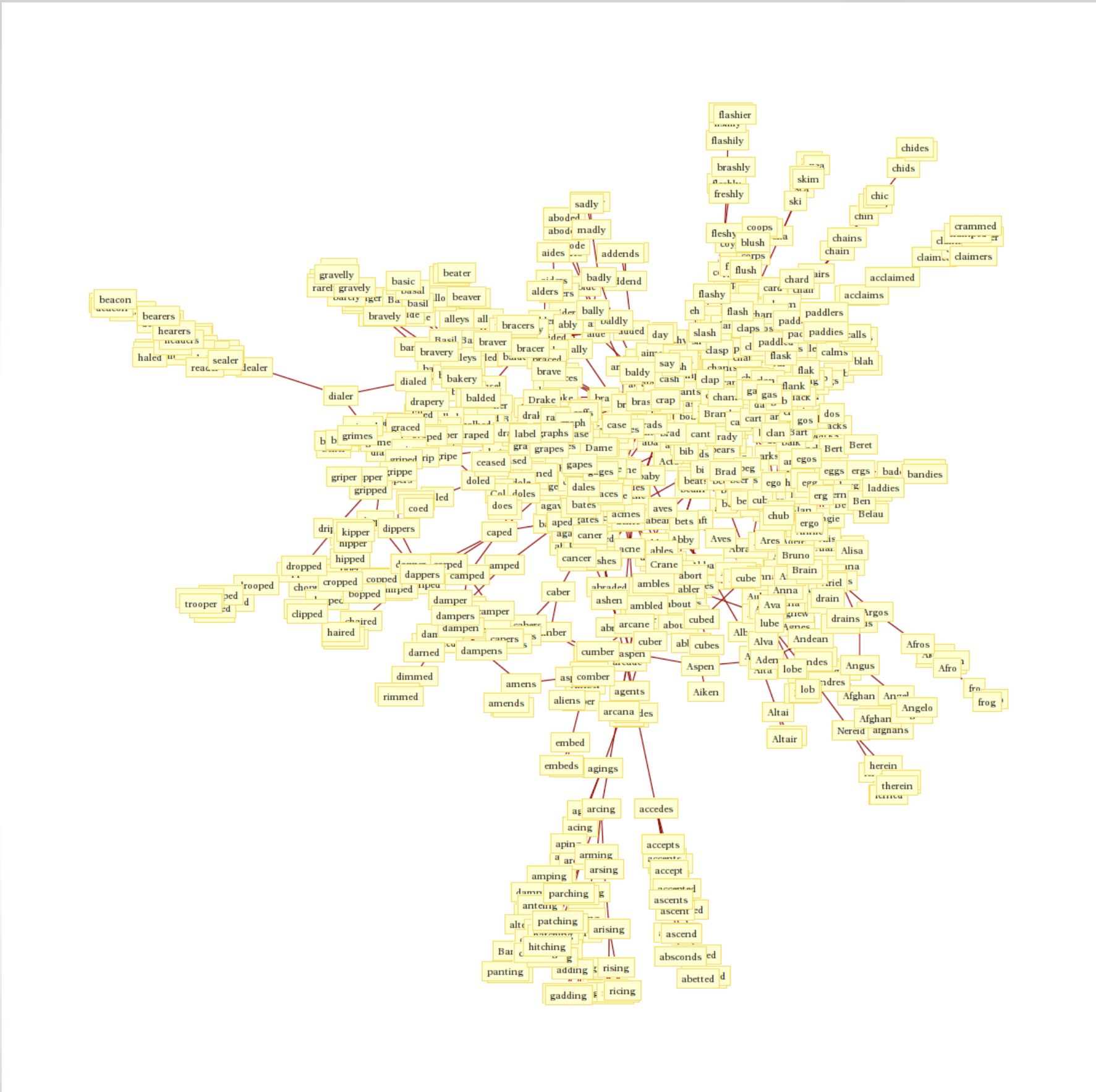
doles

distance 11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acclaims
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paddies
calms
blah
flank
bandies
laddies
Belau
Afros
Afro
frog
Angelo
Angus
Andean
Alisa
Bruno
Brain
Anna
drain
drains
Argos
Aspen
Aiken
Altai
Altair
Afghan
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therein
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madly
addends
badly
bally
baldly
day
say
baldly
cash
crap
case
cant
Dame
gapes
dales
bates
acmes
aves
caner
cancer
Crane
ambles
ashen
ambled
about
cubed
cuber
cubes
aspen
comber
agents
arcana
aliens
amens
amends
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dampen
dampens
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rimmed
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trooper
dropped
cropped
bopped
kipper
dippers
hipped
coed
doled
ceased
graced
grimes
gripped
griper
gravelly
gravely
basic
beater
beaver
bravely
bravery
braver
bracers
bracer
alleys
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drapery
balded
dialer
beacon
bearers
hearers
sealer
dealer
haled
Drake
label
grapes
slash
clap
flash
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flush
fleshy
blush
coops
chard
Beret
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eggs
ergs
ergo
chub
Ares
Aves
Abby
bets
abort
abler
cube
Ava
lube
Alva
Aden
lobe
lob
Nereid
Afghan
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embeds
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accedes
accepts
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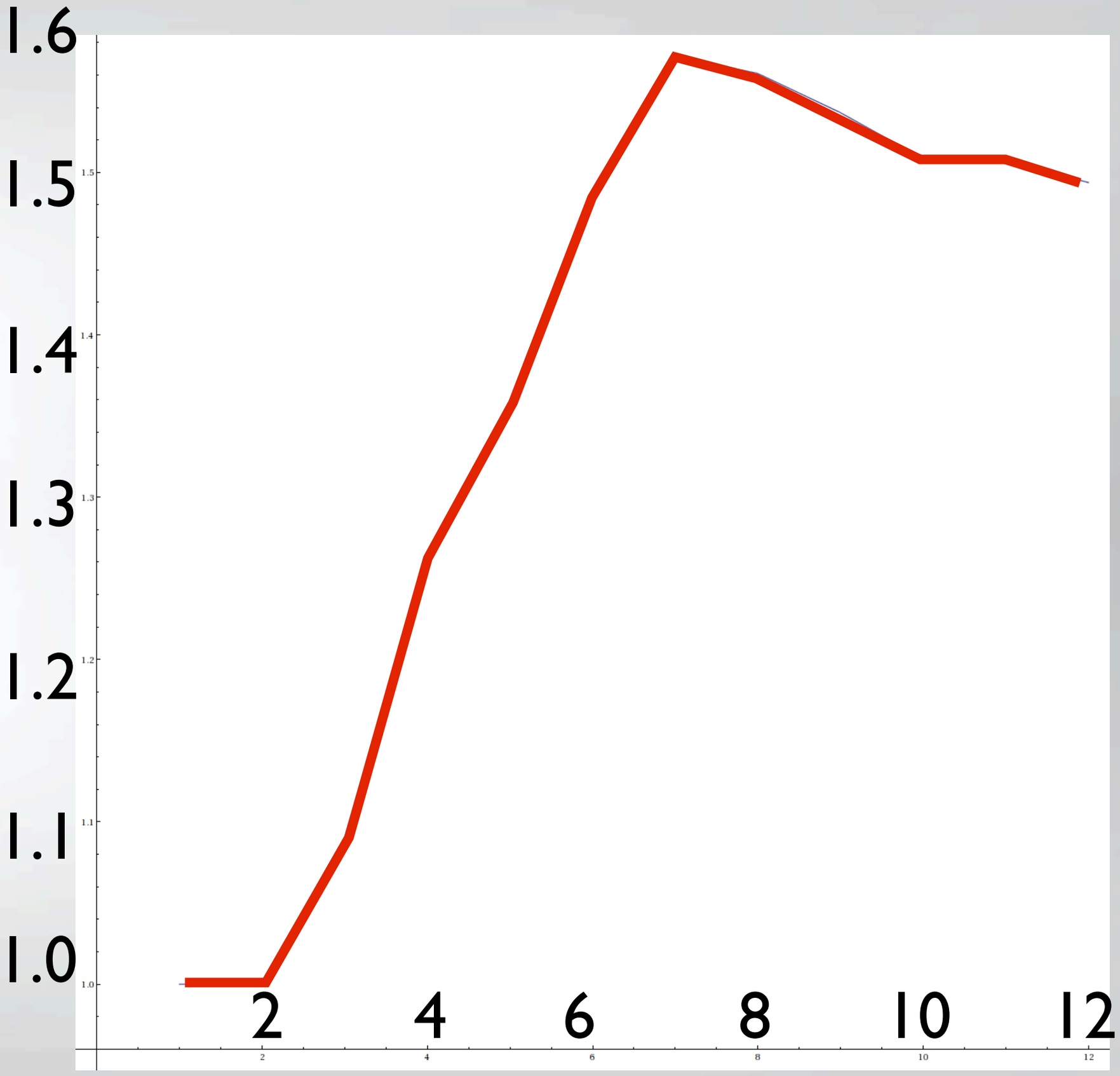
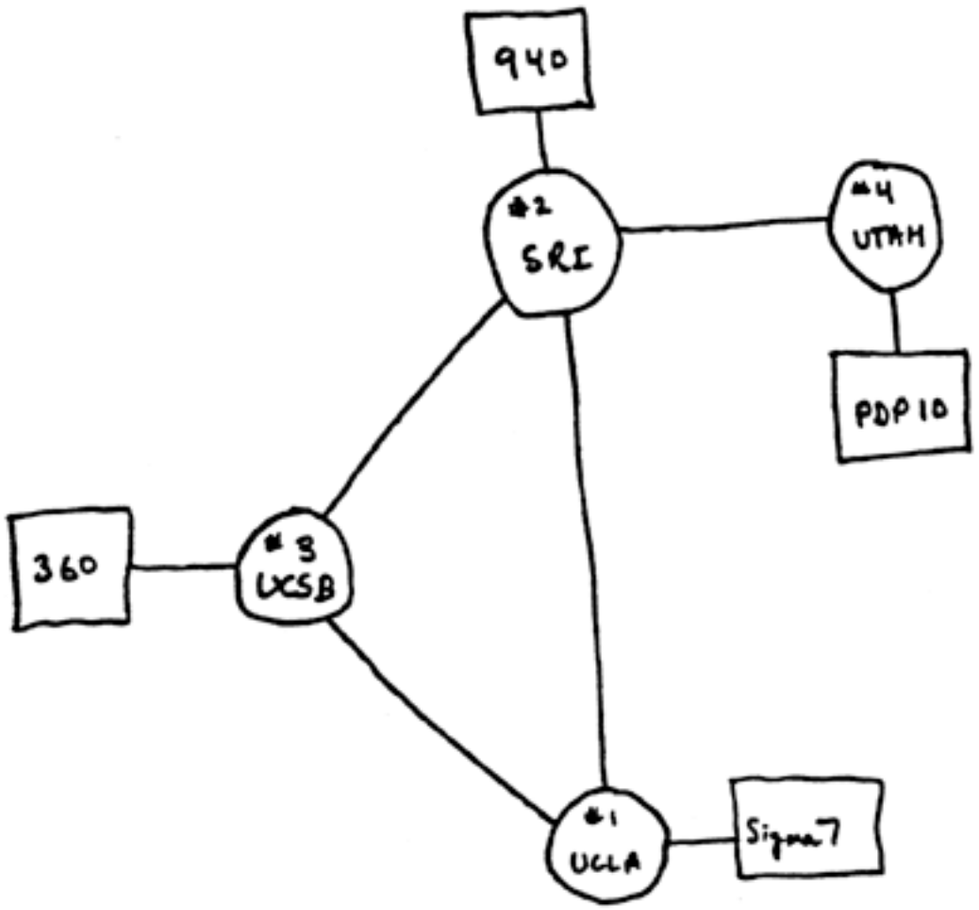
distance 12

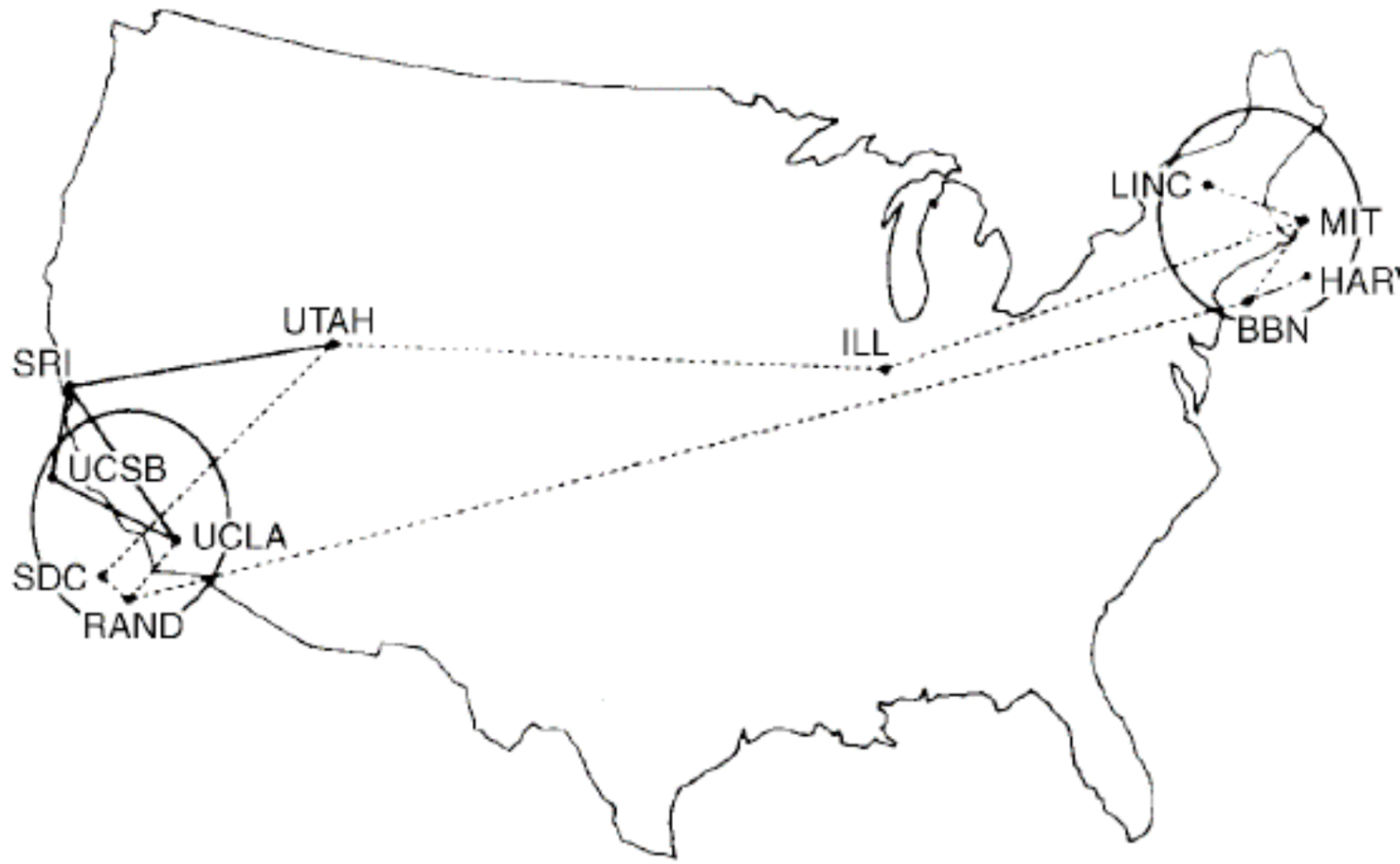
Dimension growth



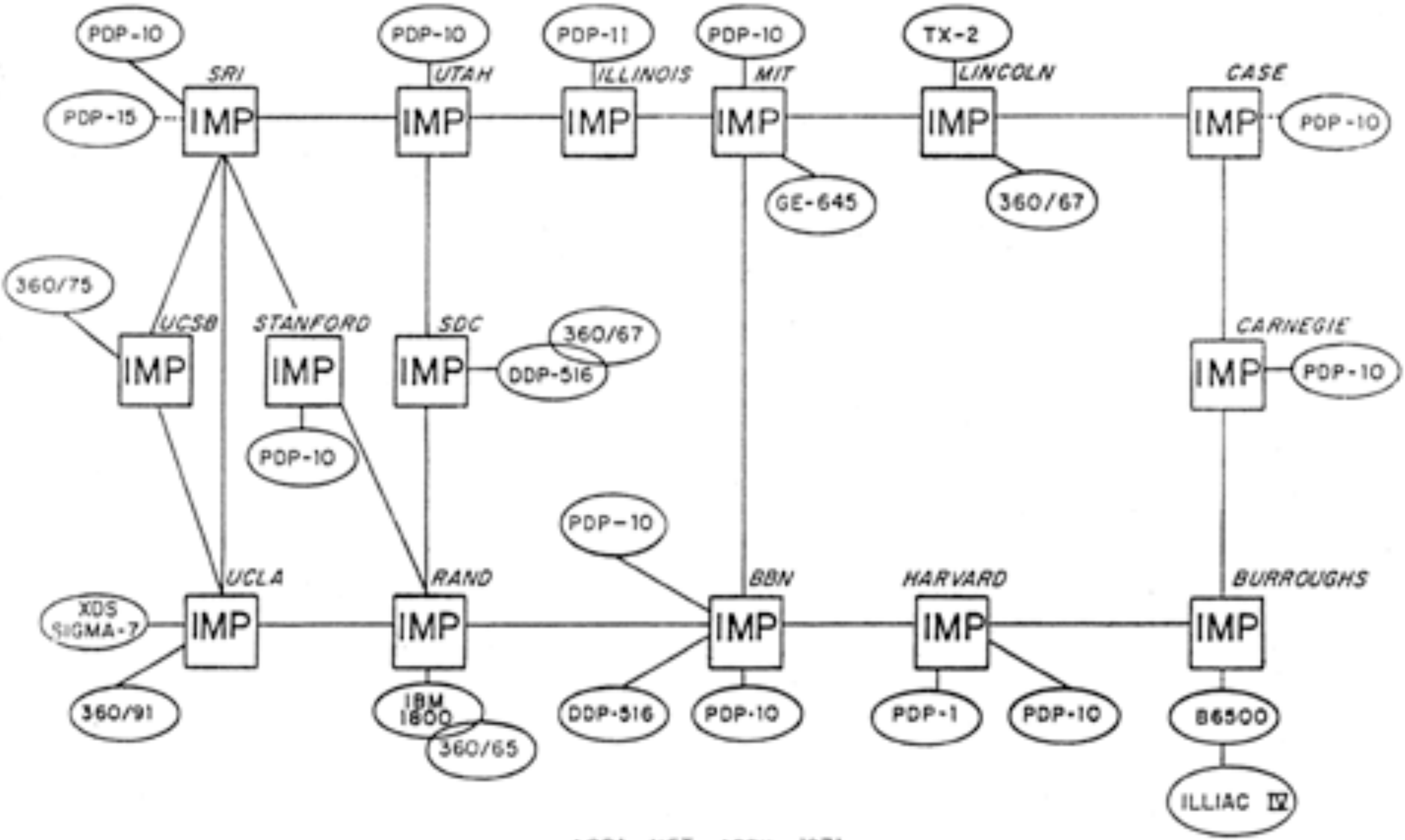
Internet



1969



1970

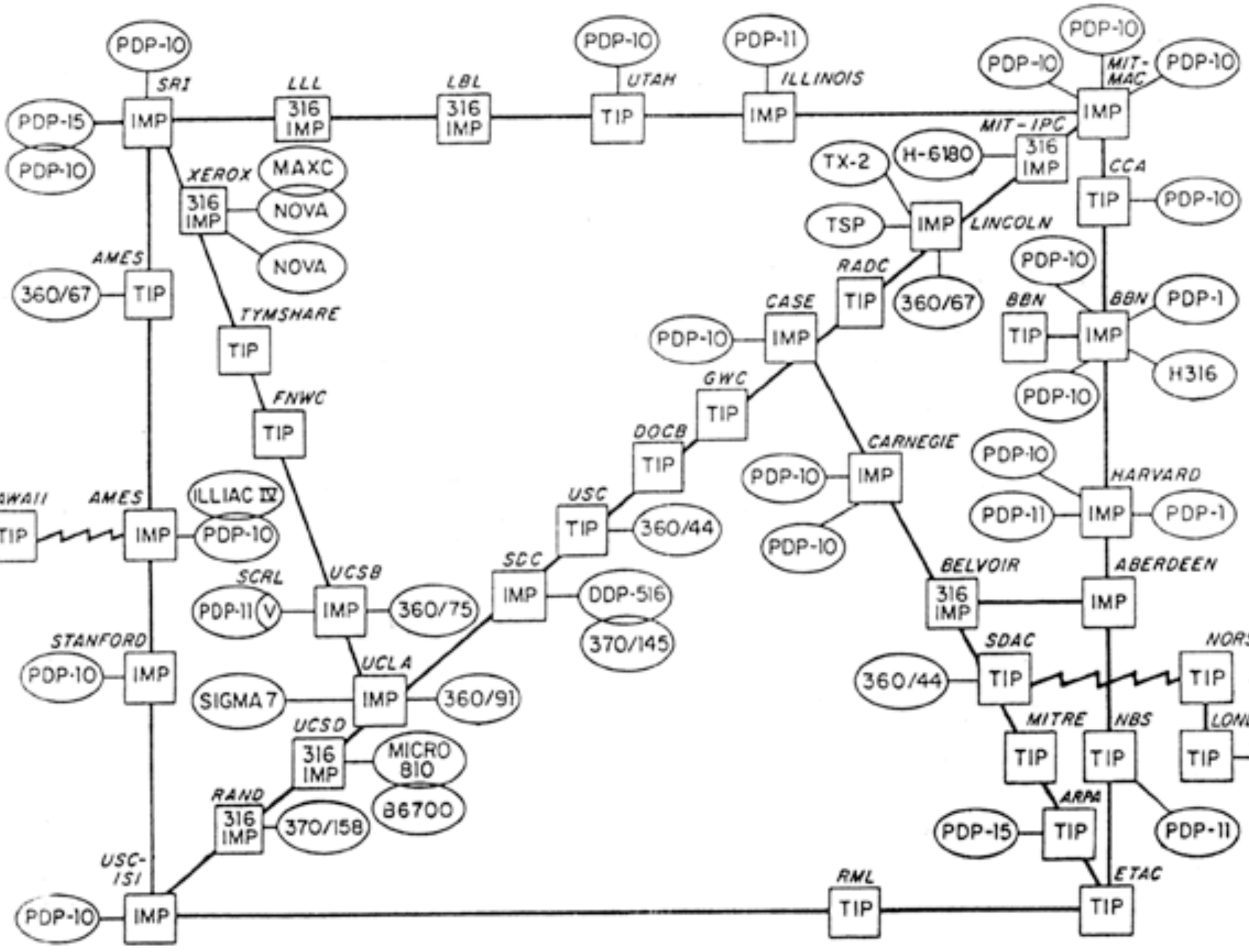


ARPA NET, APRIL 1971

1971

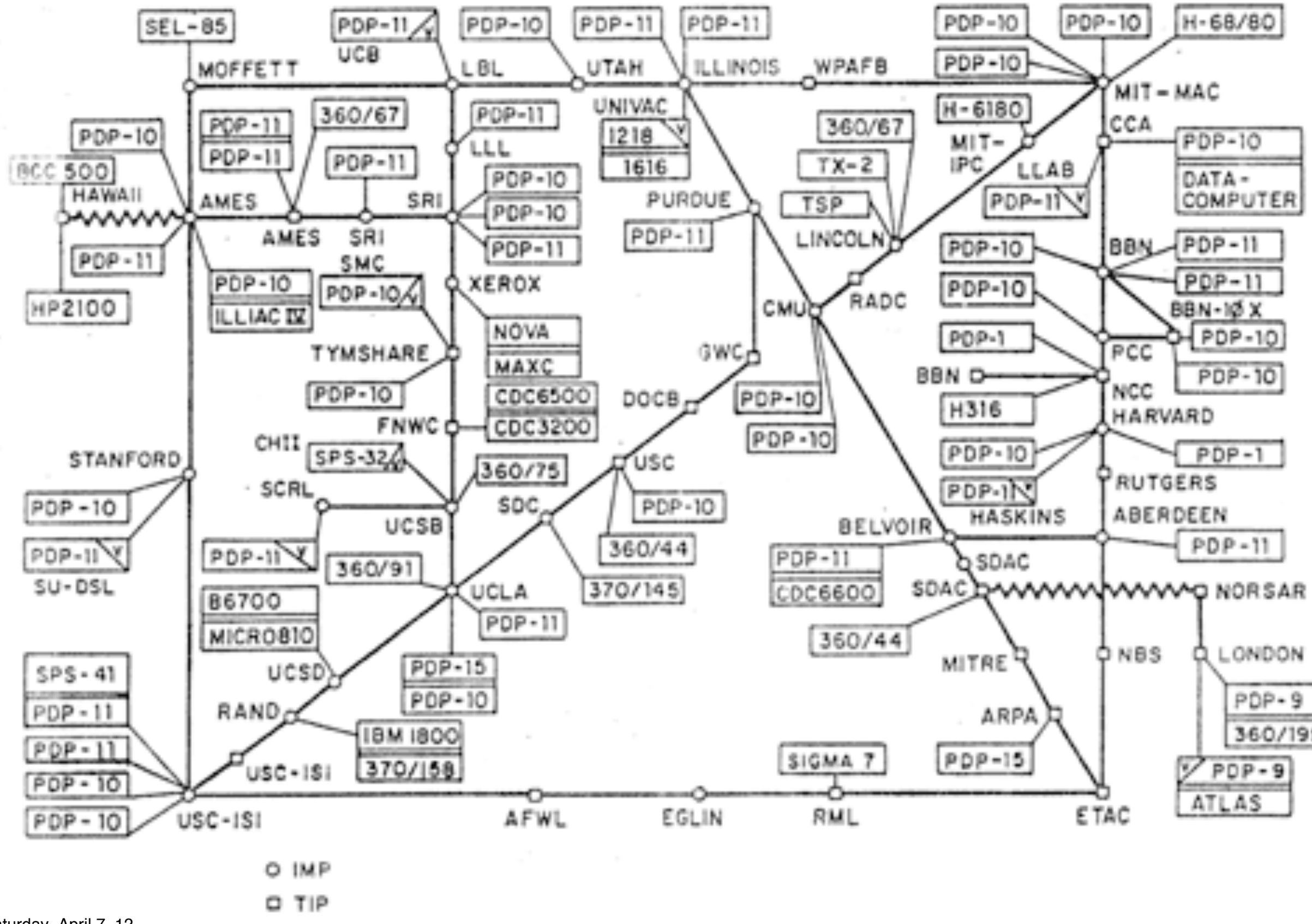
ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973

1973

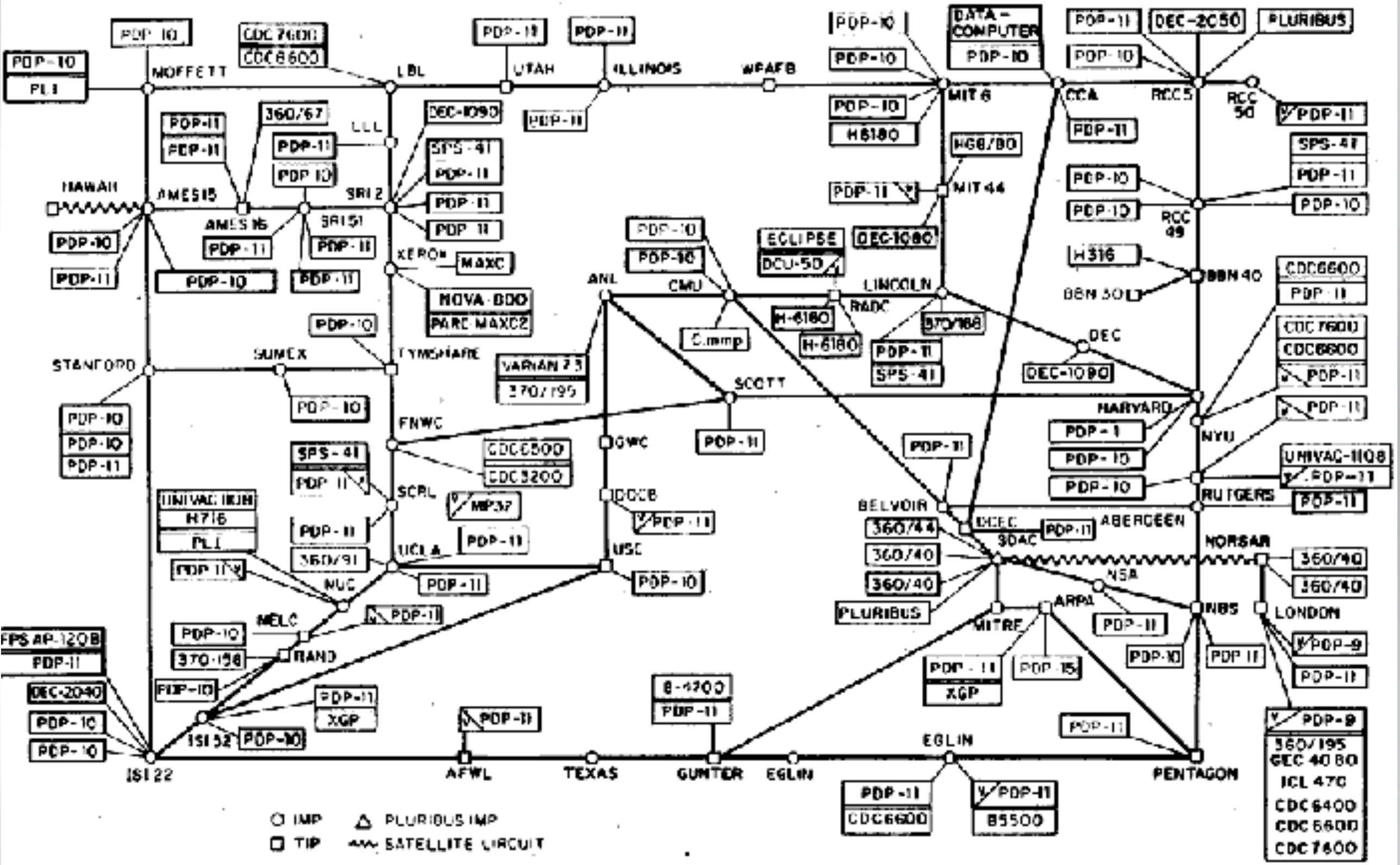


ARPA NETWORK, LOGICAL MAP, JANUARY 1975

1975



1977



MOFFETT
LBL
UTAH
ILLINOIS
WPAFB
MIT 6
CCA
RCC 5
RCC 50
DEC-2050
PLURIBUS
DATA-COMPUTER
PDP-10
PDP-11
PL1
CDC 7600
CDC 6600
360/67
LLL
DEC-1090
SPS-41
HAWAII
AMES 15
AMES 16
SRI 2
SRI 51
XEROX
MAXC
NOVA-800
PARC MAXC2
MIT 44
HG8/80
DEC-1080
ECLIPSE
DCU-50
LINCOLN
RADC
H-6180
370/168
H316
BBN 40
BBN 30
RCC 49
CDC6600
CDC 7600
DEC
DEC-1090
ANL
CMU
C.mmp
VARIAN 73
370/195
SCOTT
STANFORD
SUMEX
TYMSHARE
FNWC
GWC
CDC6500
CDC3200
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DCCB
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H716
PL1
360/91
UCLA
USC
NUC
MELC
RAND
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ISI 22
AFWL
TEXAS
GUNTER
EGLIN
8-4200
PENTAGON
HARVARD
NYU
RUTGERS
ABERDEEN
BELVOIR
DCEC
SDAC
NORSAR
NSA
ARPA
MITRE
NBS
LONDON
360/44
360/40
PLURIBUS
XGP
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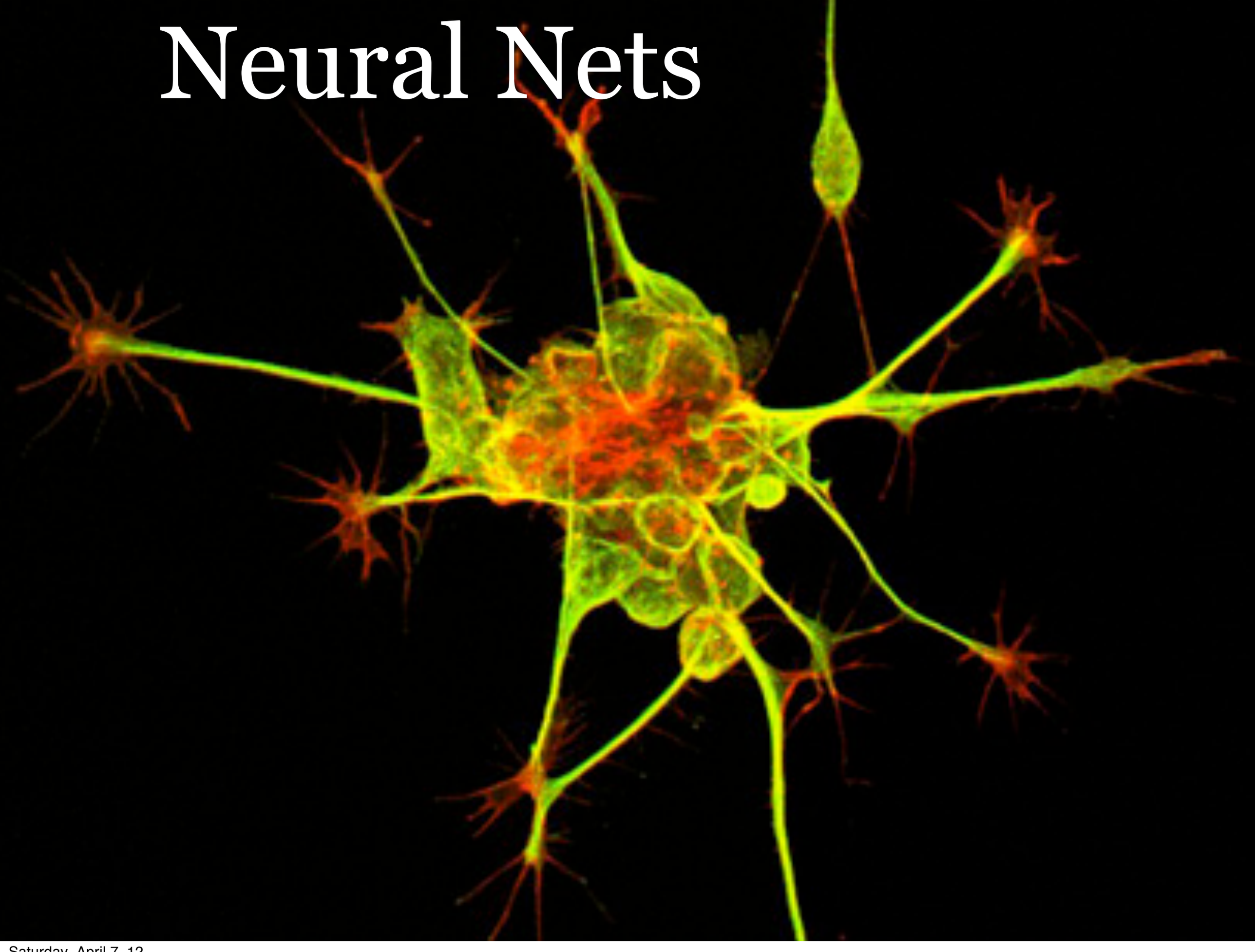
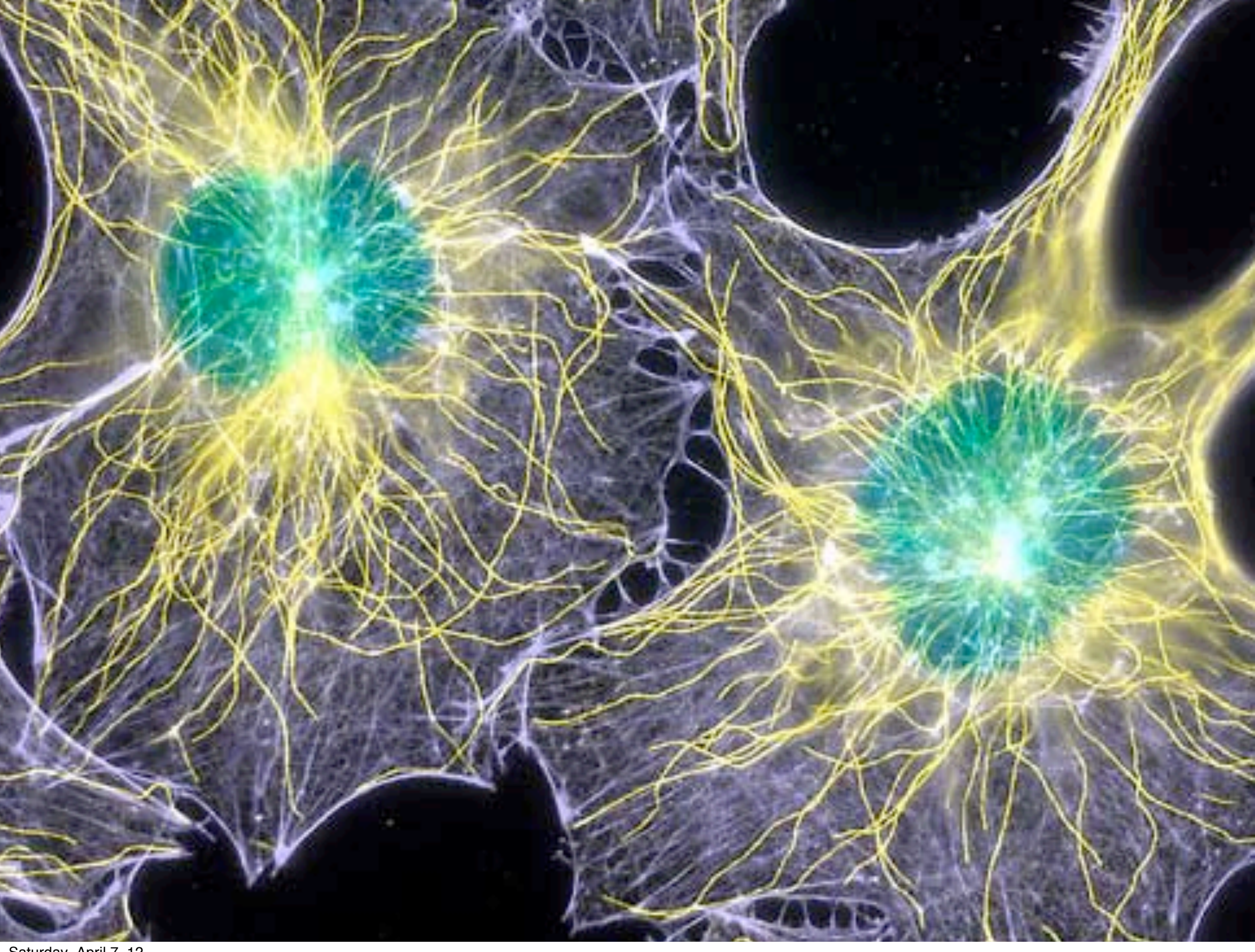
PDP-9
360/195
GEC 4080
ICL 470
CDC6400
CDC 6600
CDC 7600
B5500
IMP
TIP
PLURIBUS IMP
SATELLITE CIRCUIT

World Wide Web

Picture: The math book

Neural Nets





Brain

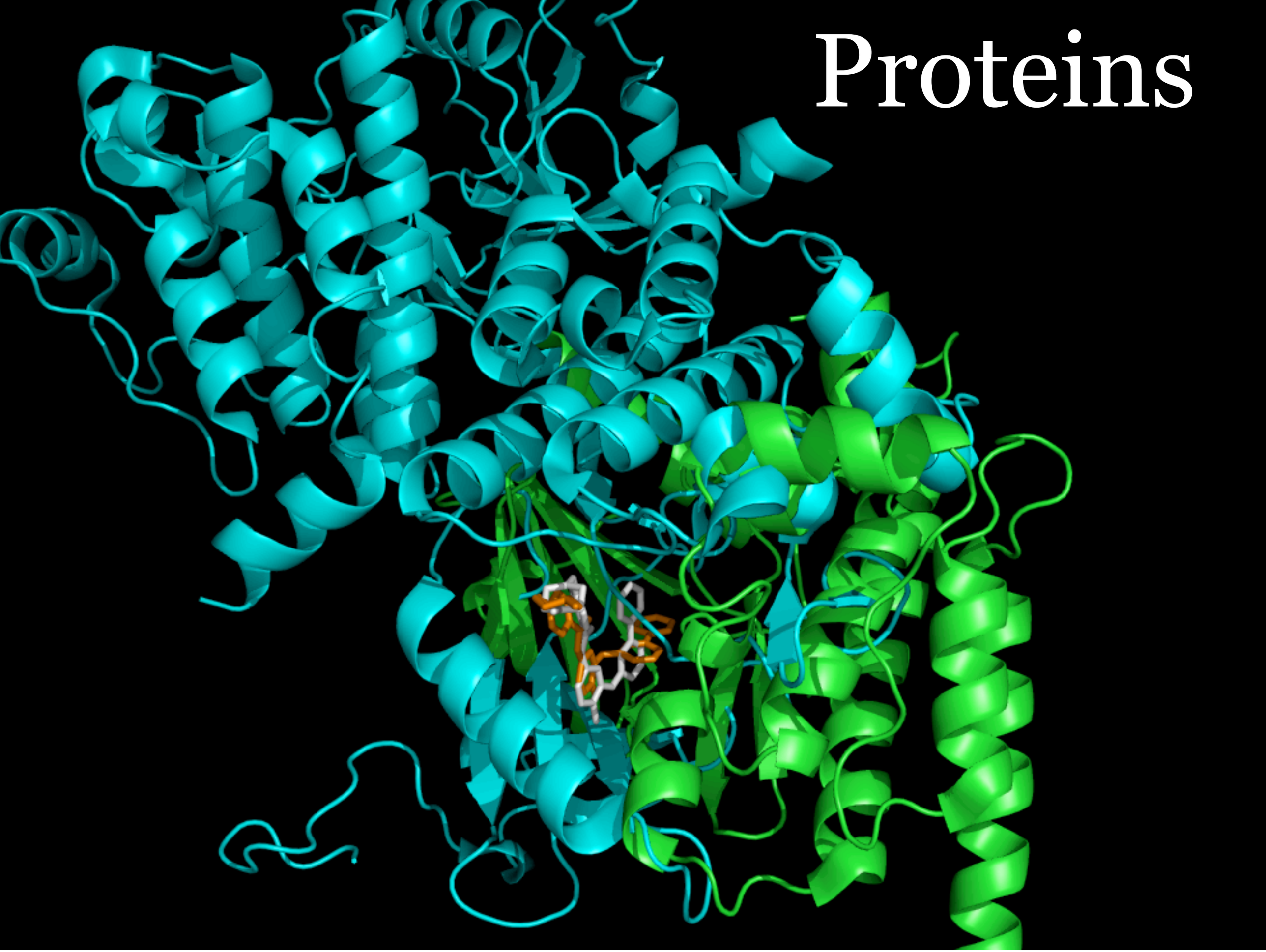
van Wedeen Harvard University

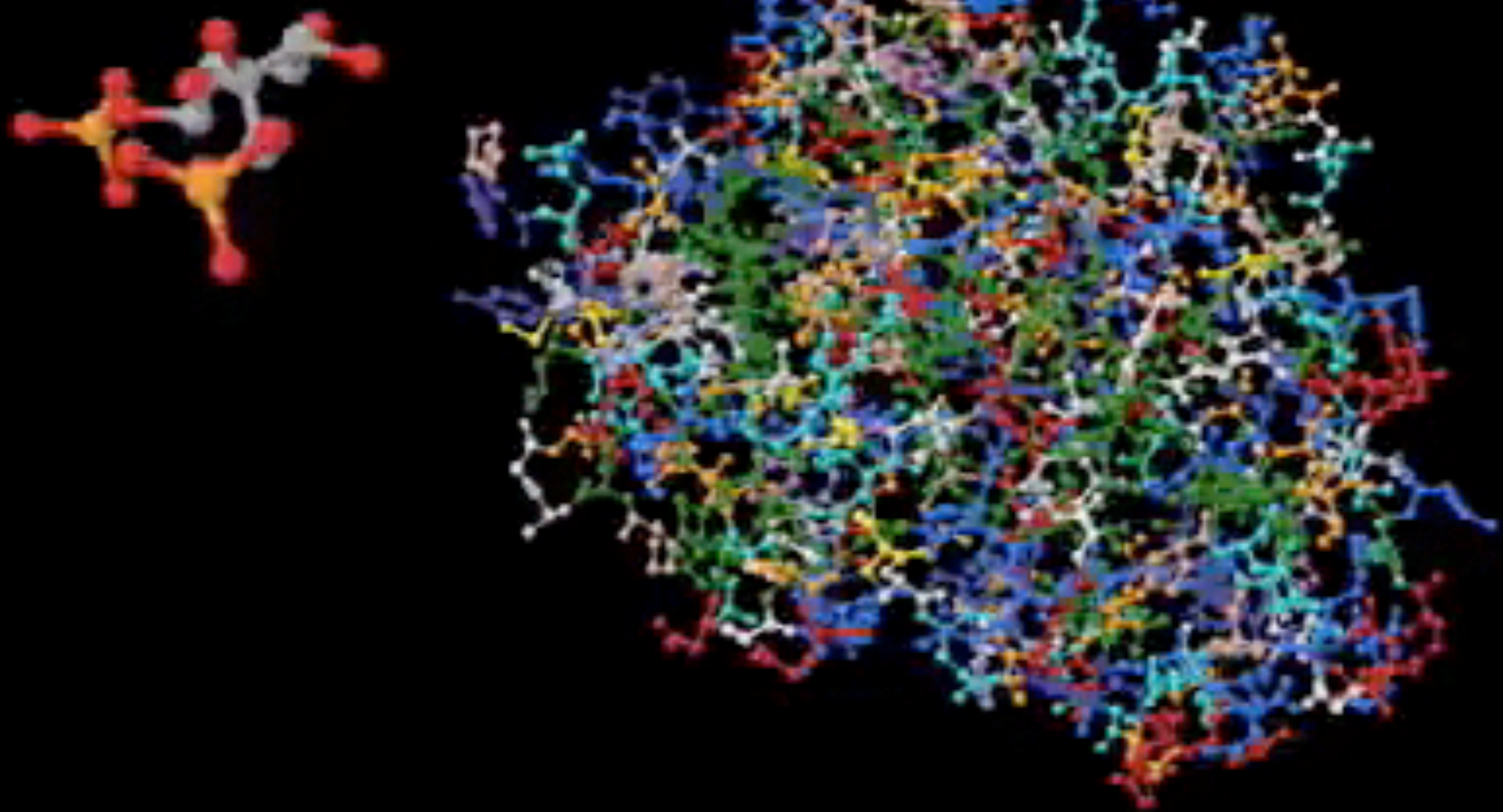
Quantum Spin Network

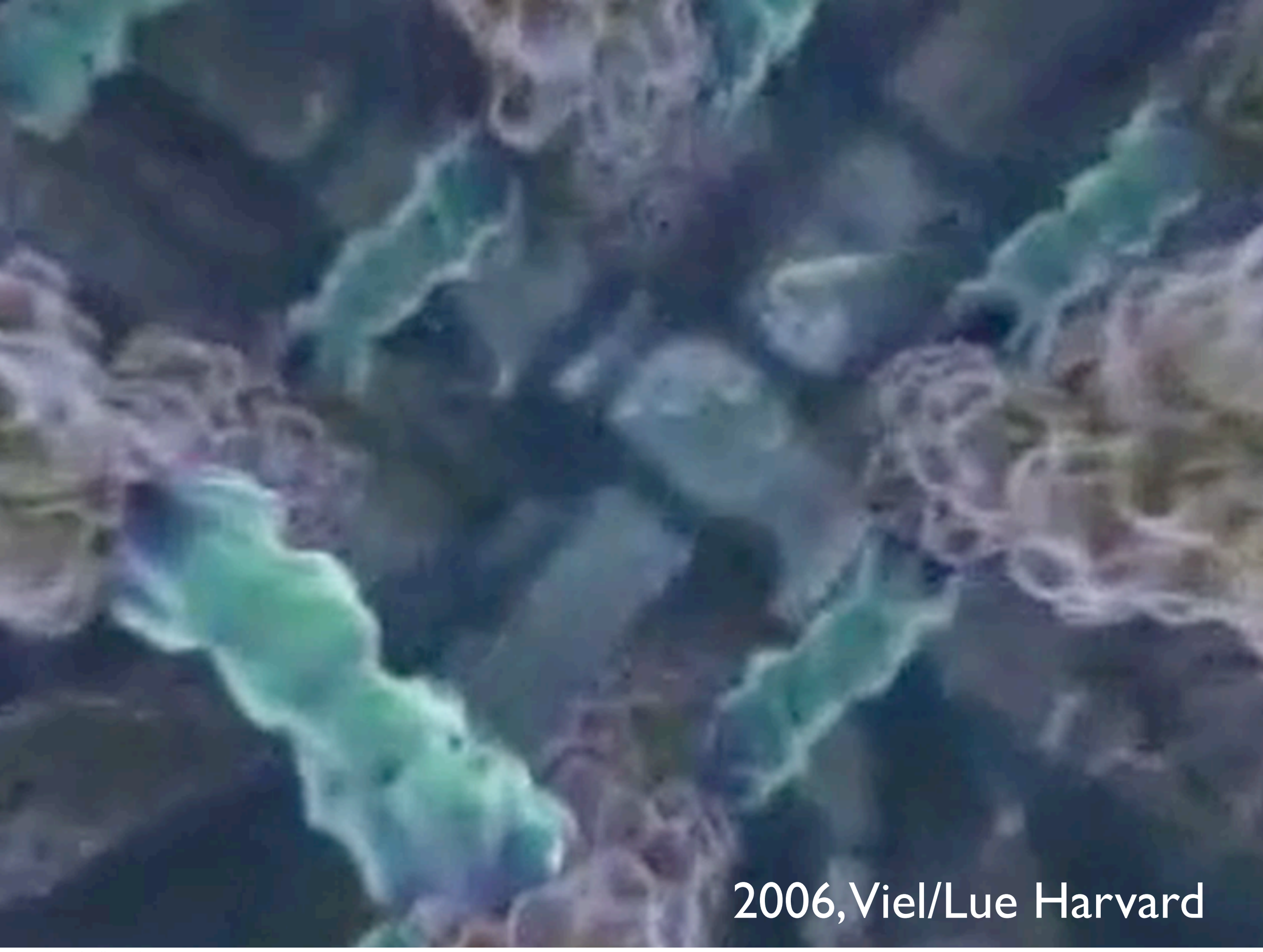
NOVA

Max Planck Institut, Potsdam

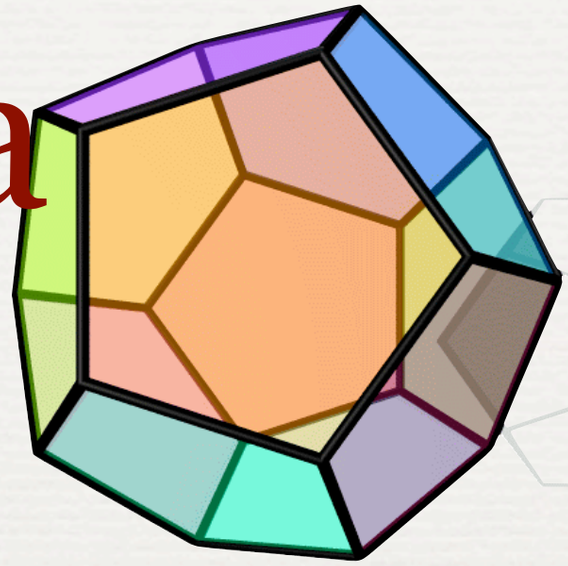
Proteins

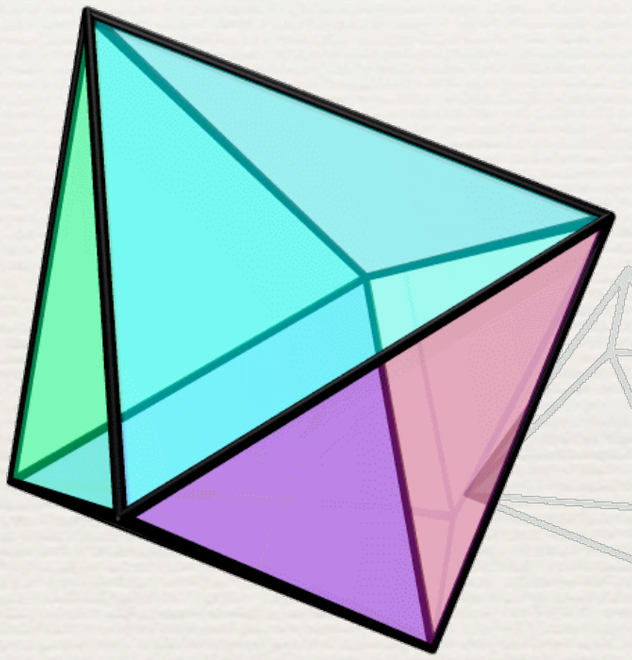


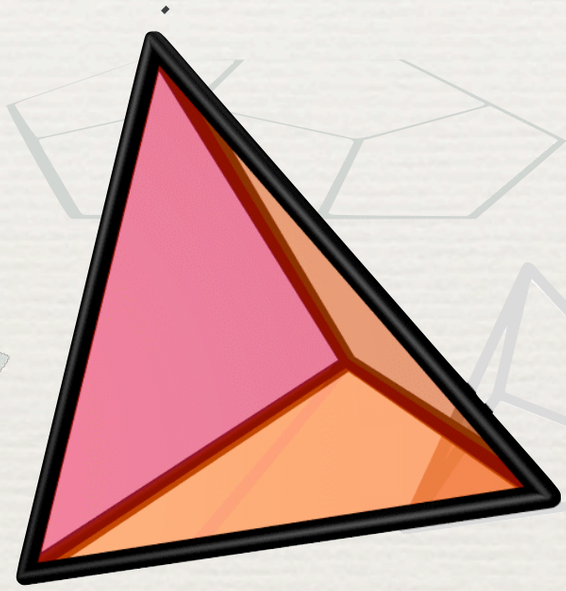


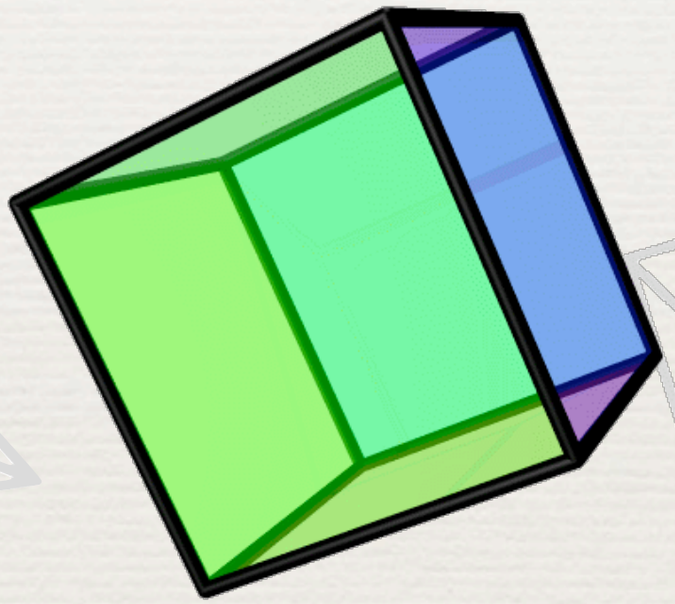

2006, Viel/Lue Harvard

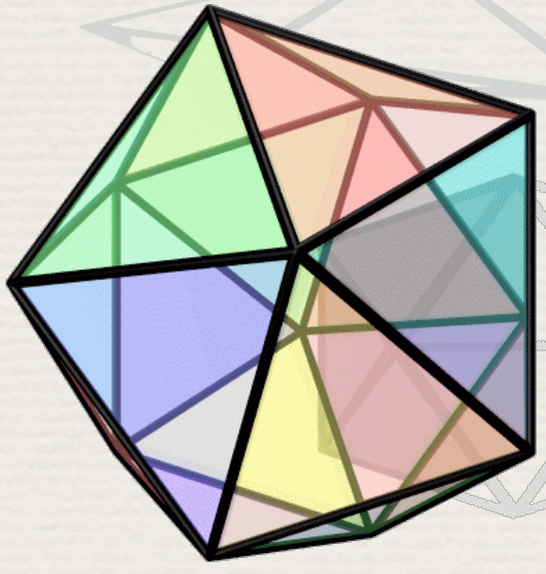
Polyhedra



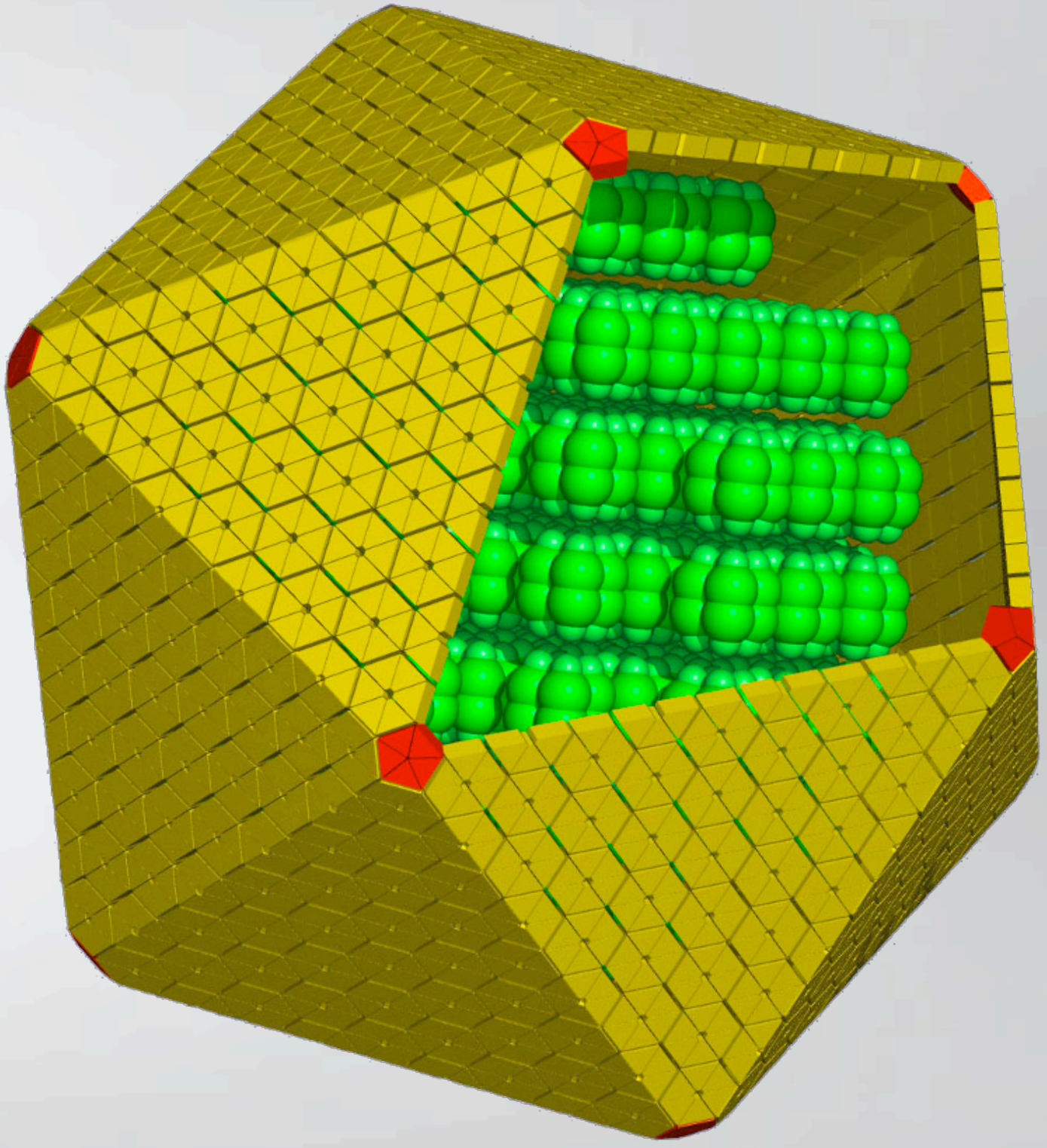




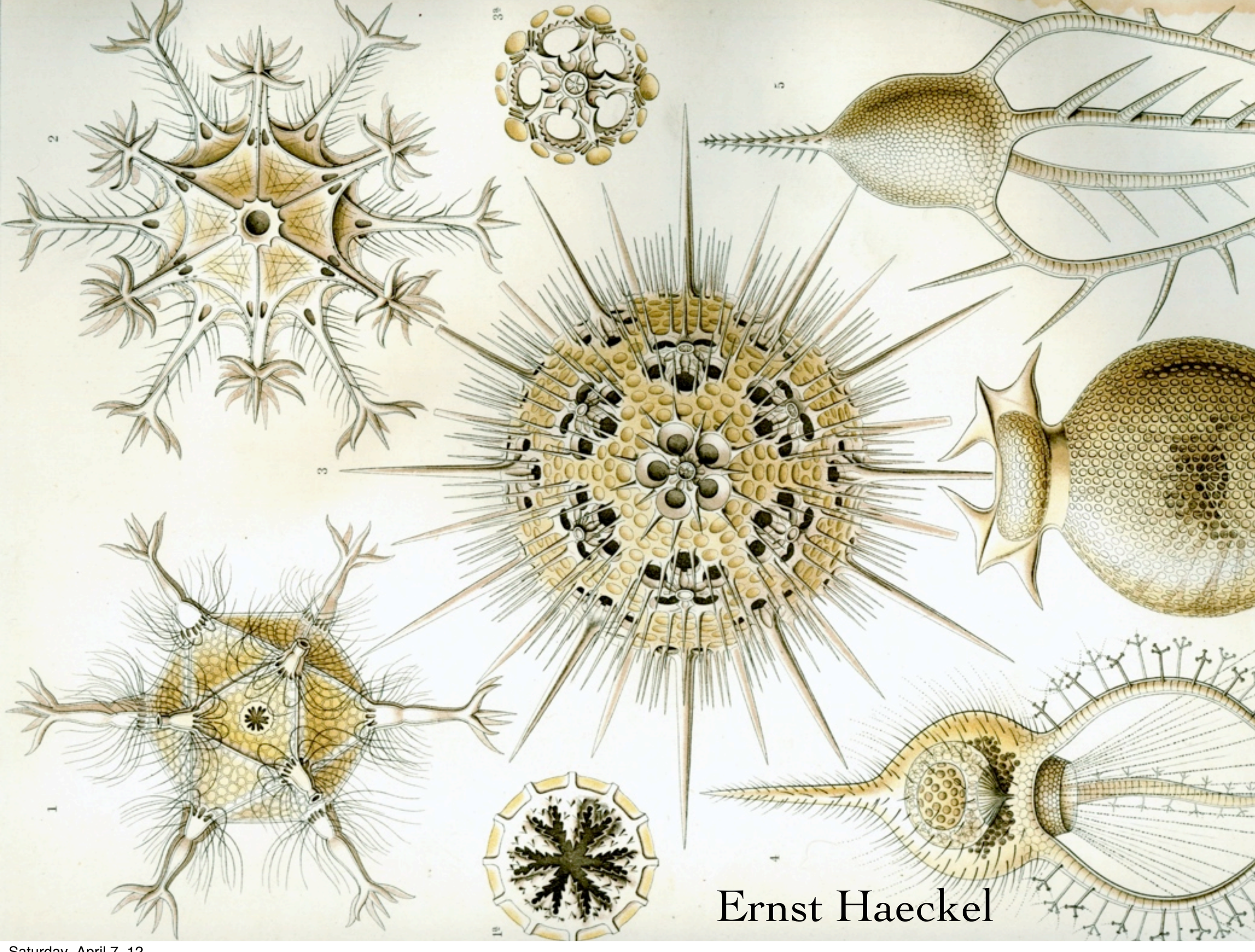




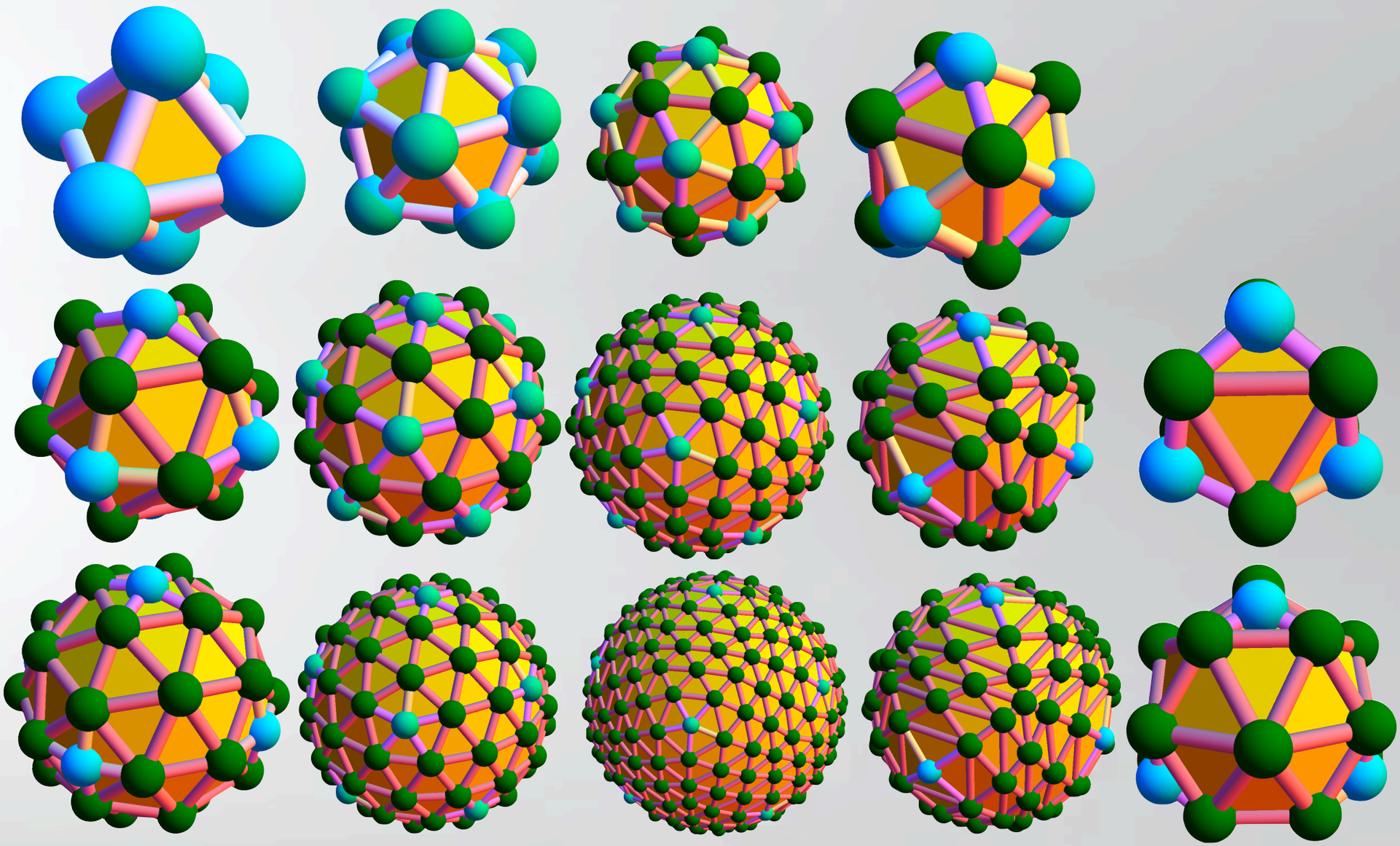
Carboxysomes



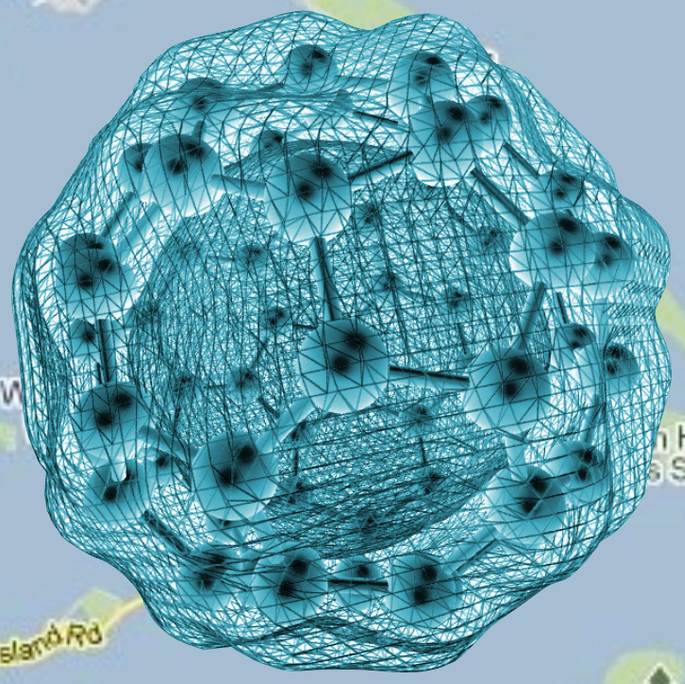
radiolarian


Ernst Haeckel

Fullerene



Buckminster Fullerene



R. Buckminster-Fuller1895-1983

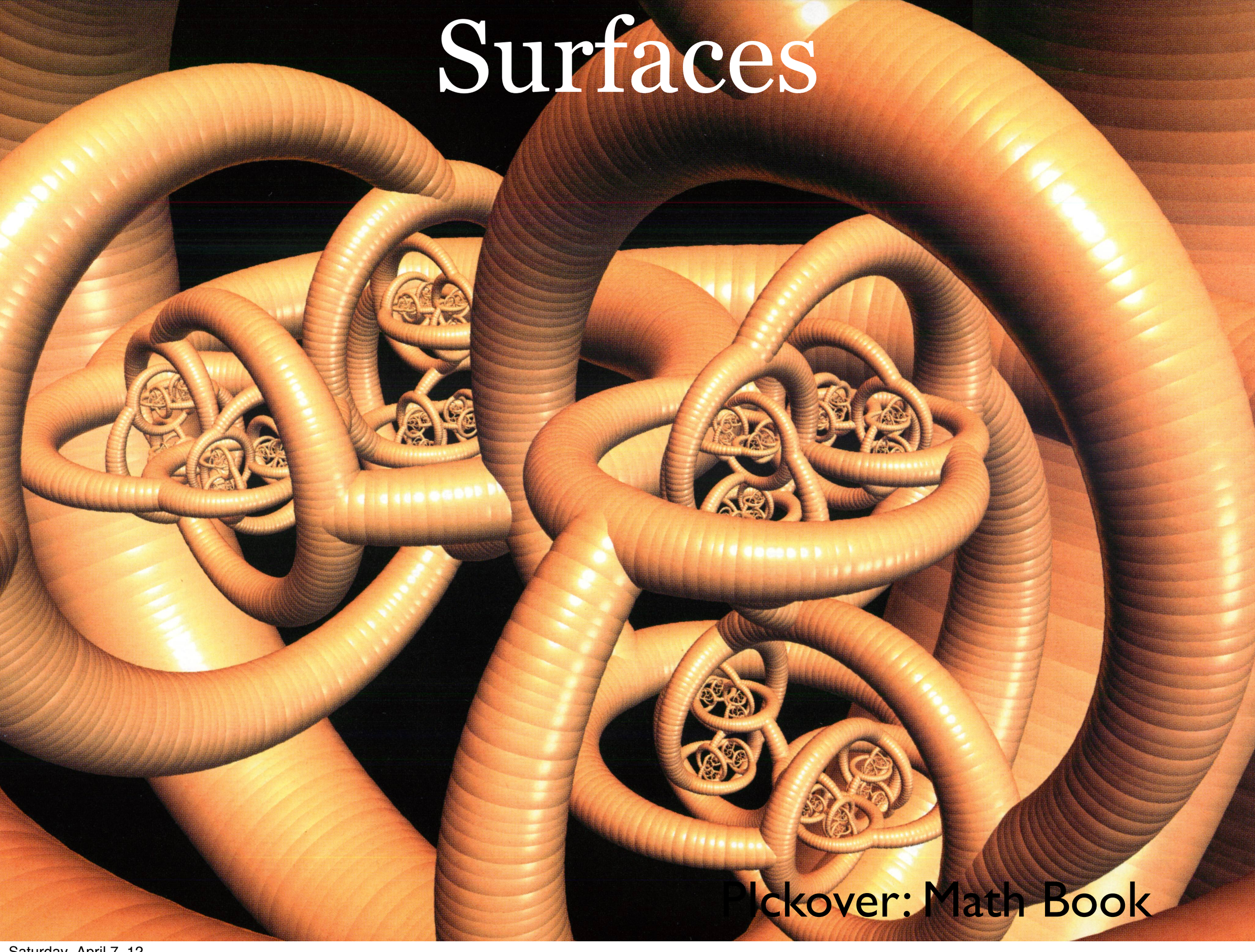
Arcitecture

Montreal
biosphere

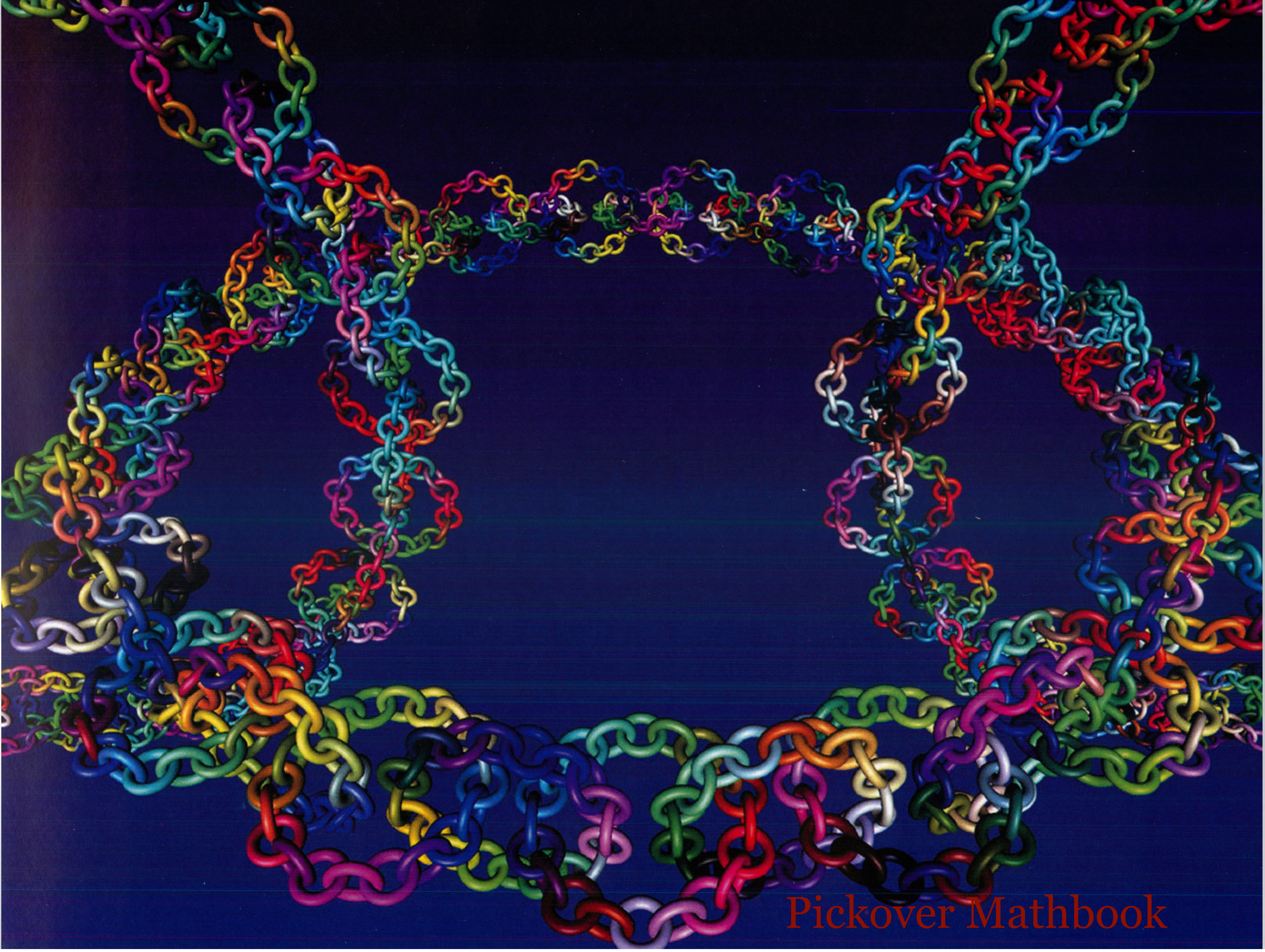
Zeil Frankfurt

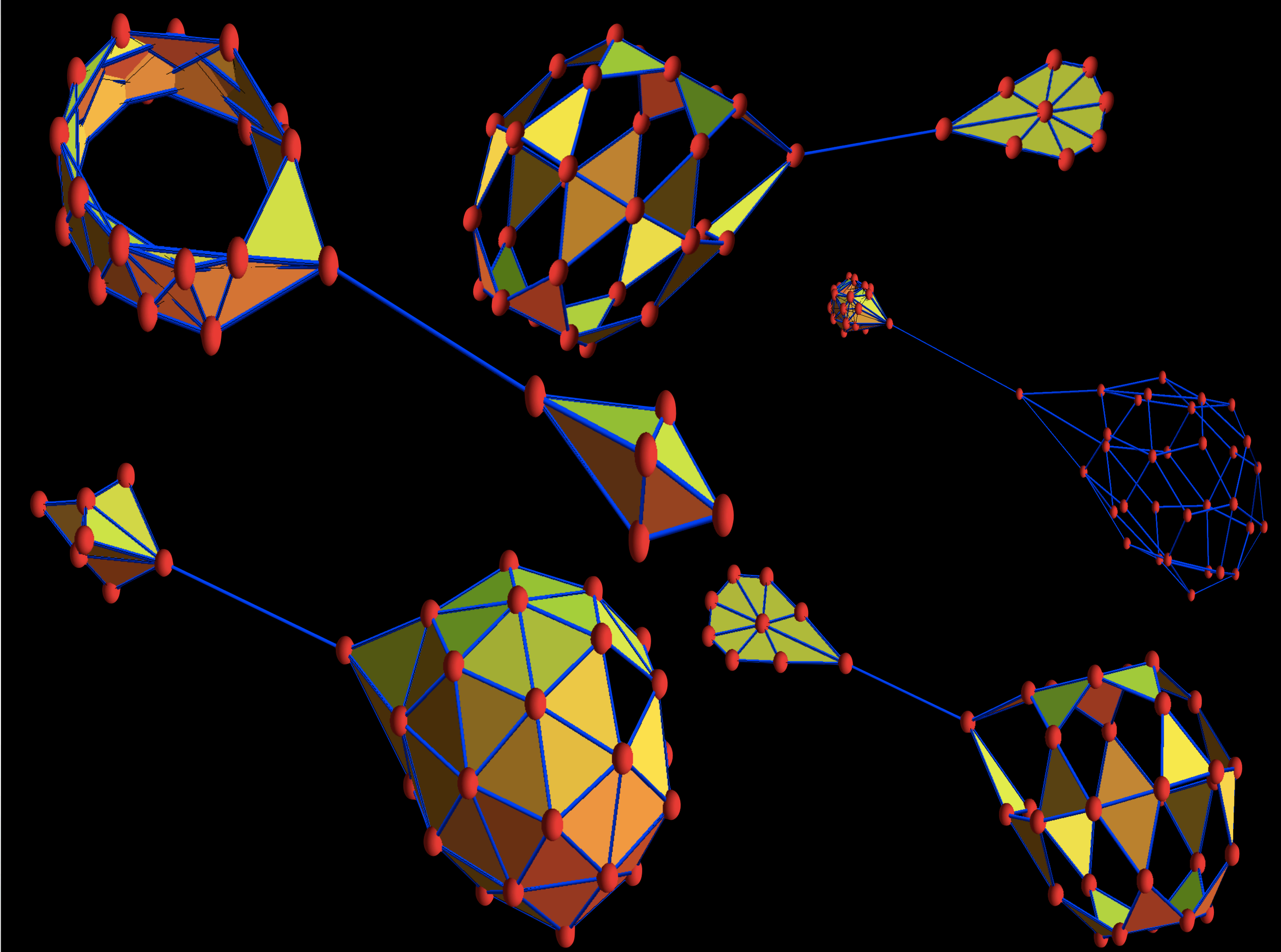
Michael Hansmeyer

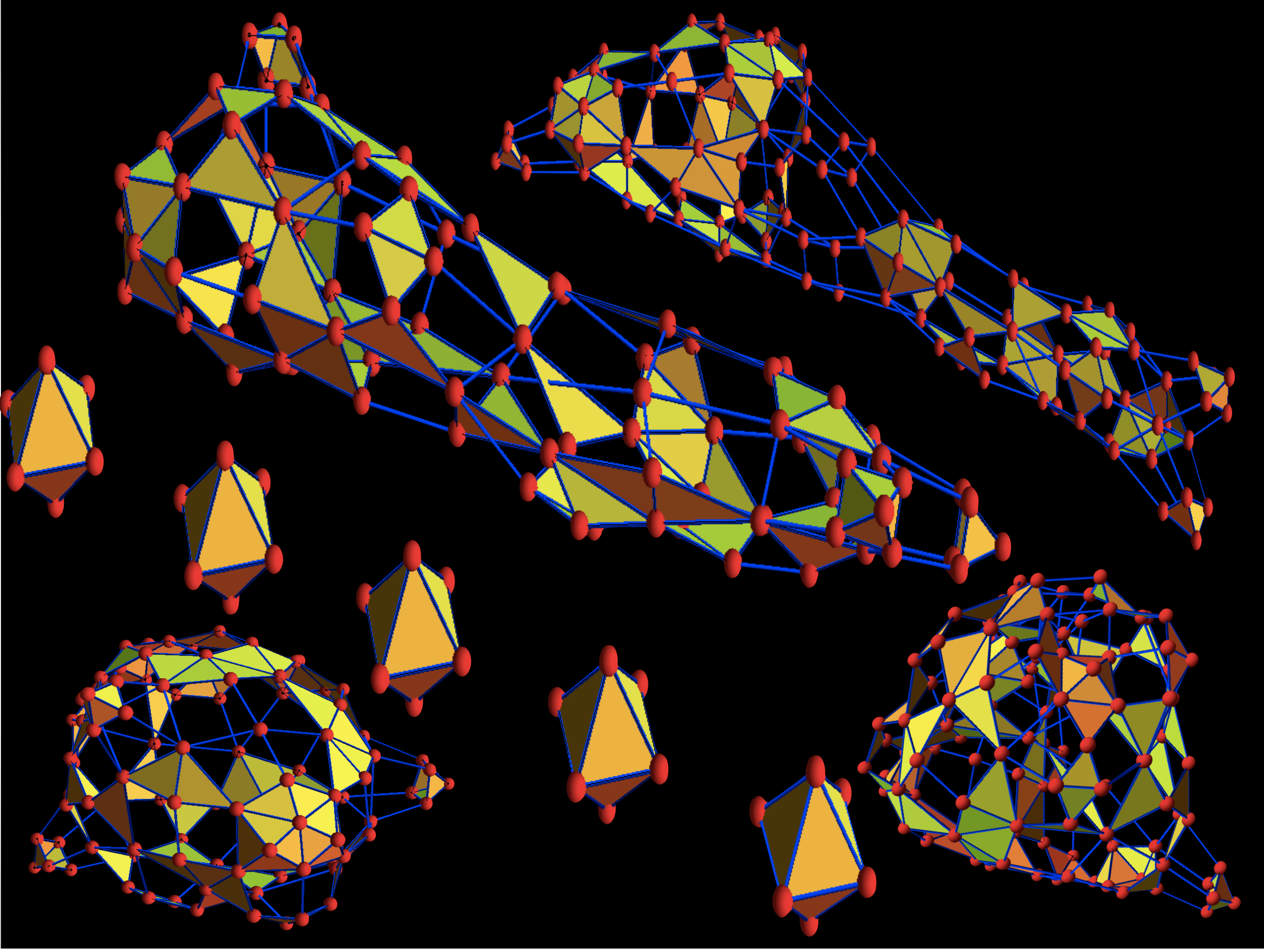
Surfaces



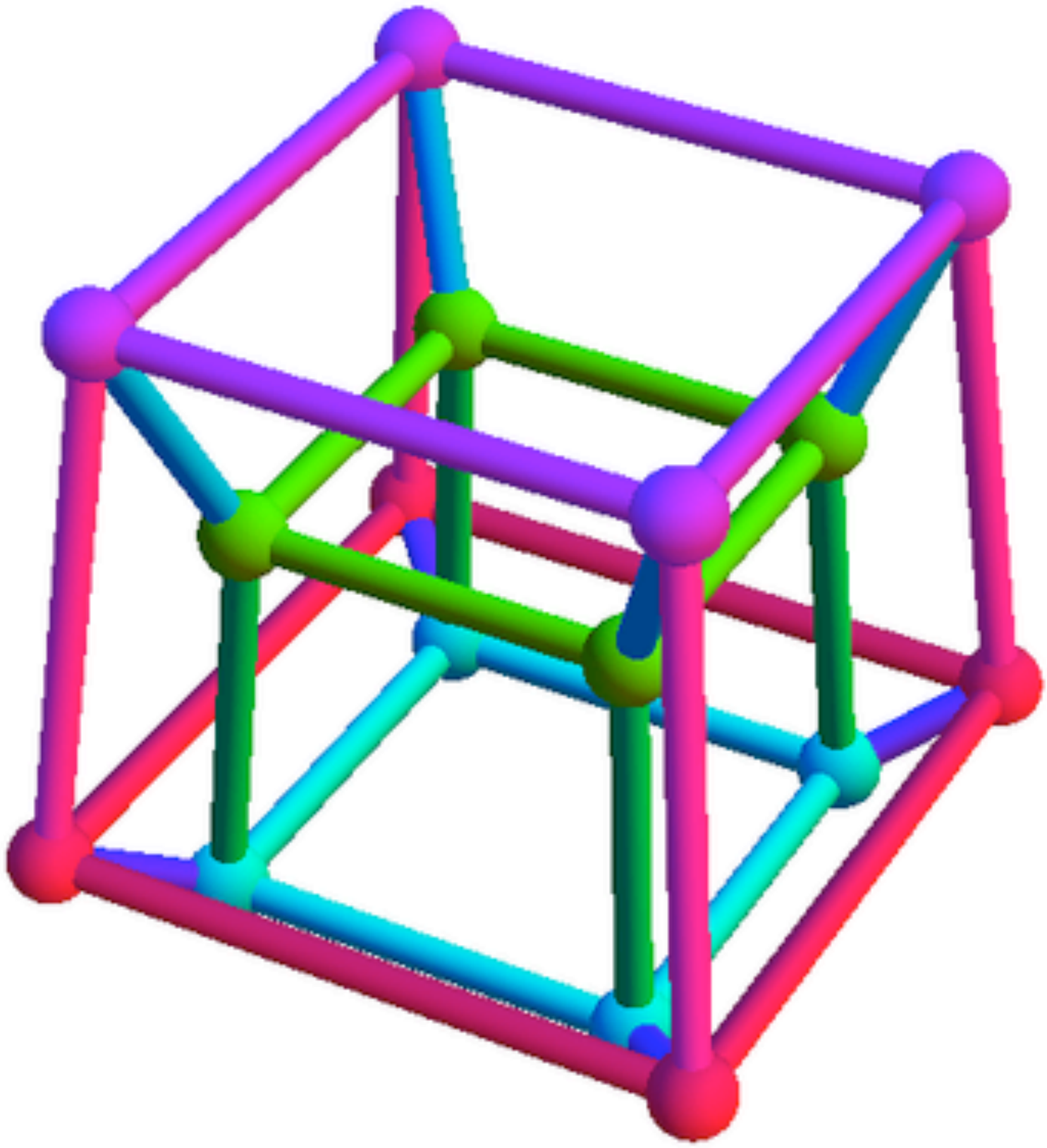
Pickover: Math Book


Pickover Mathbook

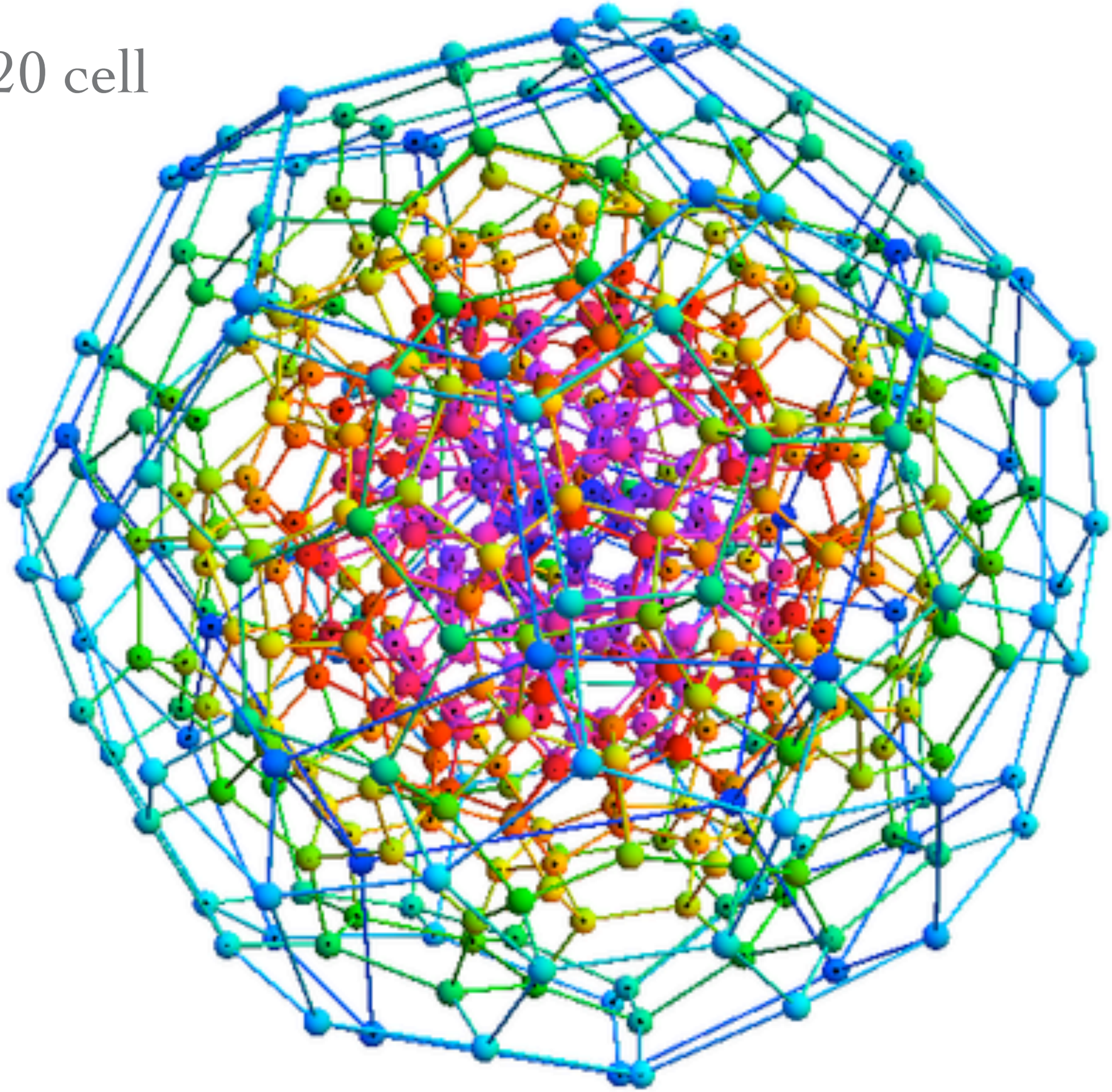


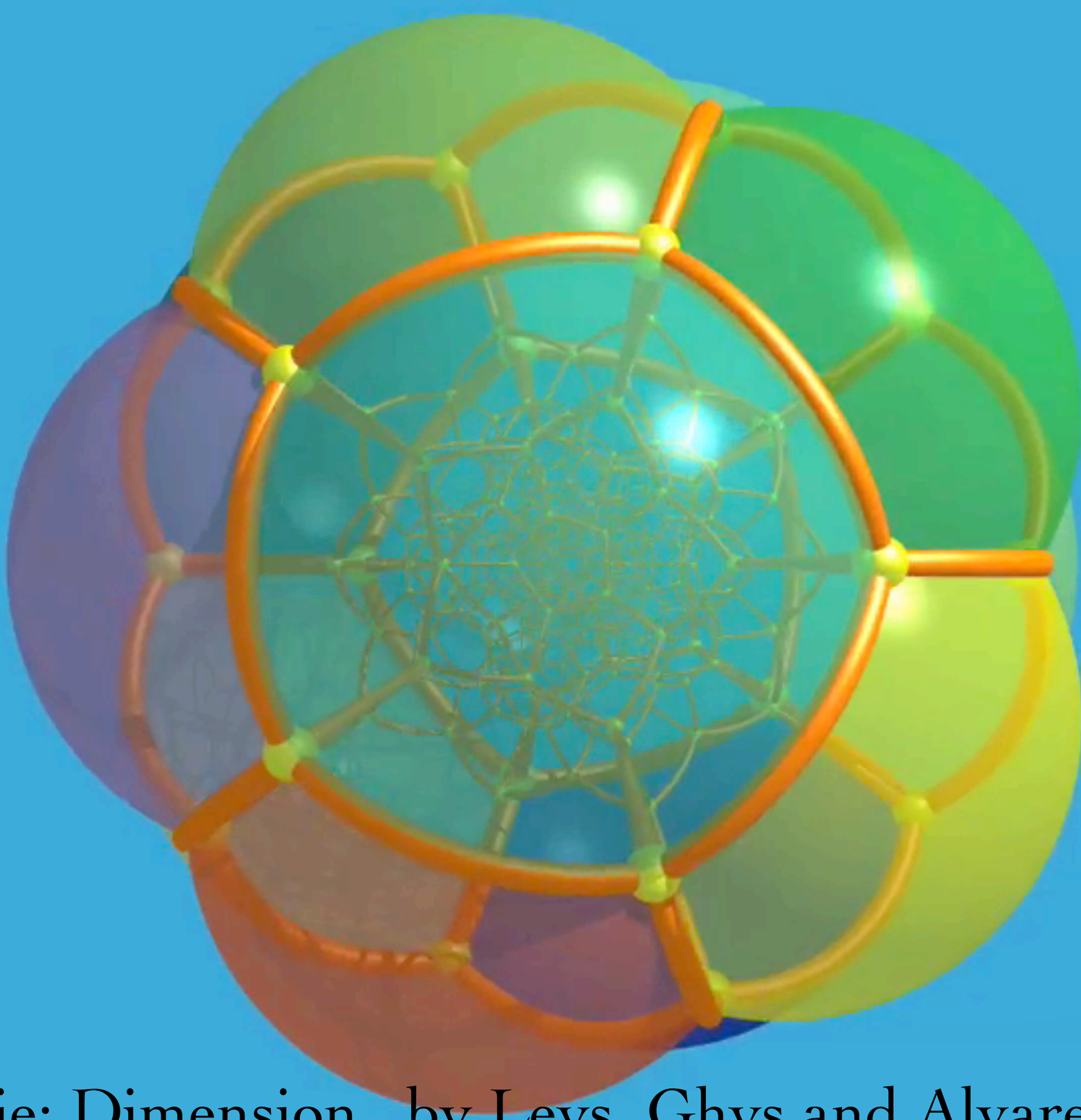


8 cell
tesseract

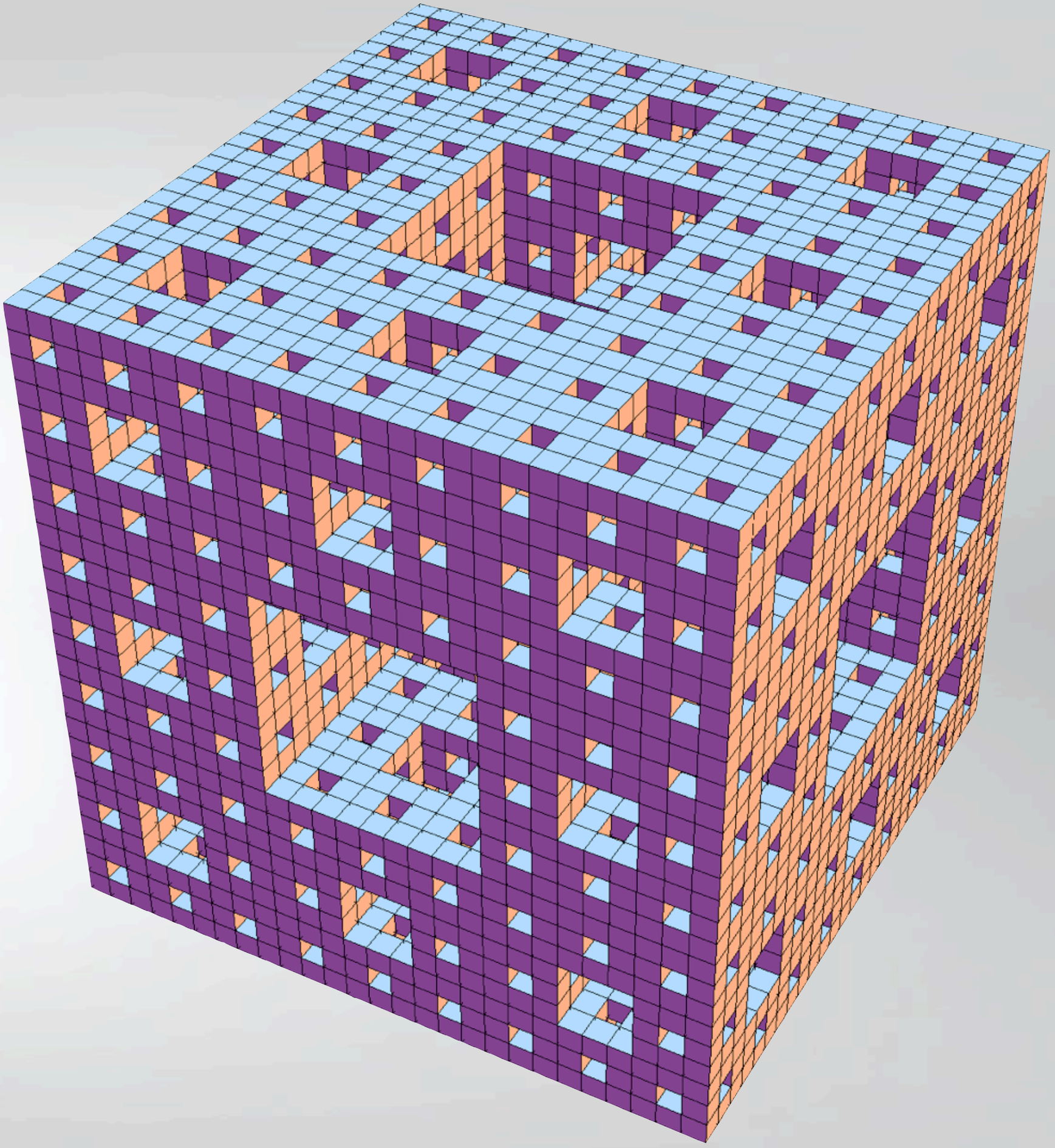


120 cell

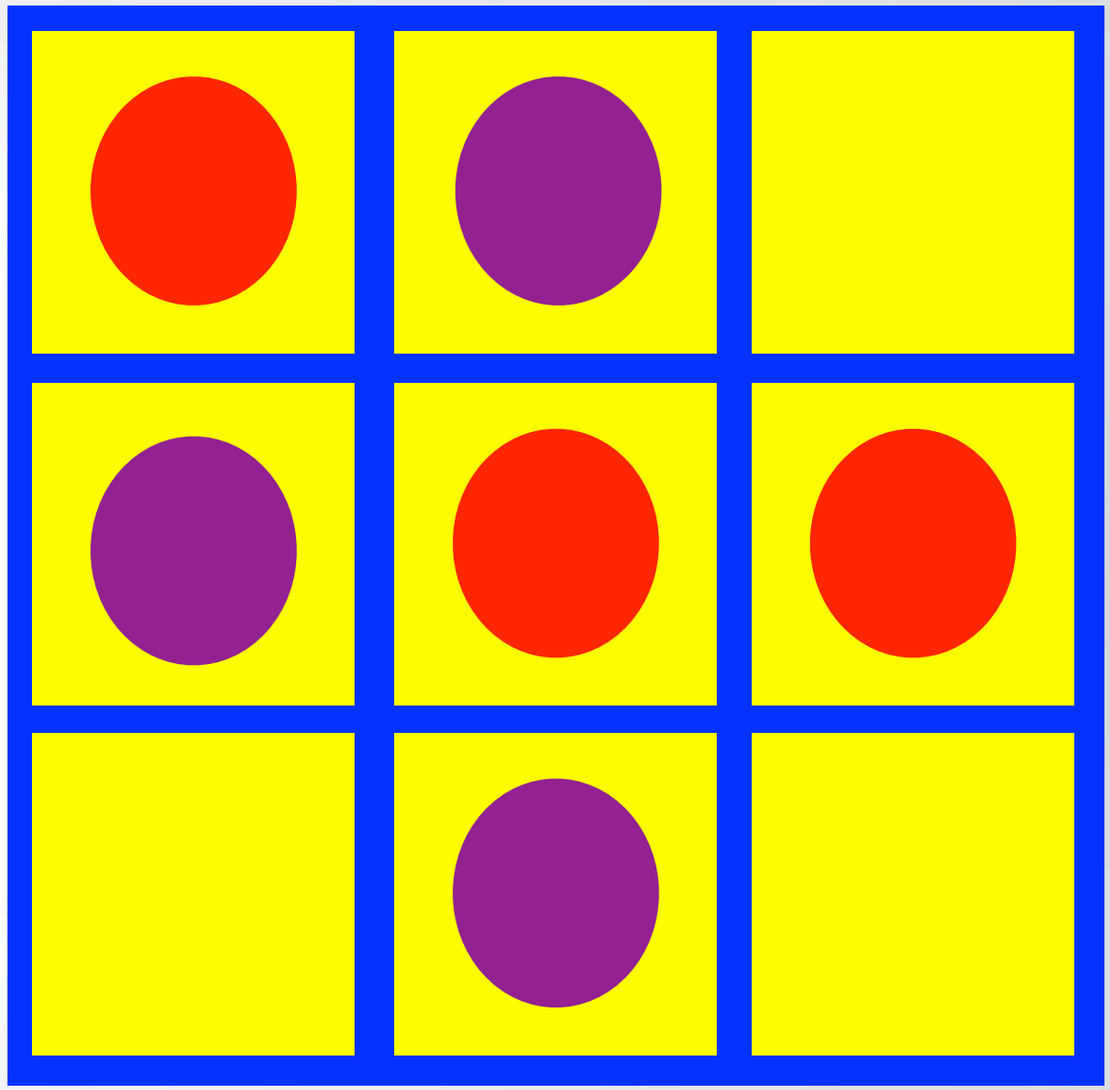




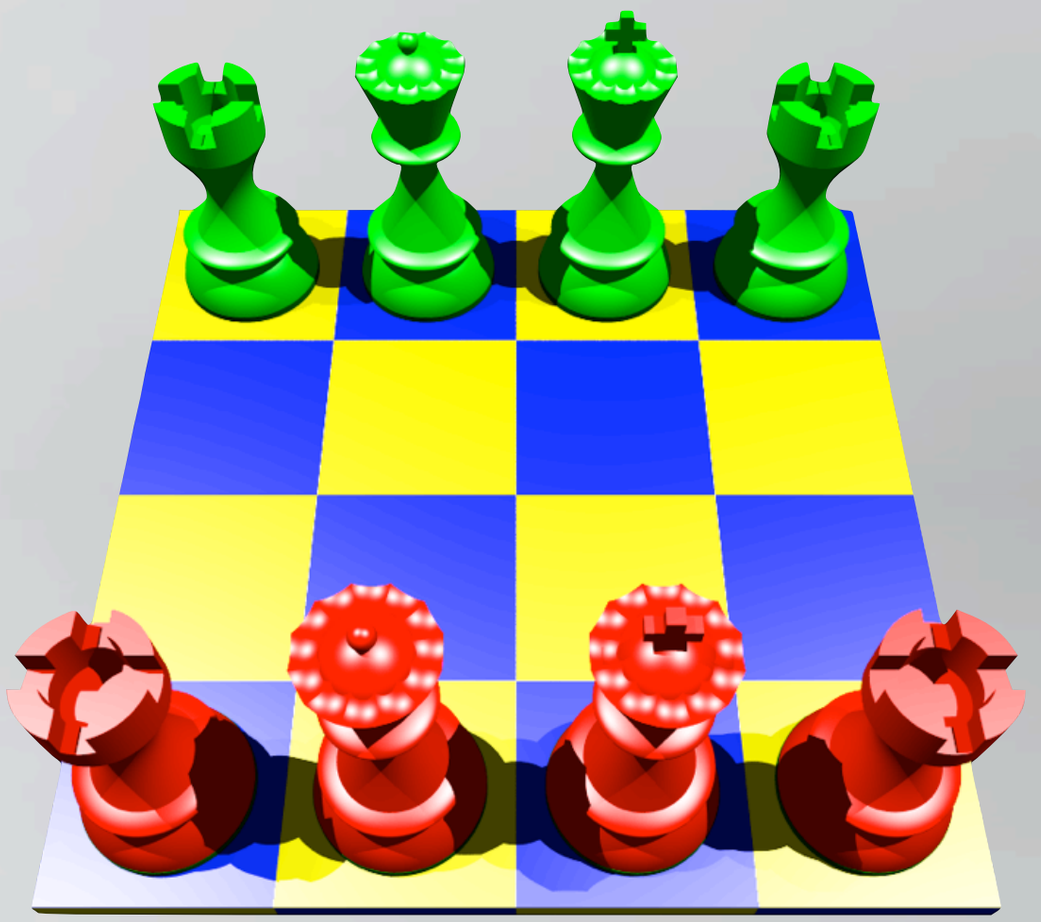
Movie: Dimension, by Leys, Ghys and Alvarez, 2008



Games



Tic Tac Toe



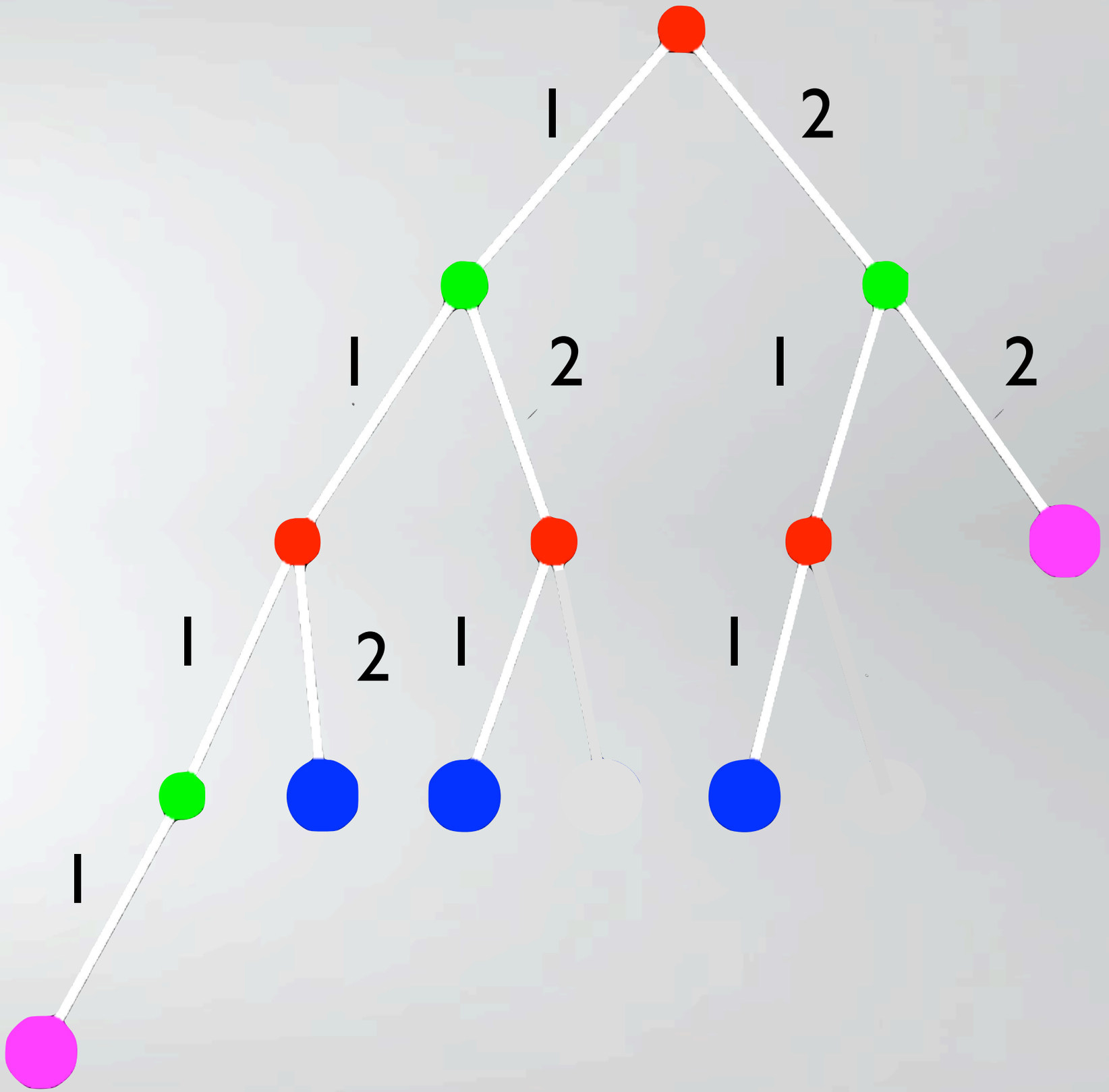
Chess

Games: 4 wins

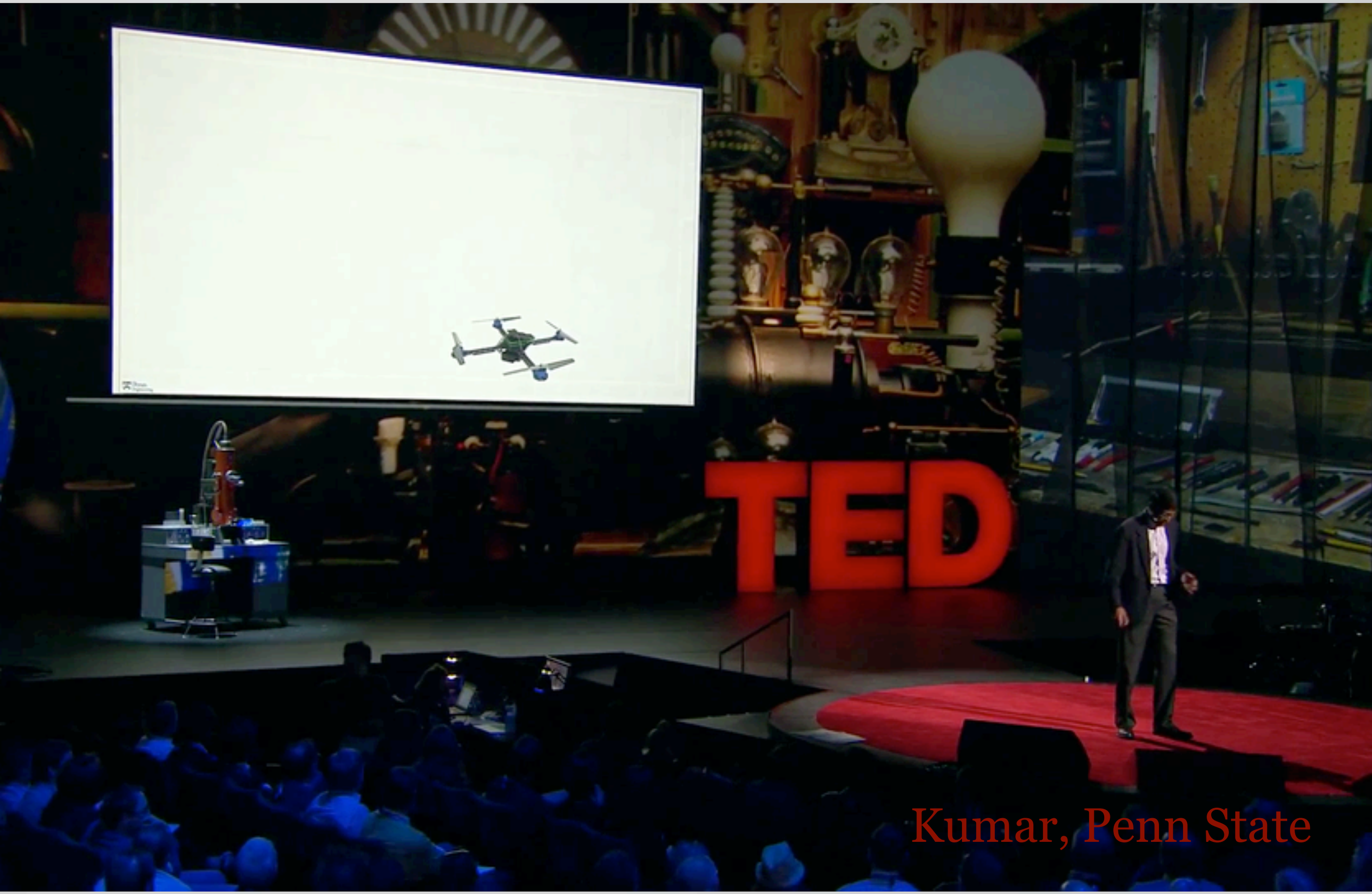
Rules: Each player picks one or two. The one who gets the last one, wins.

NIM: taking the last, loses

The graph

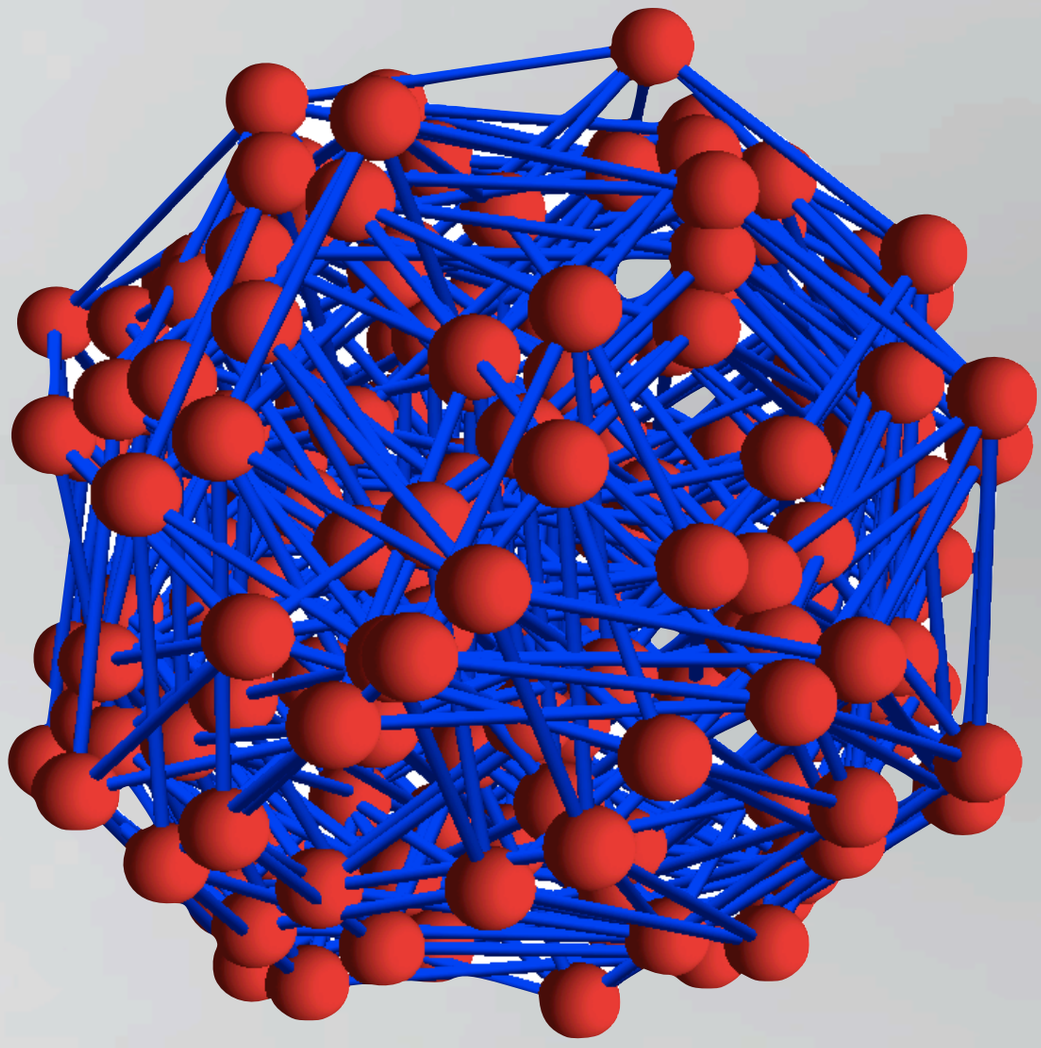


Swarm intelligence



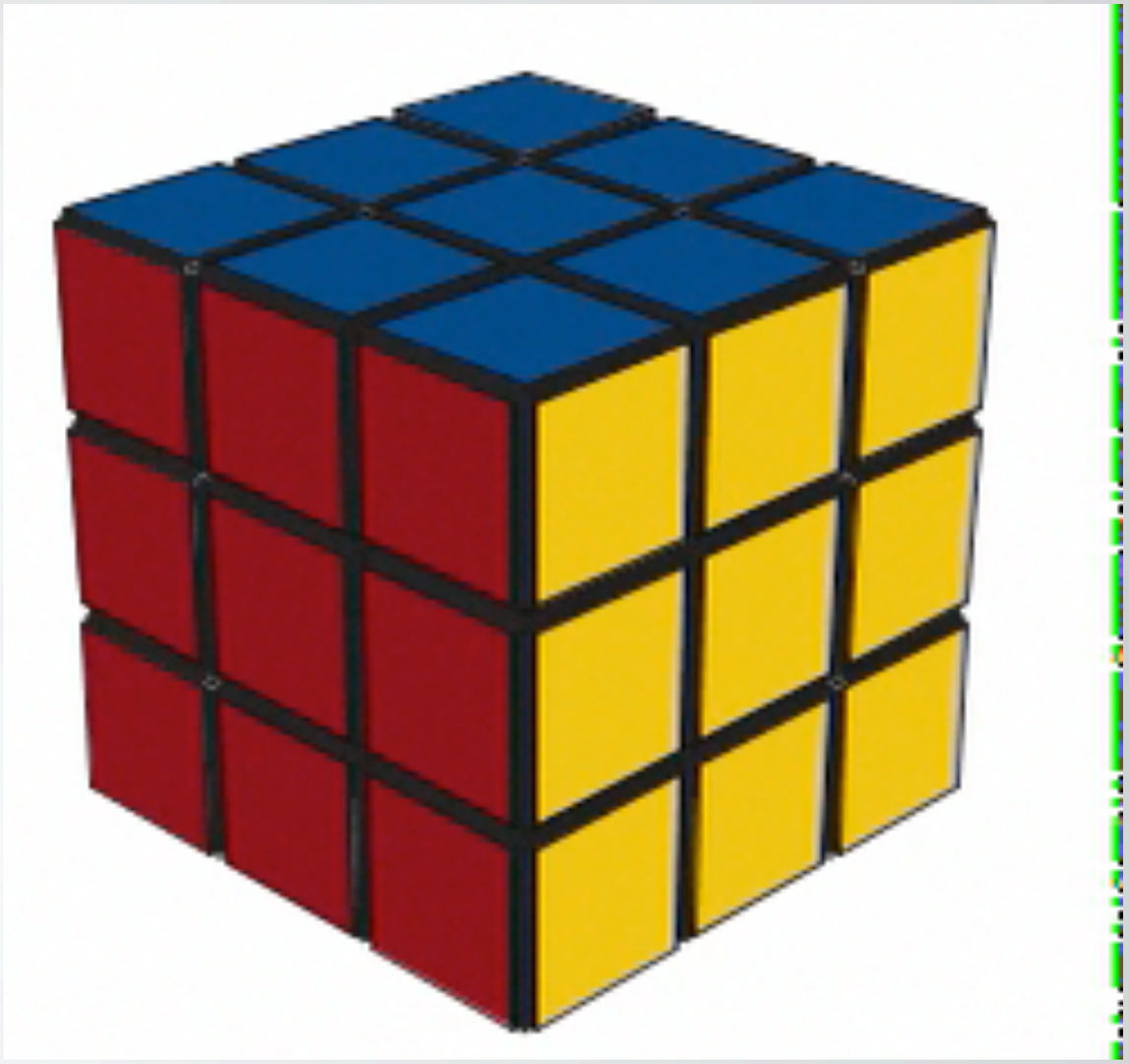
Kumar, Penn State

Puzzles



Floppy

Rubik



Superflip

The diameter of the Rubik network is 20

God Number (cube20.org)

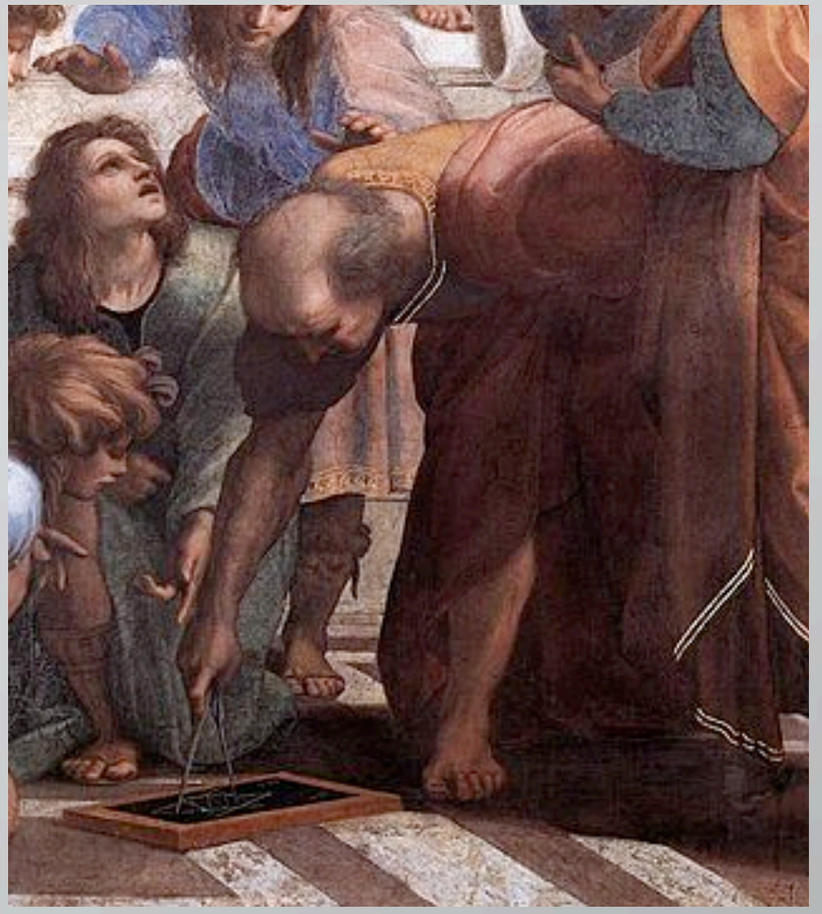
What is Geometry?

Antiquity

Geodesy. Measure length and area

Euclid

300 BC



Axiomatics of planimetry

points

circles

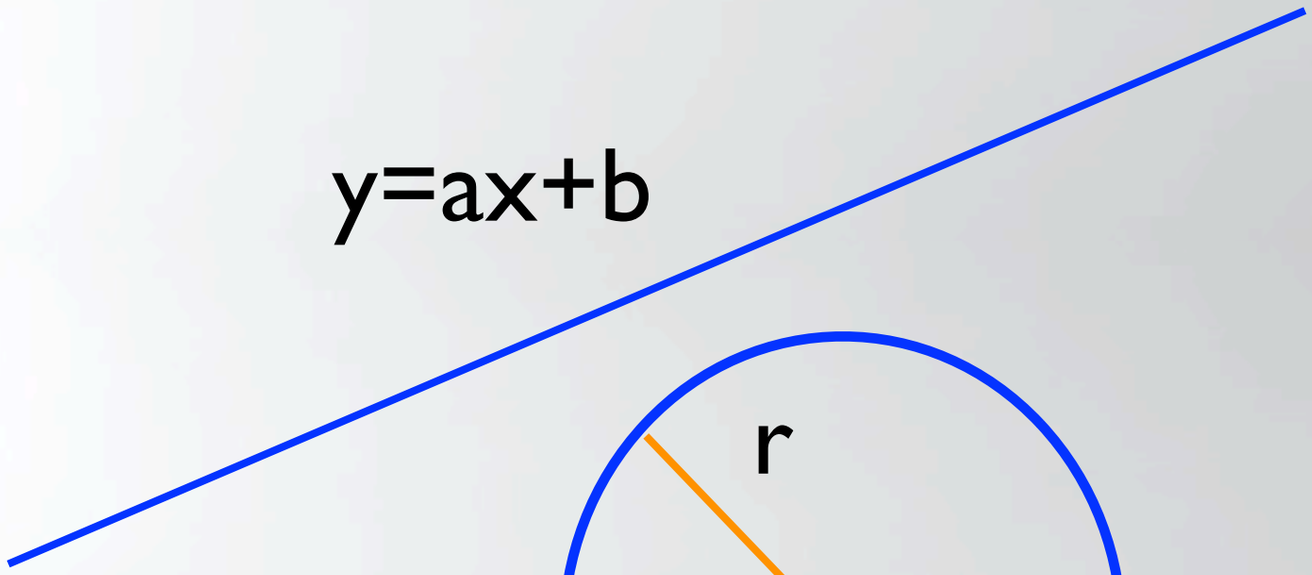
angles

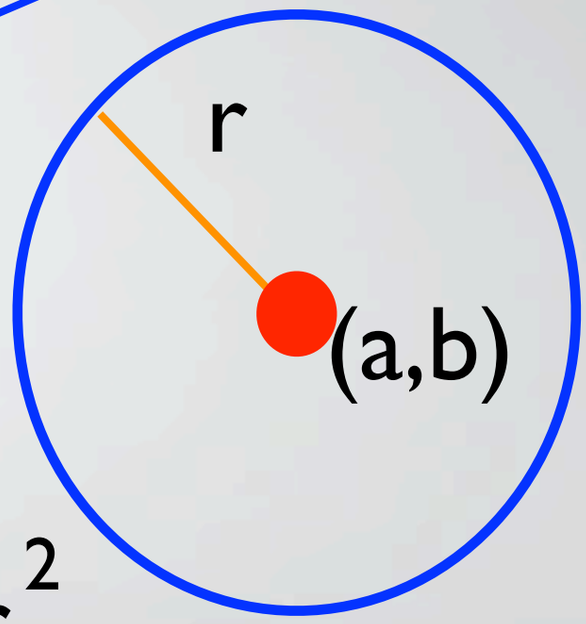
lines

Descartes 1596-1650

Geometric objects can be defined algebraically

y=ax+b

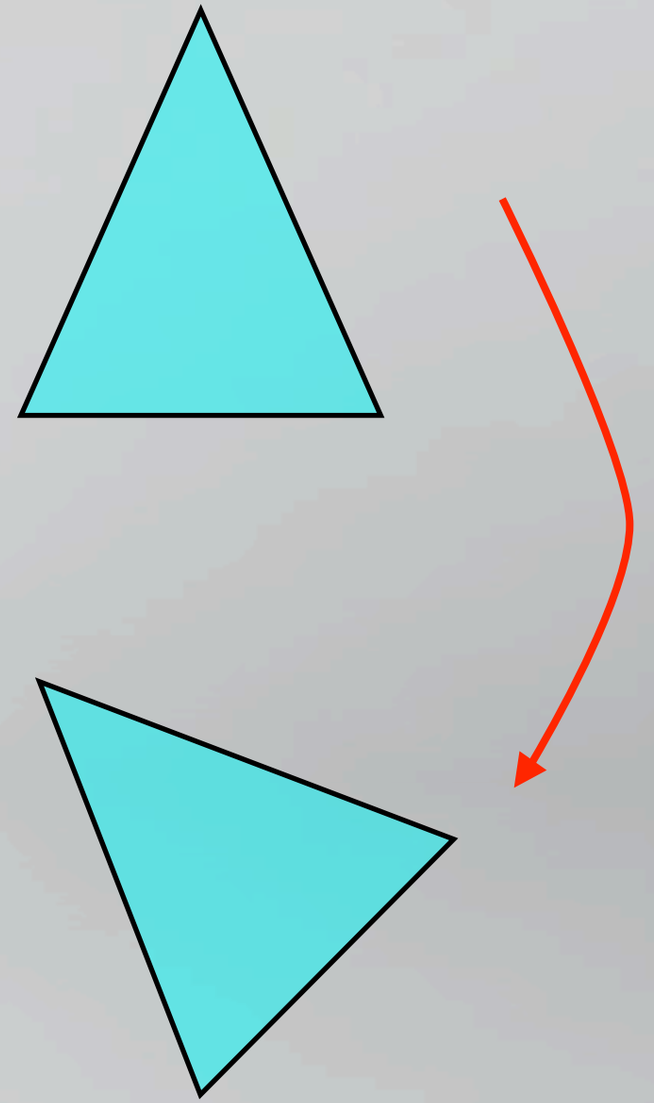




$$(x-a)^2+(y-b)^2 = r^2$$

Klein 1849-1925

Geometry is defined by the group of symmetries of the Geometry.

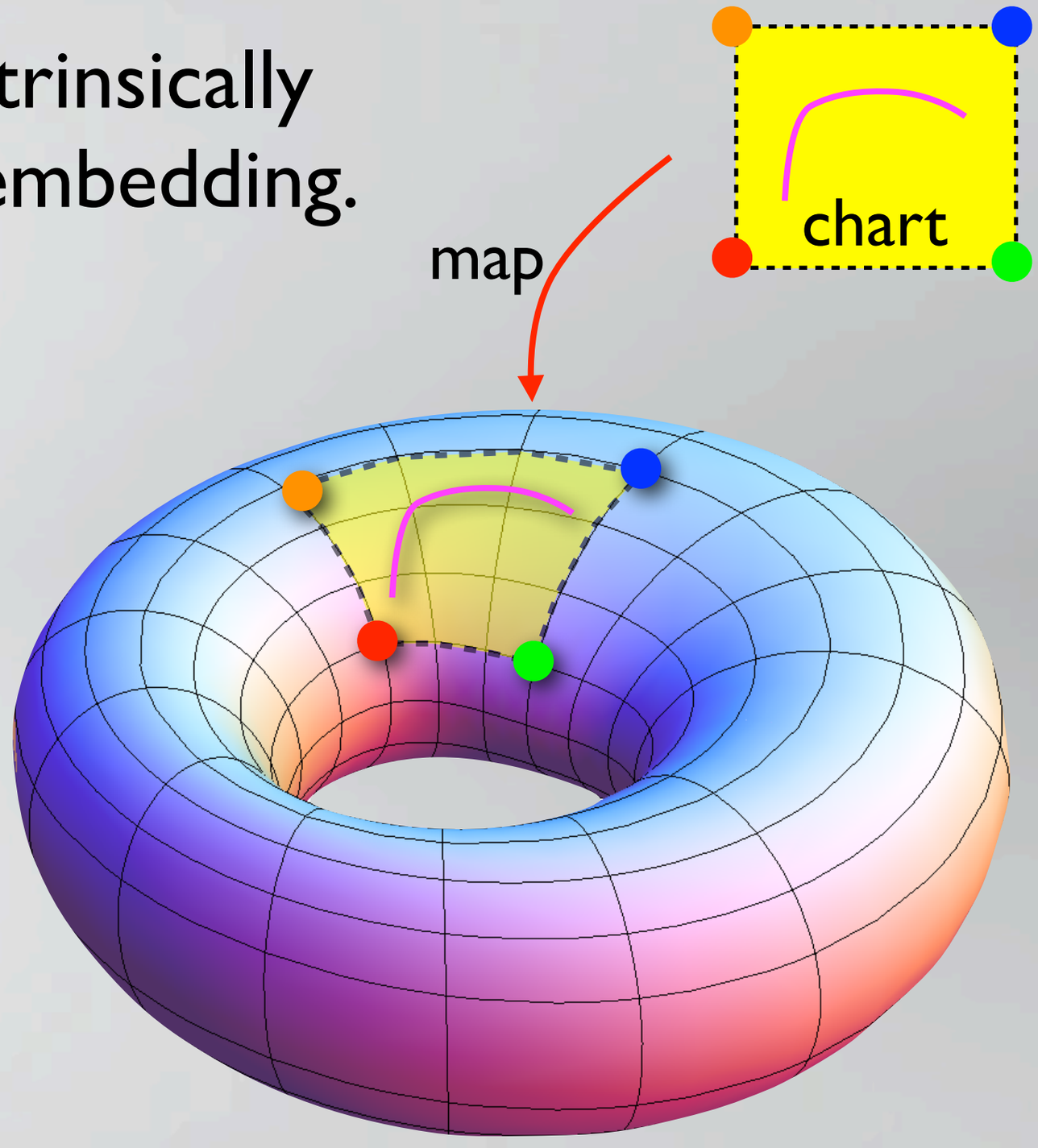


examples:

Conformal geometry
Affine geometry
Projective Geometry
Topology
Differential geometry

Rieman 1826-1866

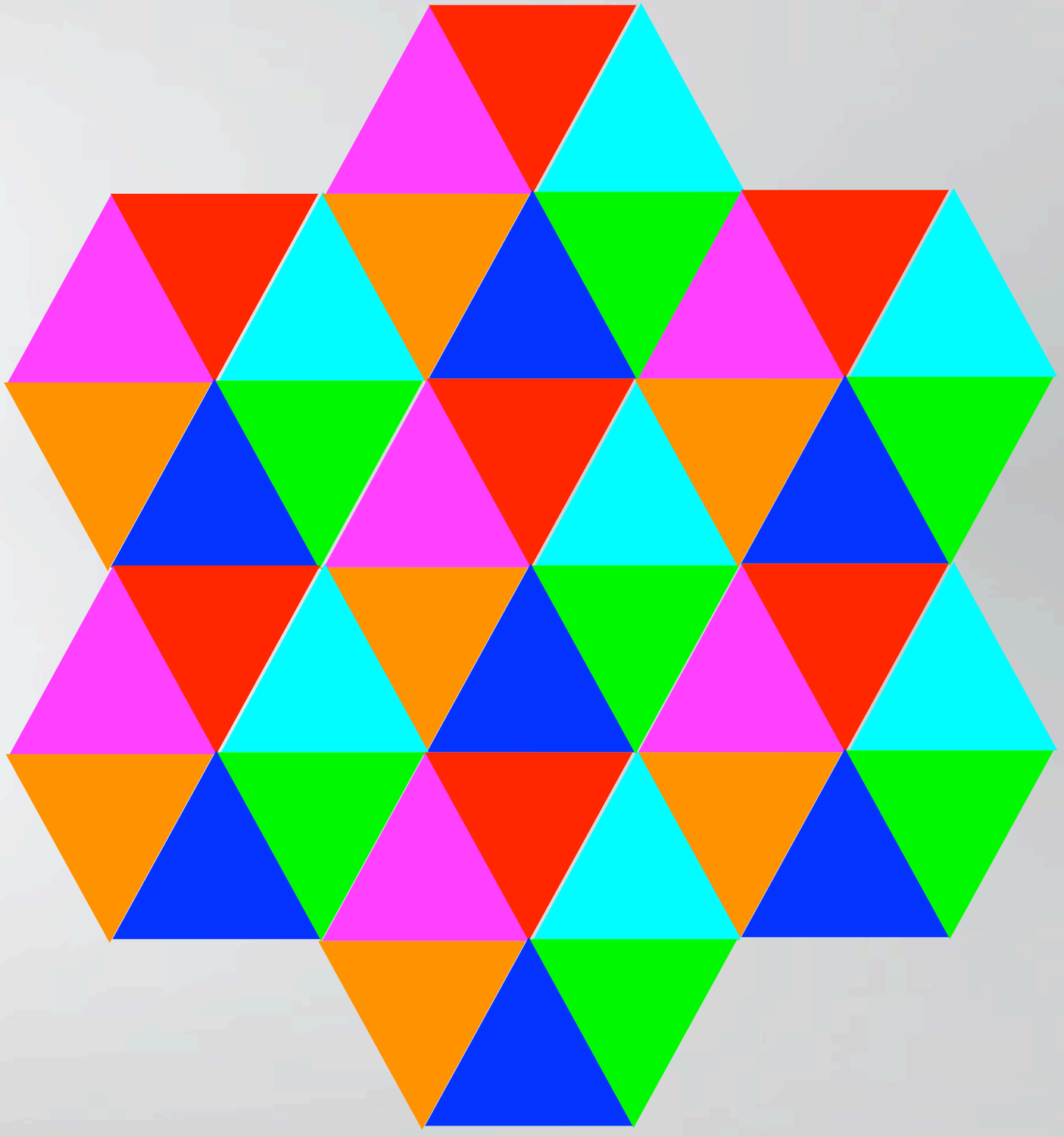
Riemannian manifold.Intrinsically defined metric without embedding.

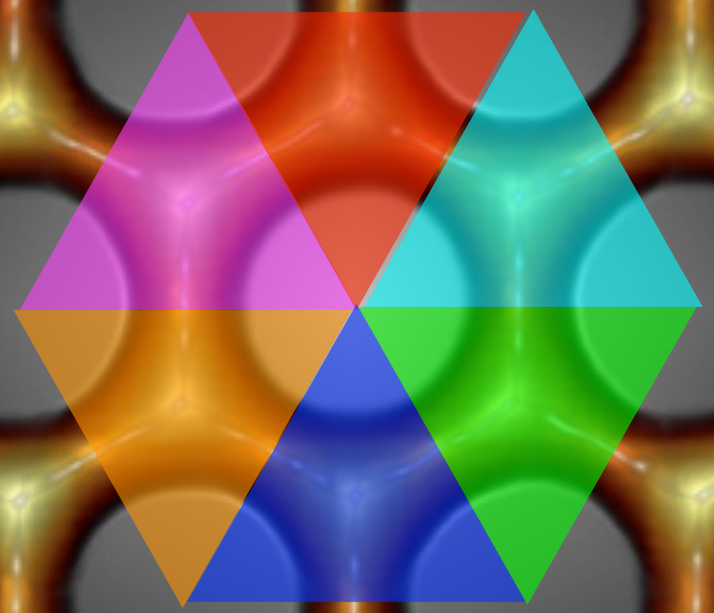


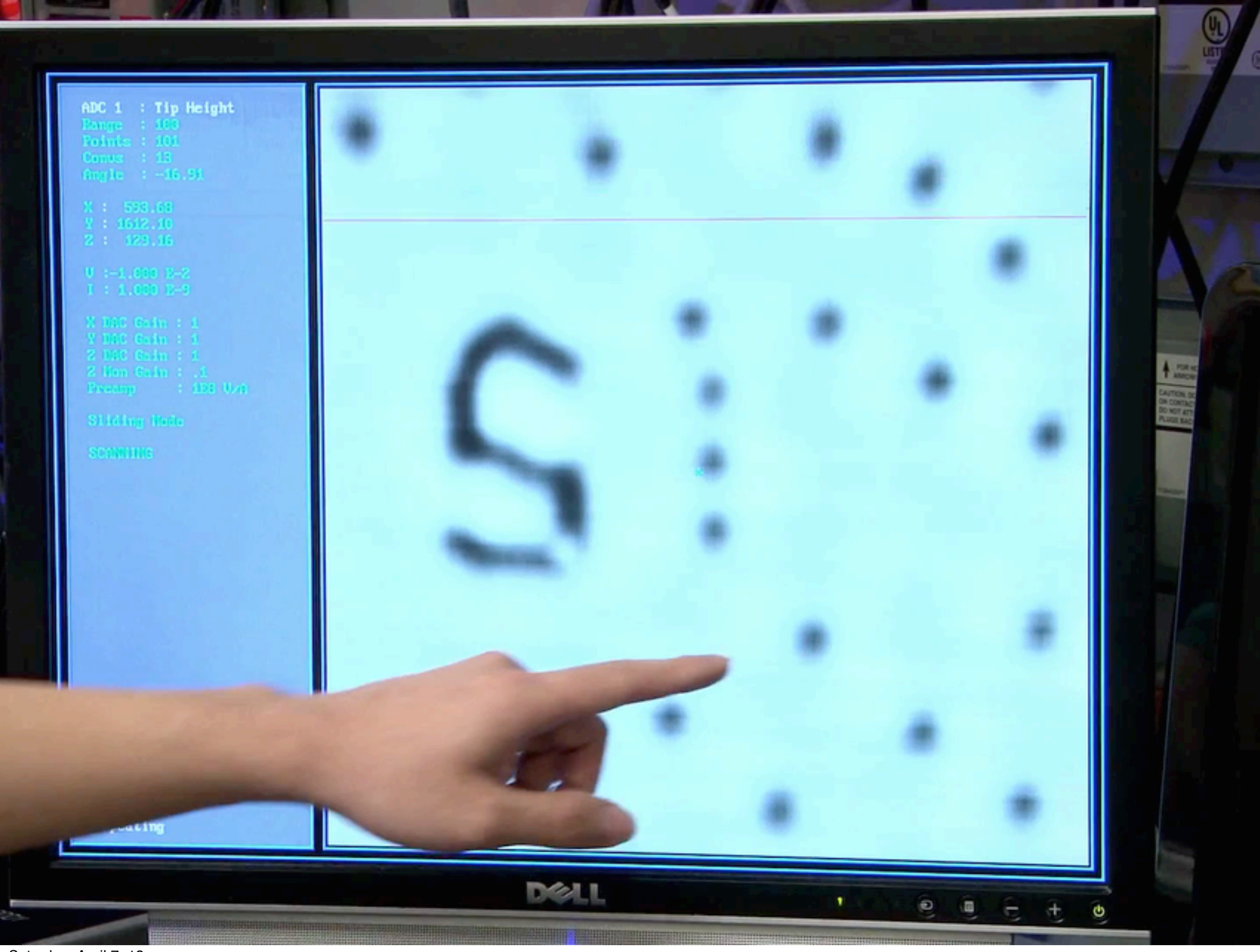
Manifold: space equiped with atlas

Some geometric questions in Network

The Triangonal lattice

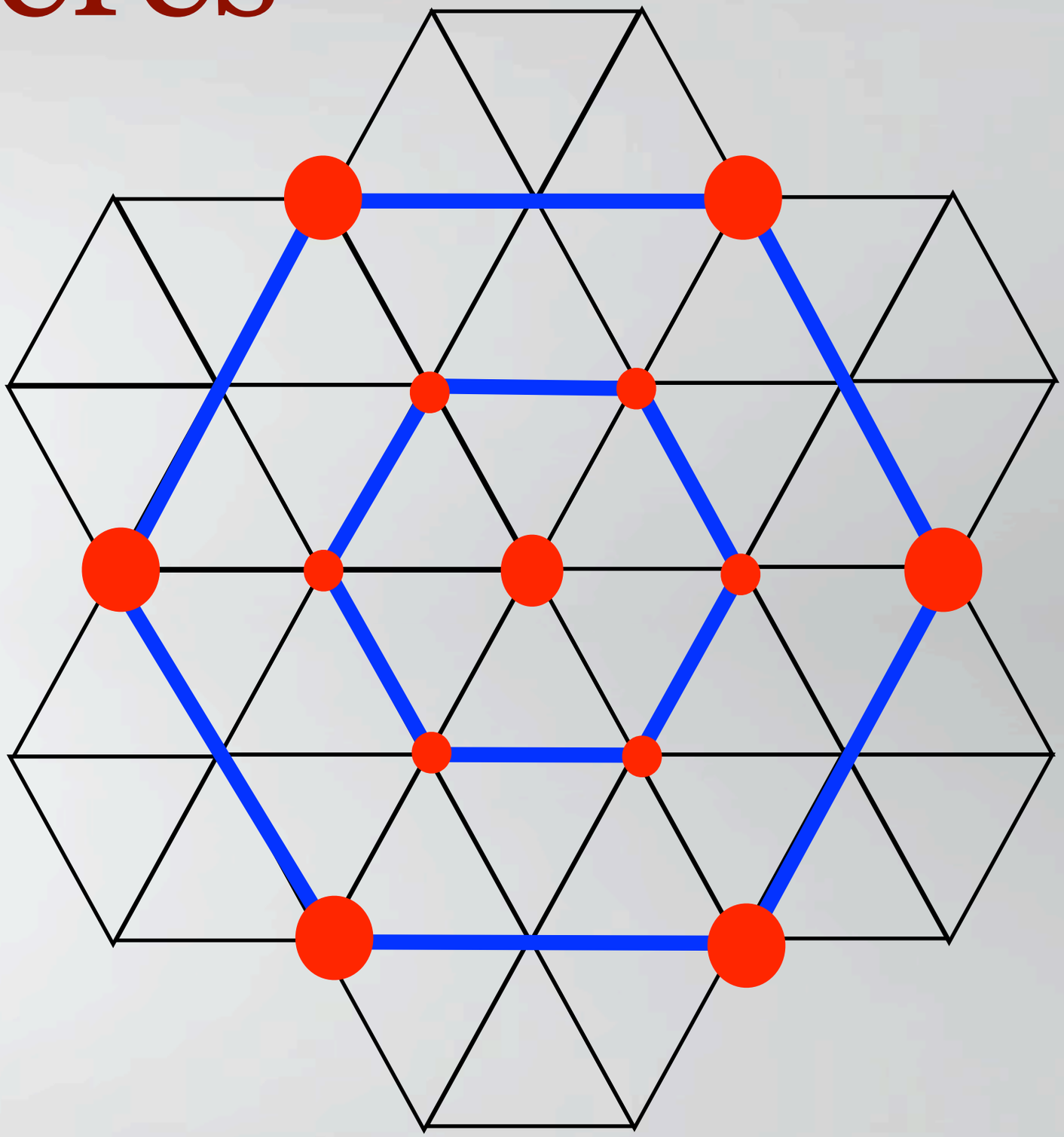




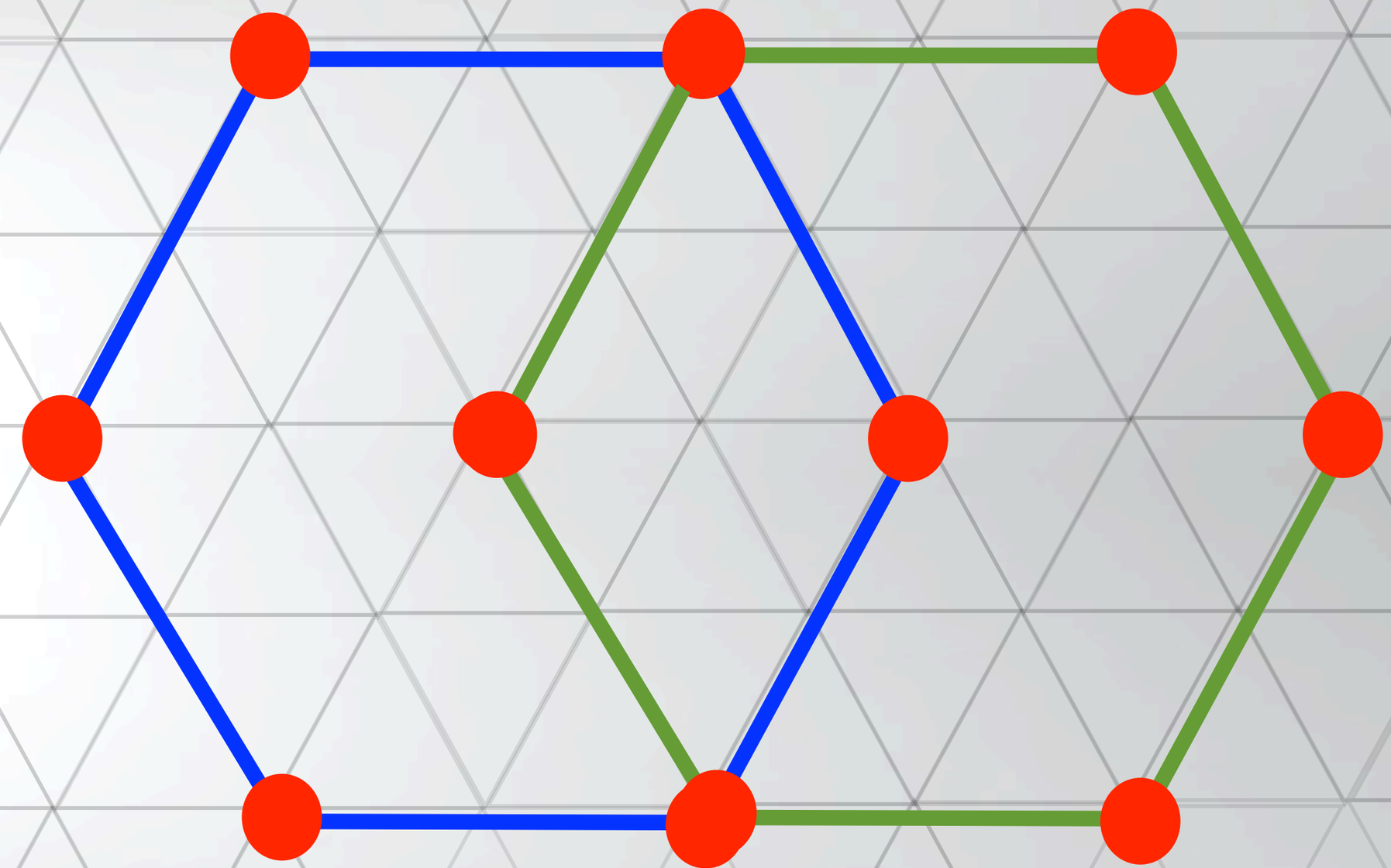


Saturday, April 7, 12

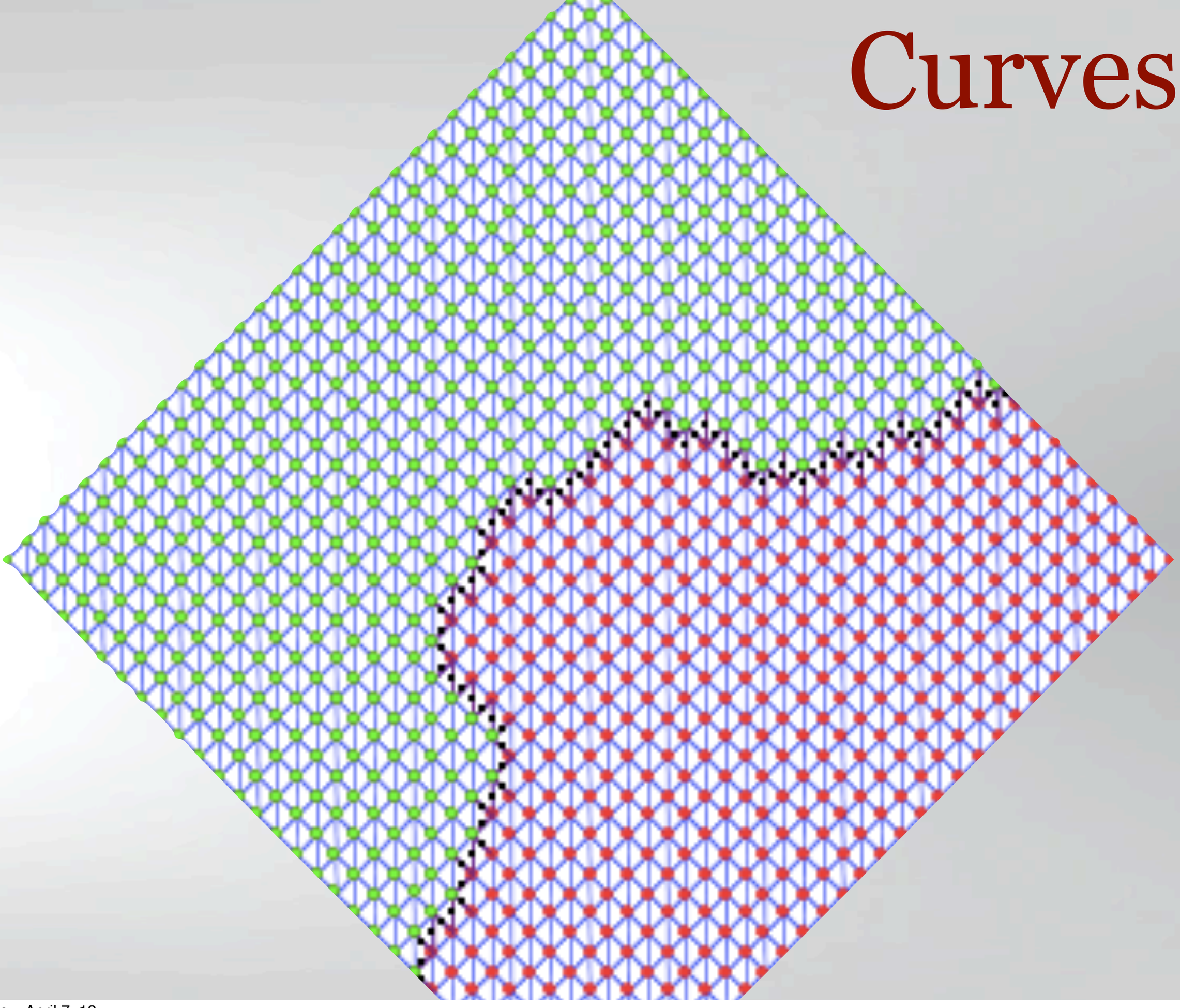
Spheres



Intersection of Spheres



Curves

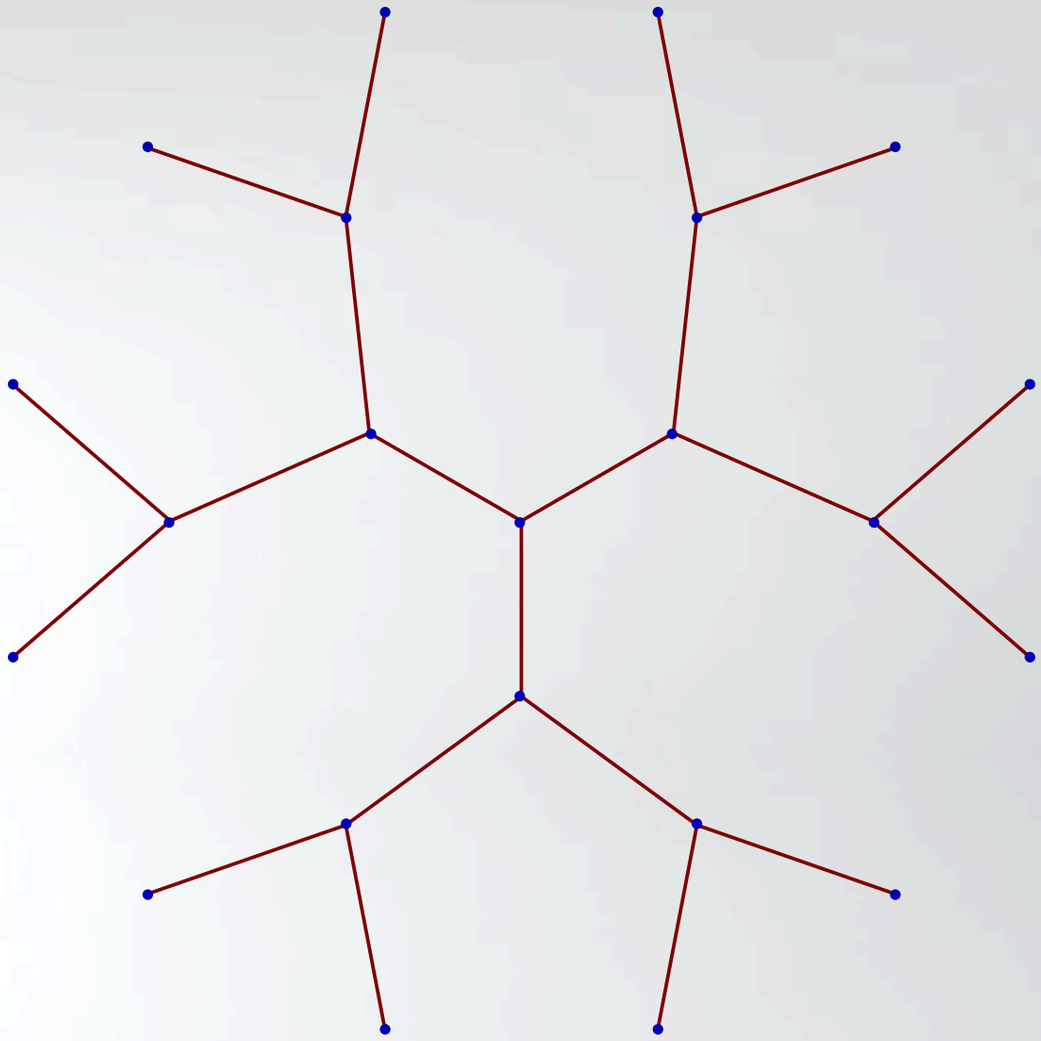


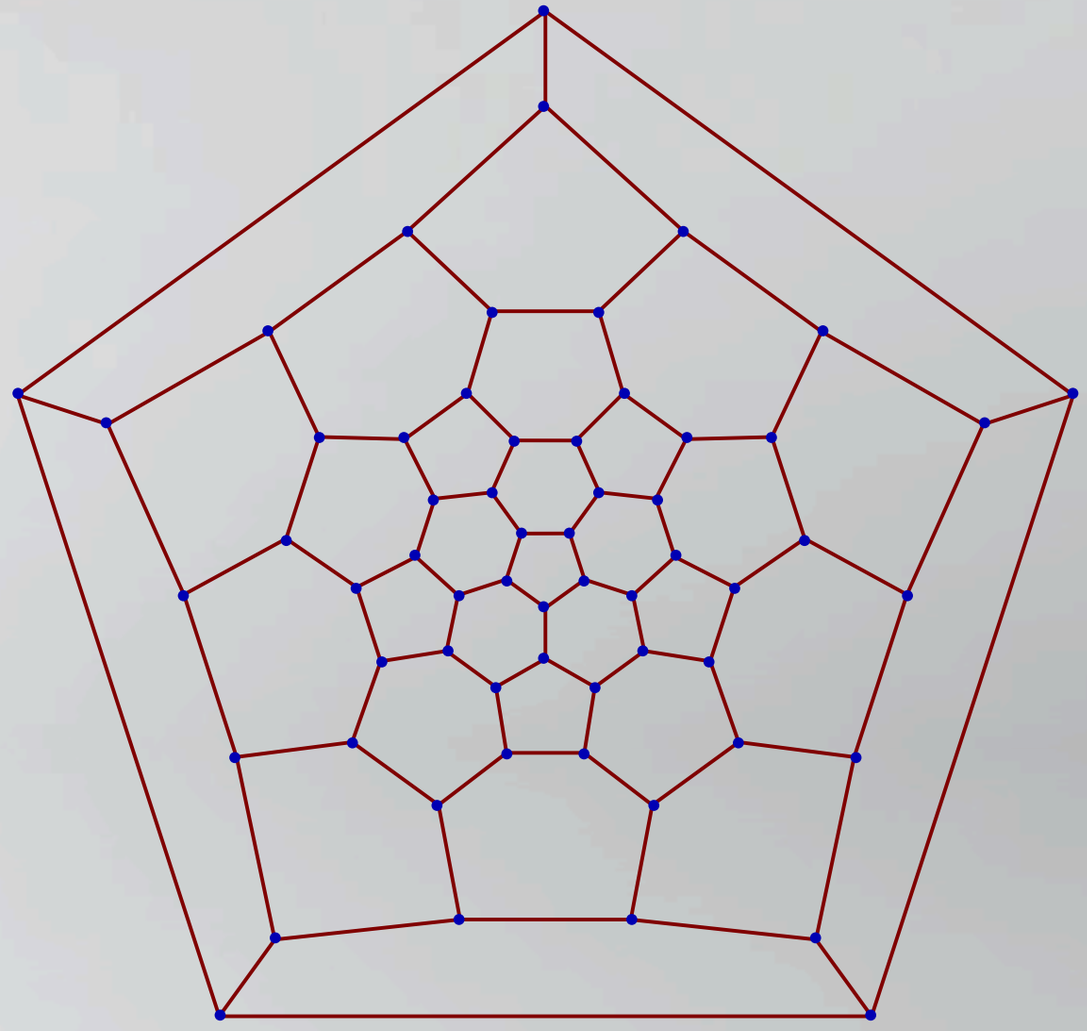
Growth of Circle Length

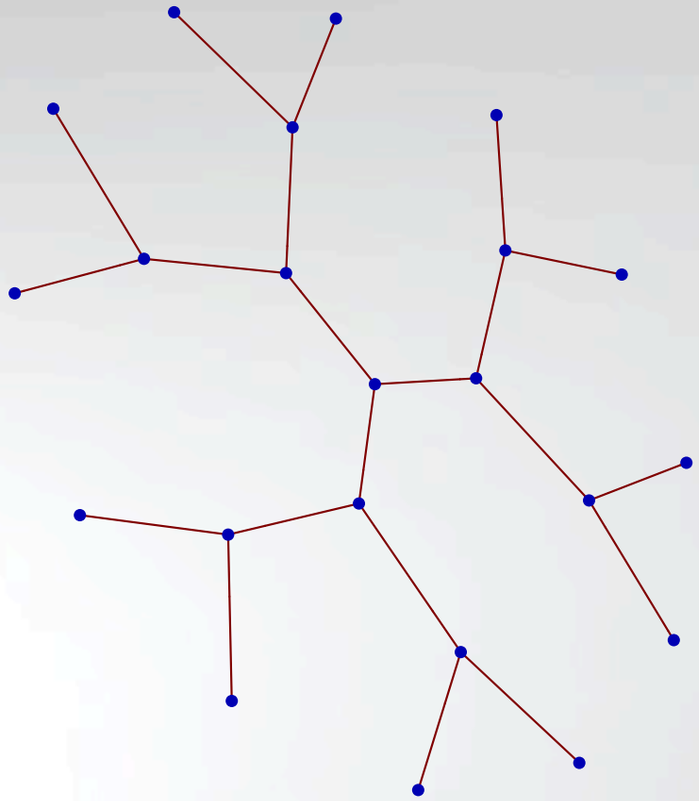
|S(r)|" positive: hyperbolic

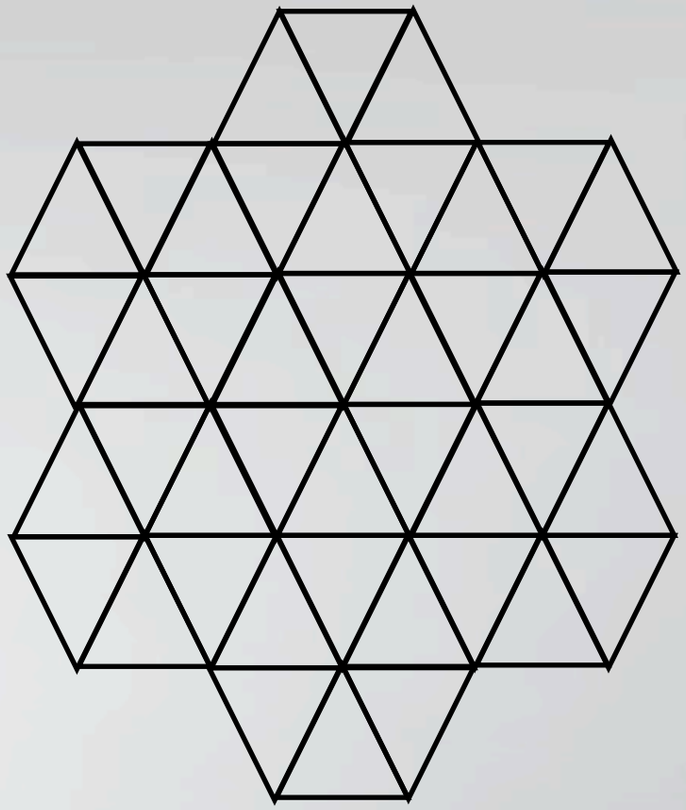
|S(r)|" =0 flat

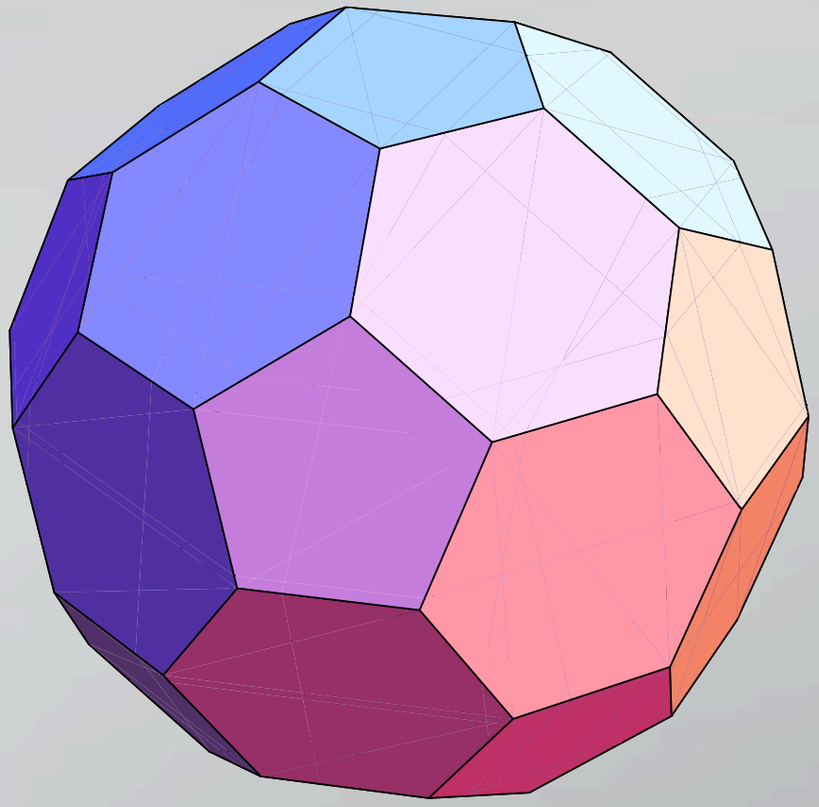
|S(r)|" negative grows polynomially: elliptic



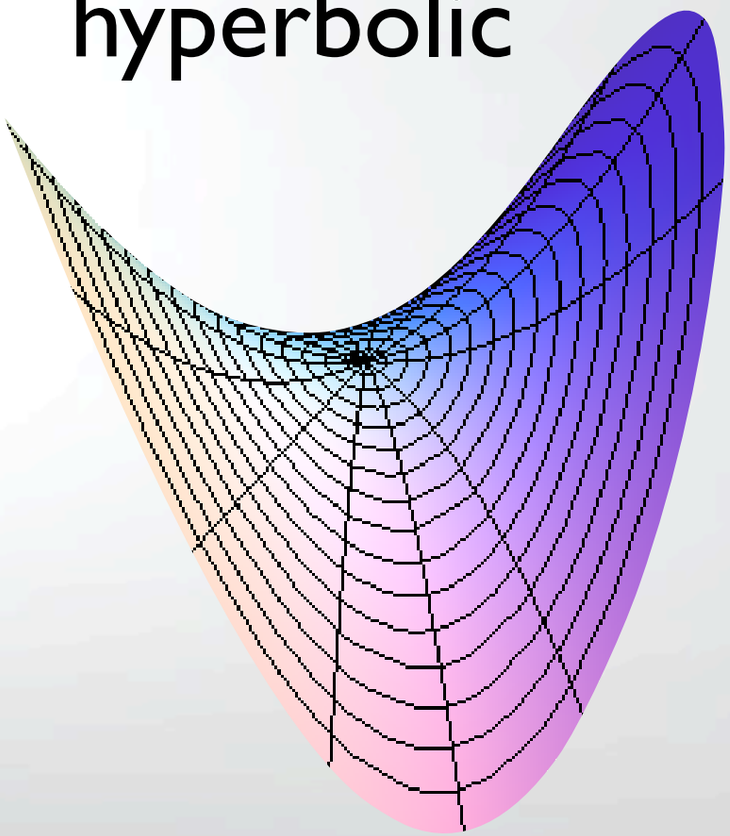




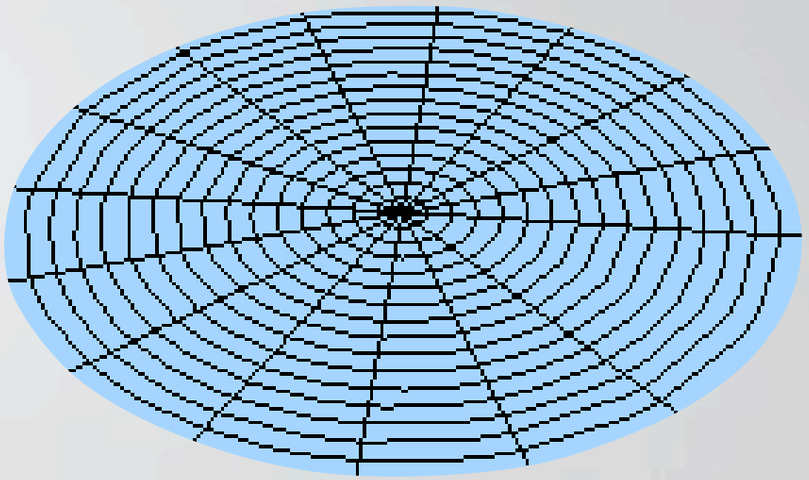




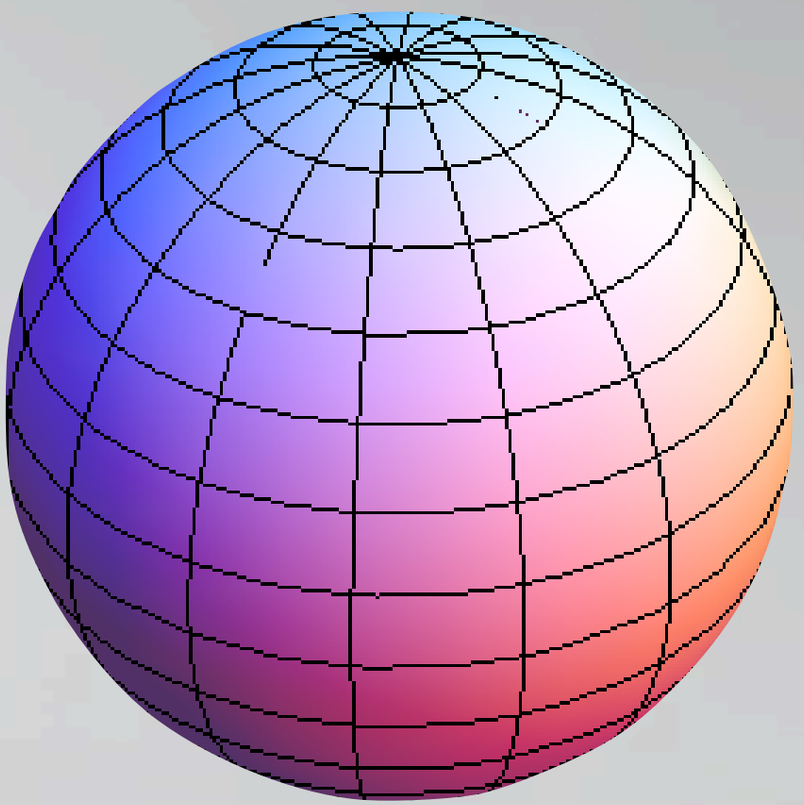
hyperbolic



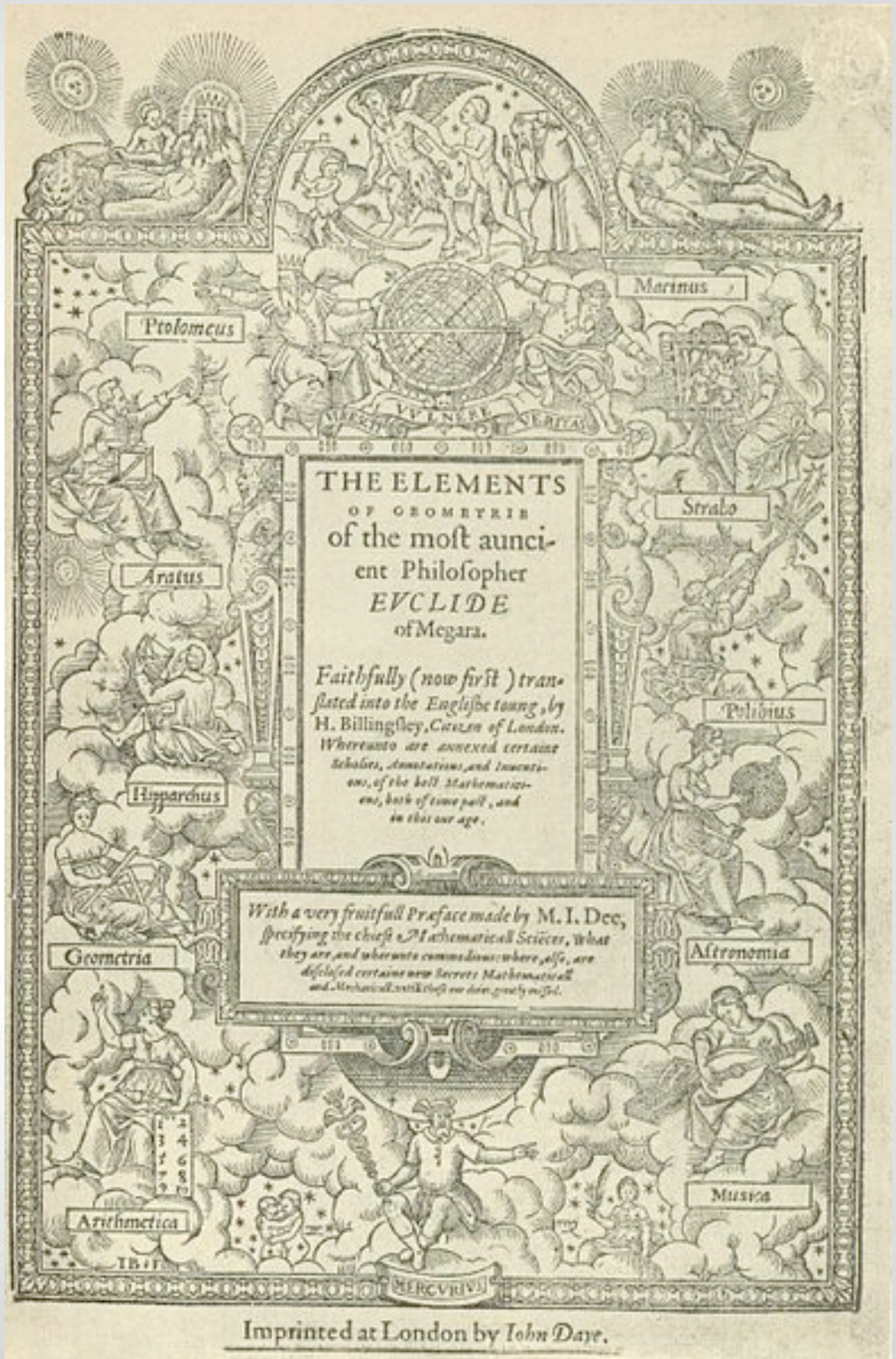
flat

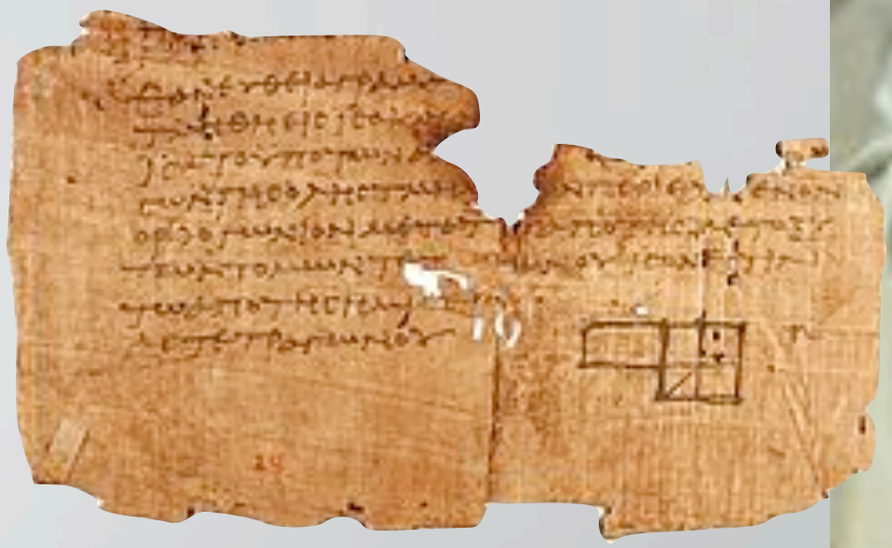


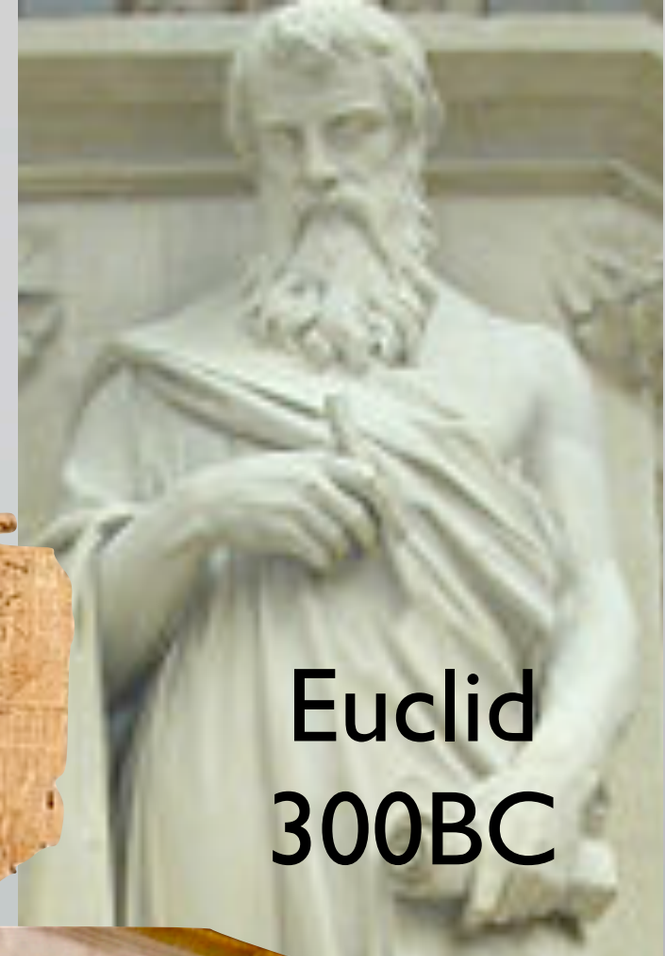
elliptic



Euclids Axioms



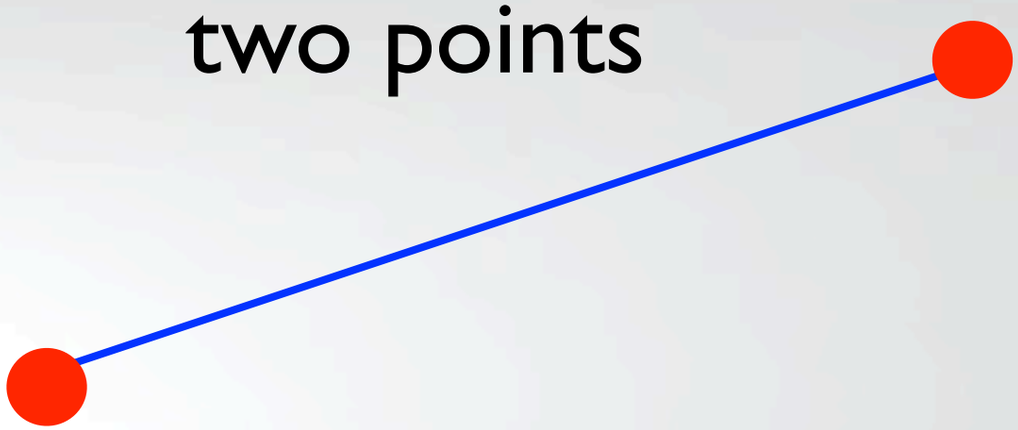




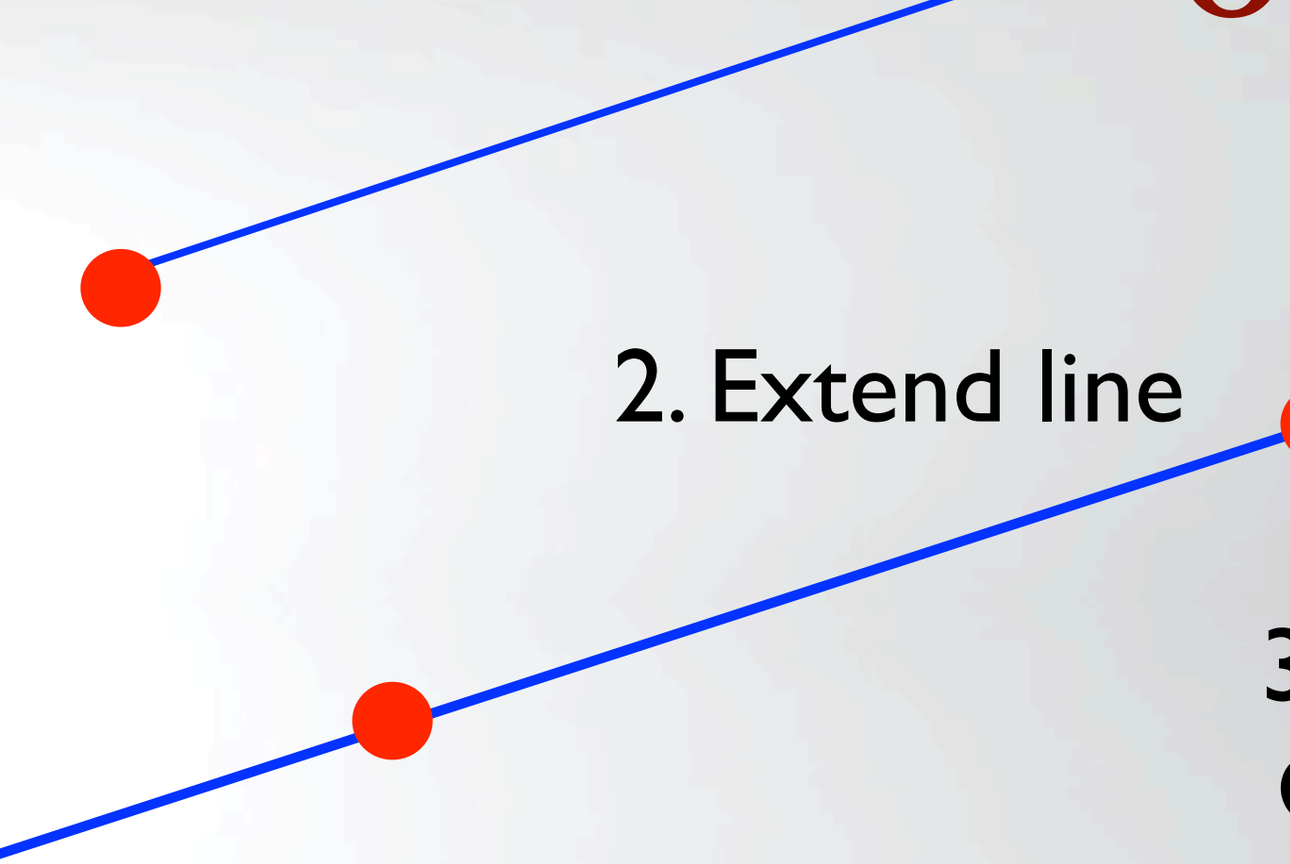
Euclid
300BC

Euclid's Axioms of Planimetry

1. Line between two points

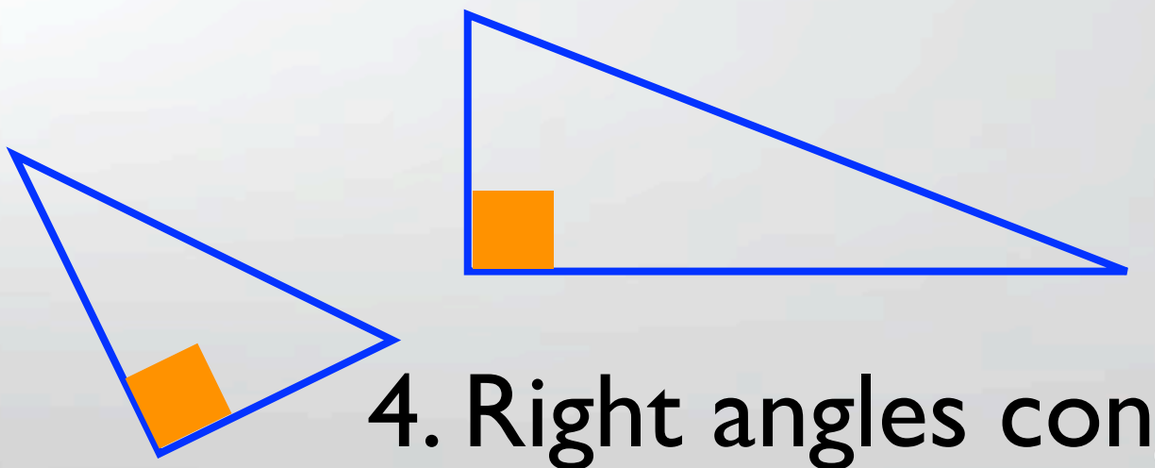


2. Extend line

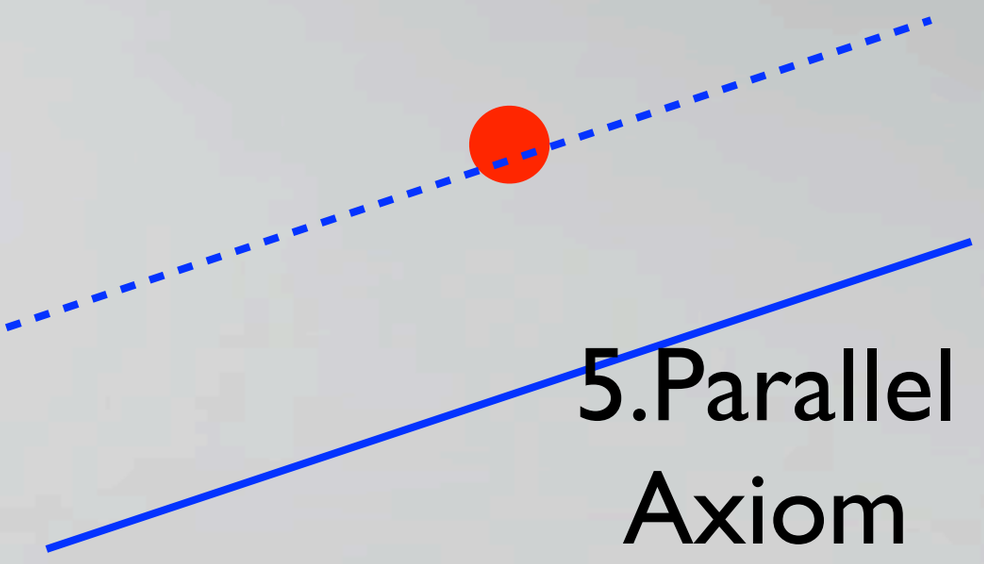


3.Build Circle

4. Right angles congruent

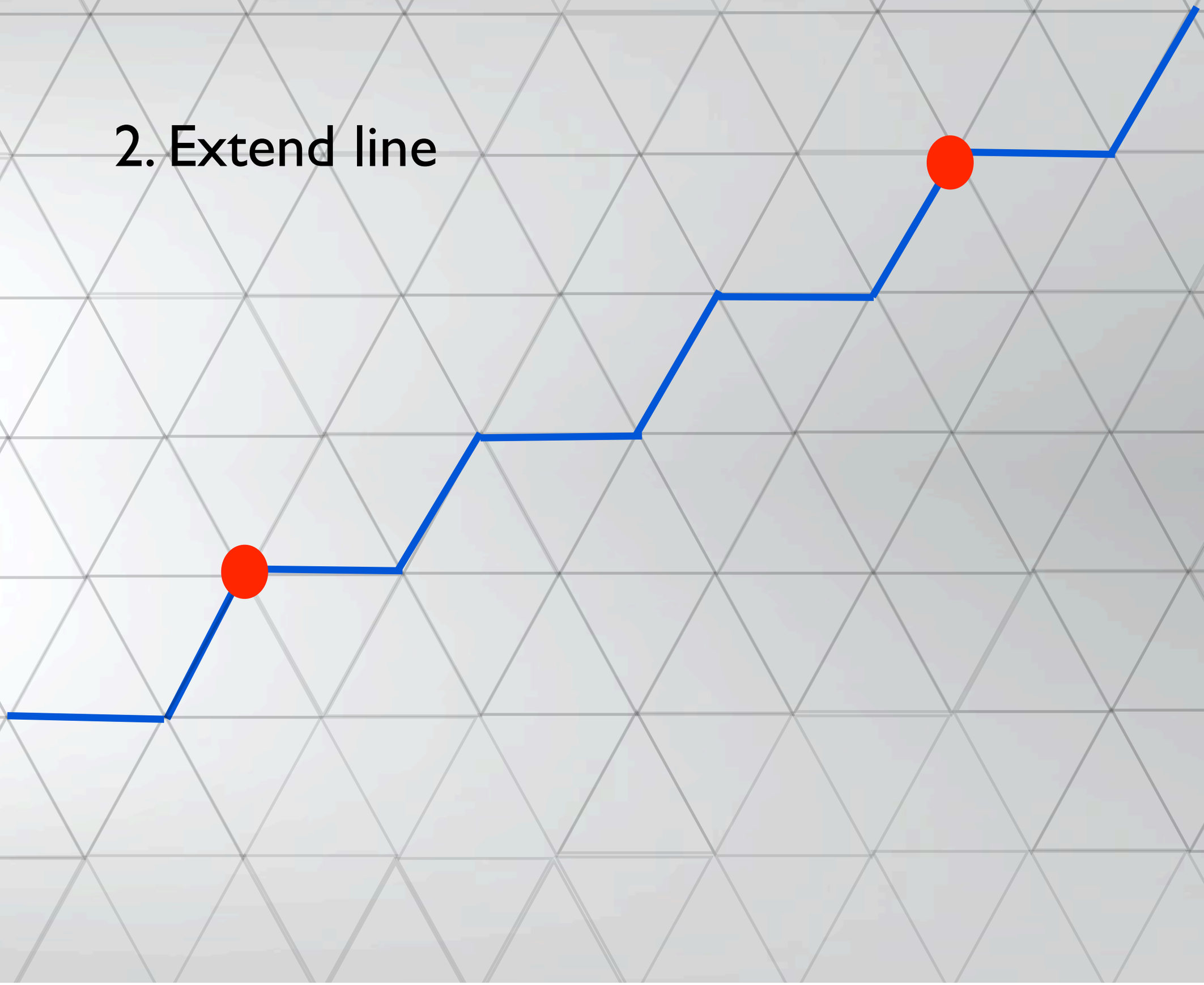


5.Parallel Axiom

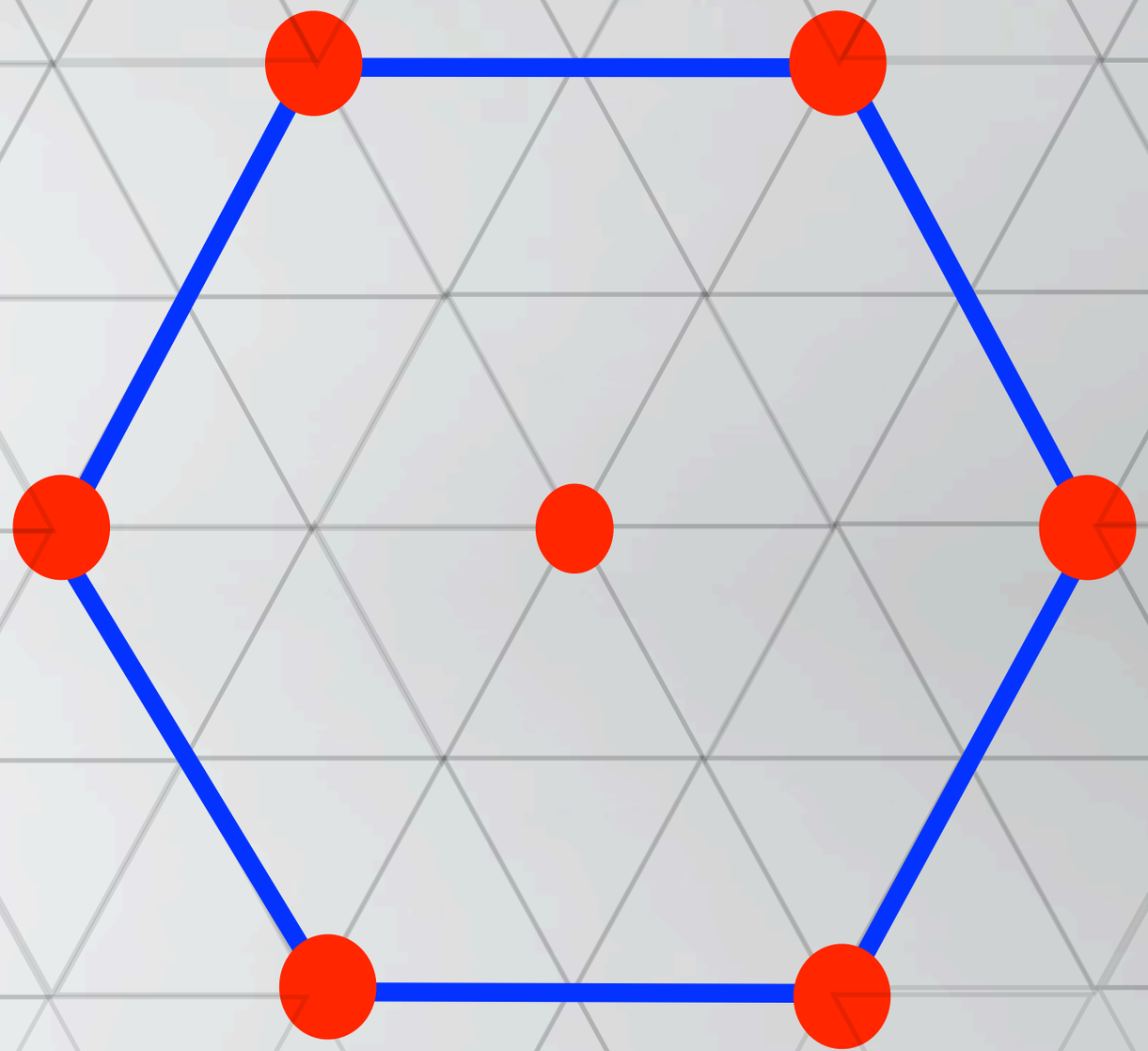


1. Line between two points

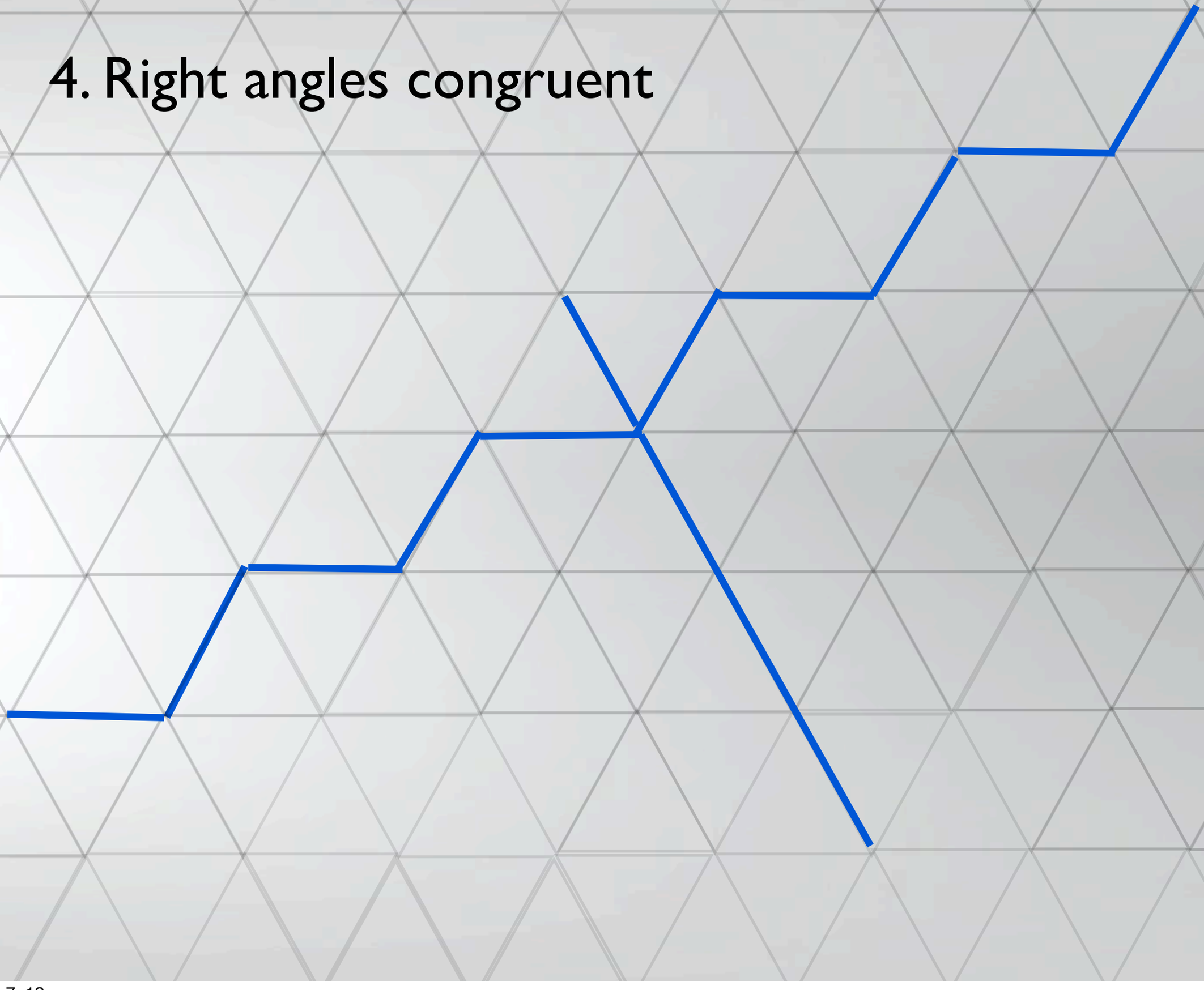
2. Extend line



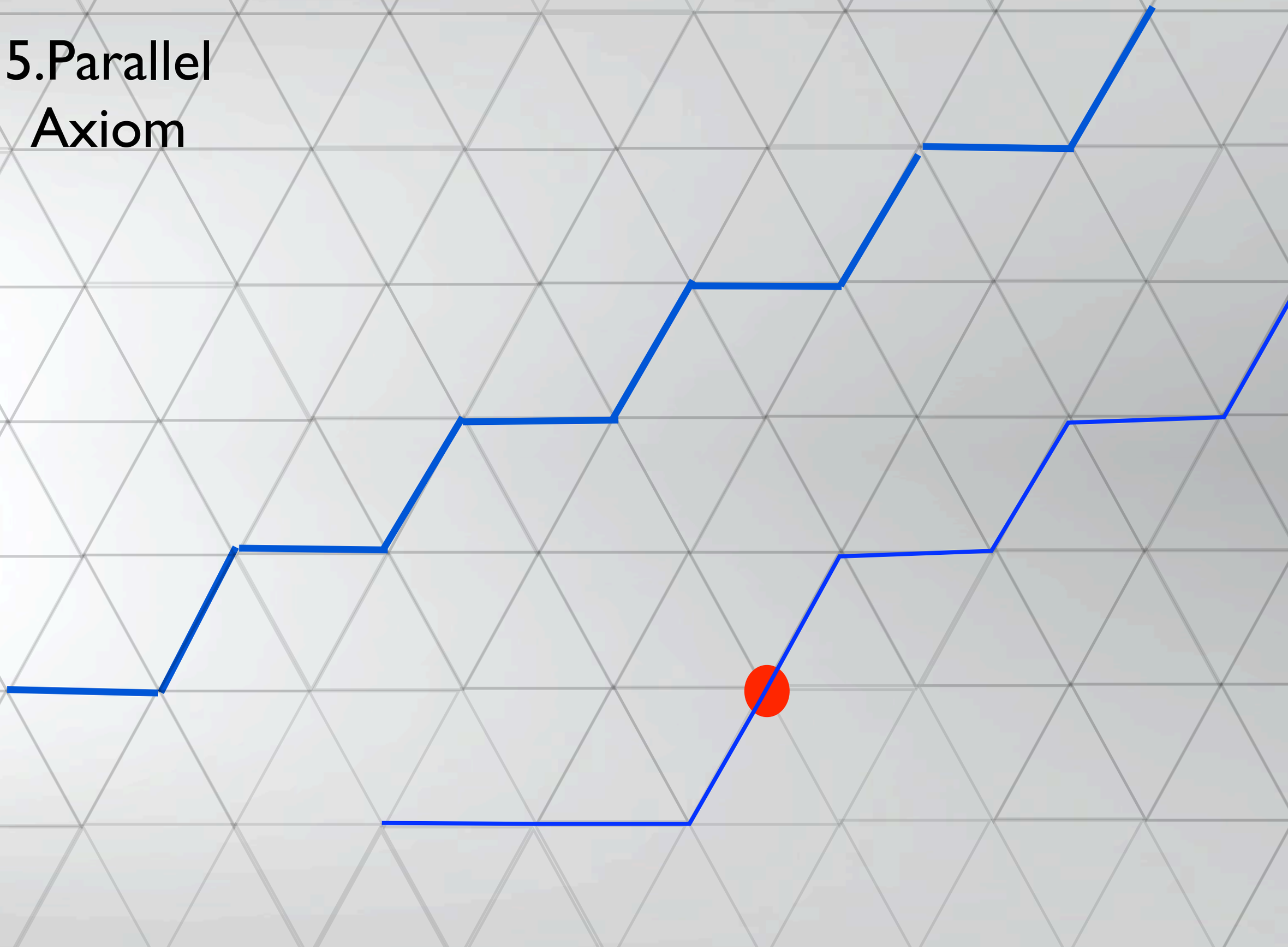
3.Build
Circle



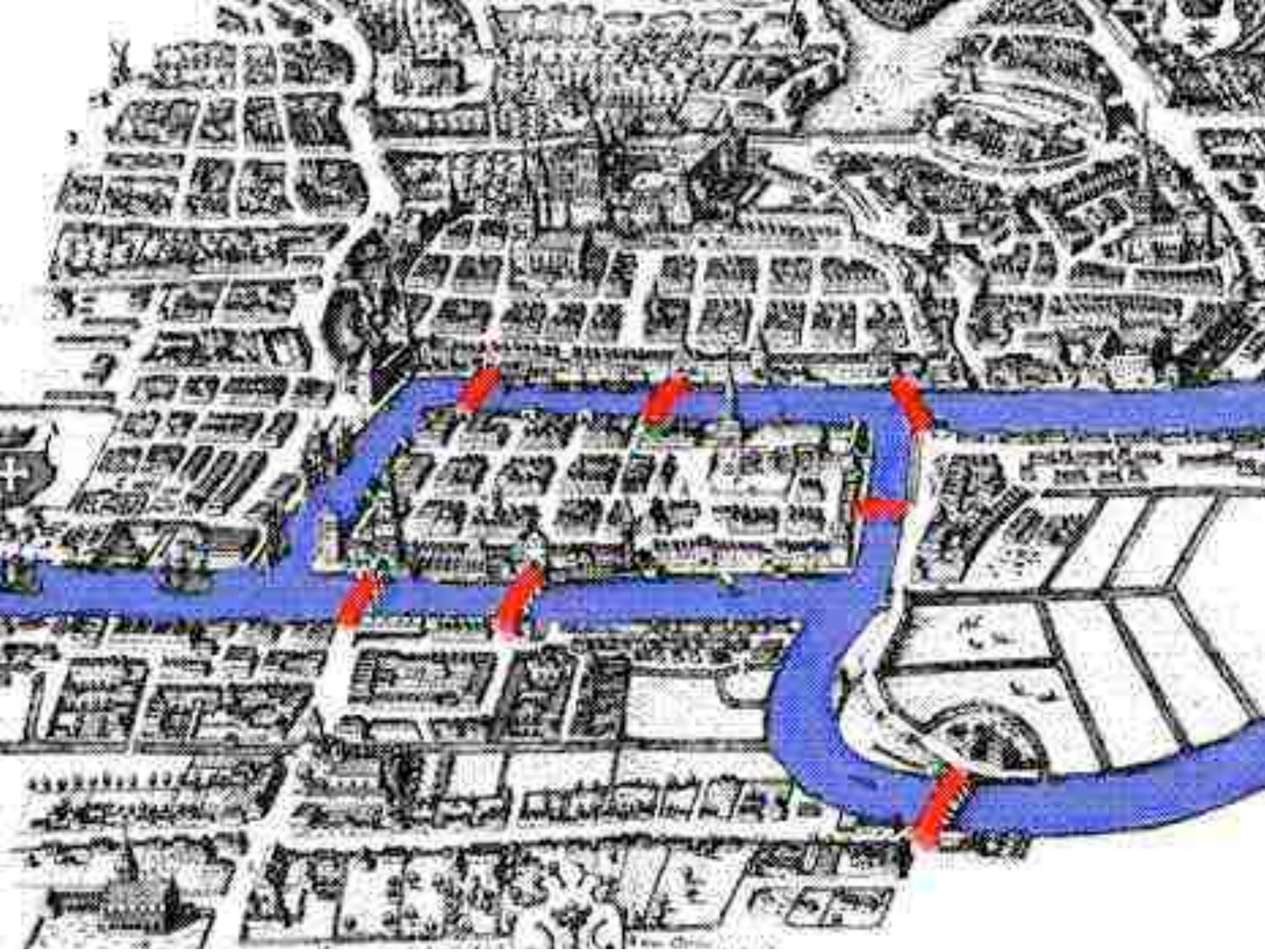
4. Right angles congruent



5.Parallel Axiom



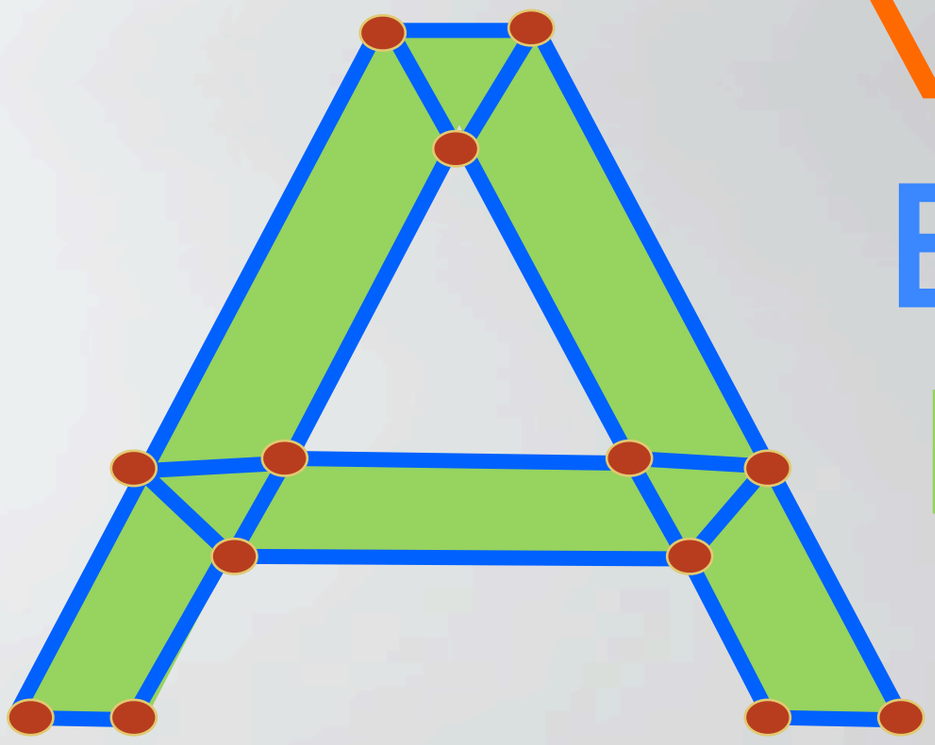
Birth of Topology



Story of Math II

Euler Characteristic

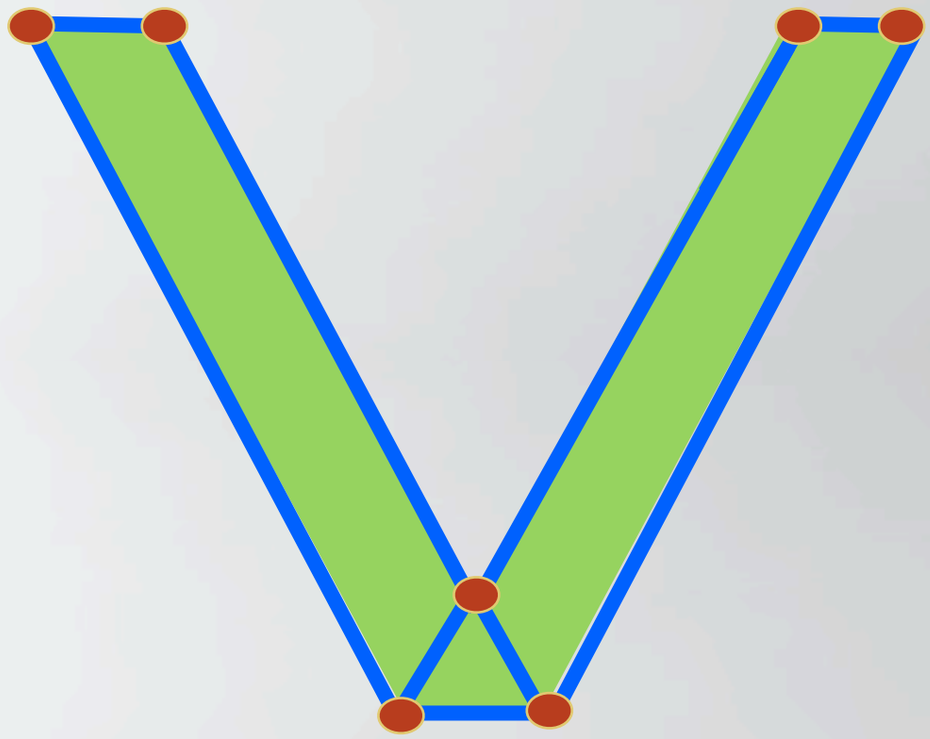
$$\chi = V - E + F$$



V=13

E=21

F=8



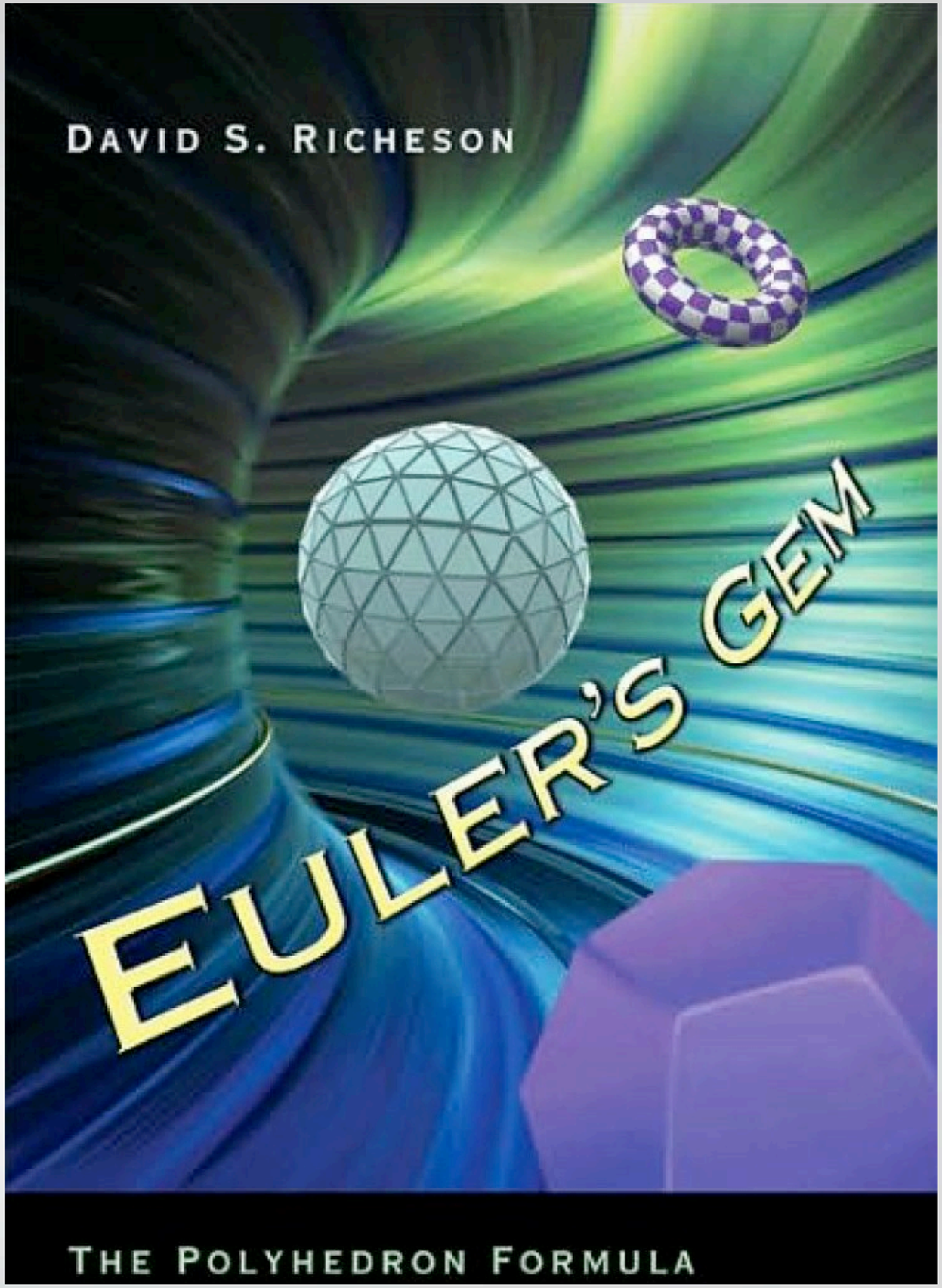
V=7

E=9

F=3

Euler's Gem $V-E+F=2$

V	E	F
4	6	4
6	12	8
8	12	6
12	30	20
20	30	12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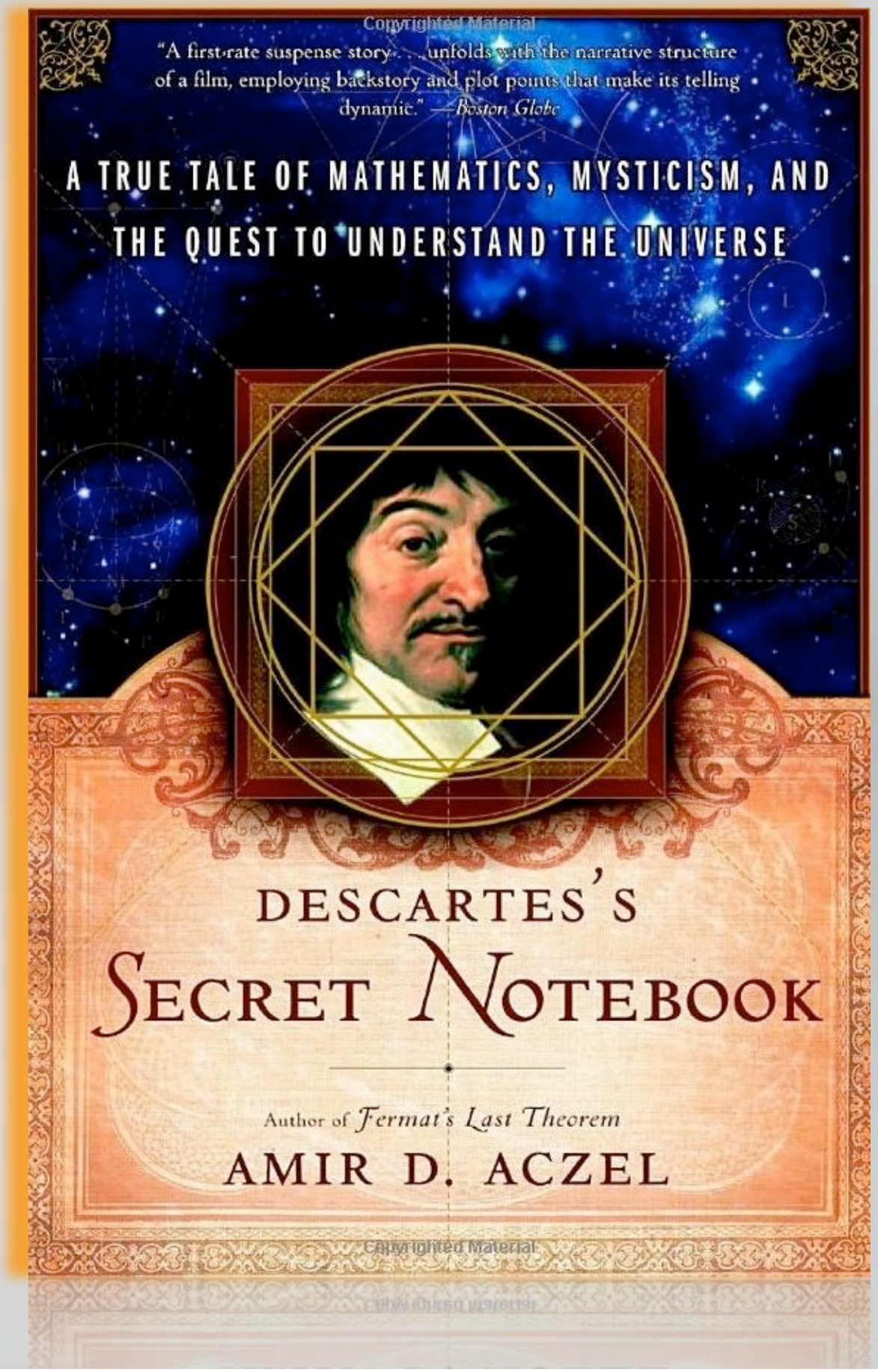
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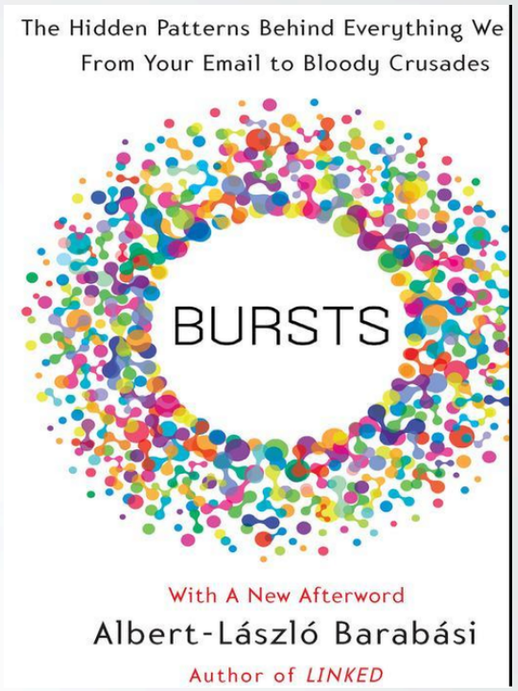
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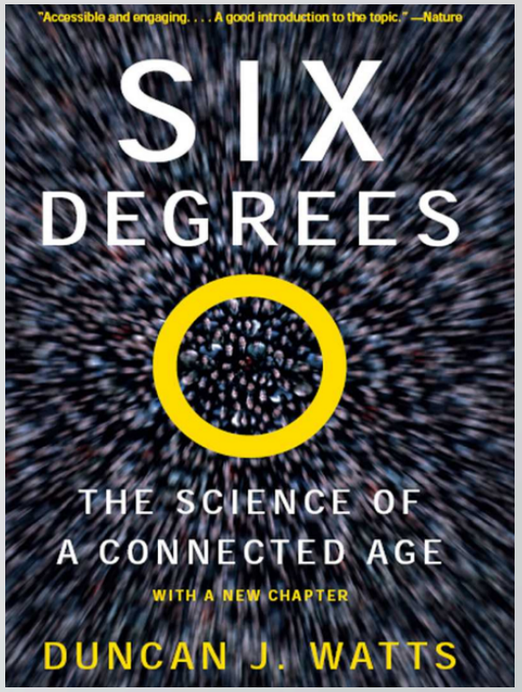
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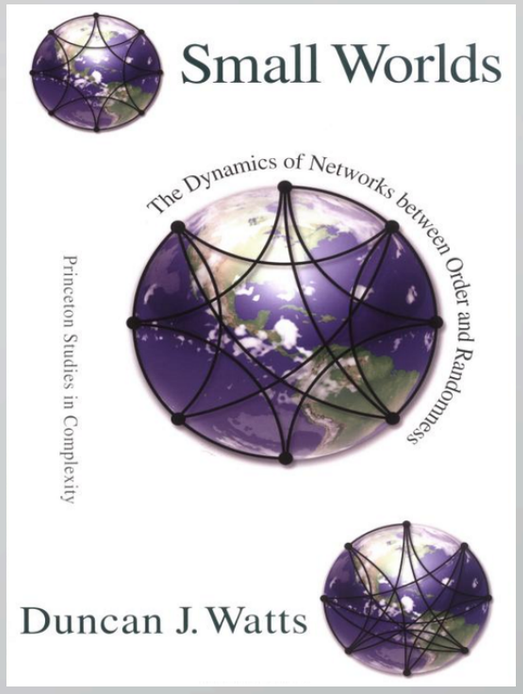
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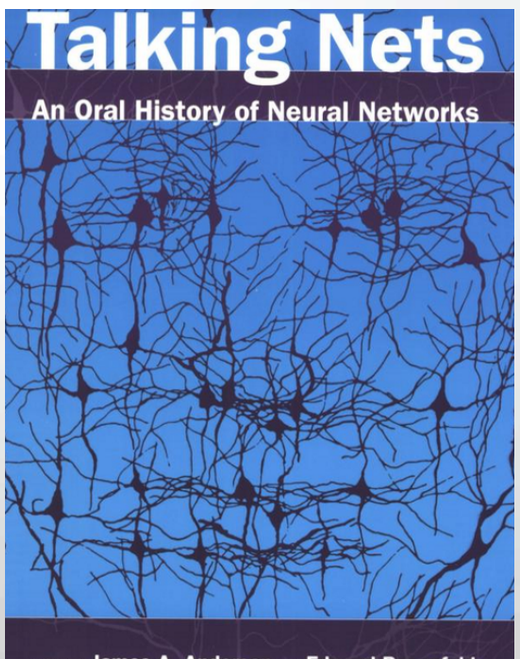
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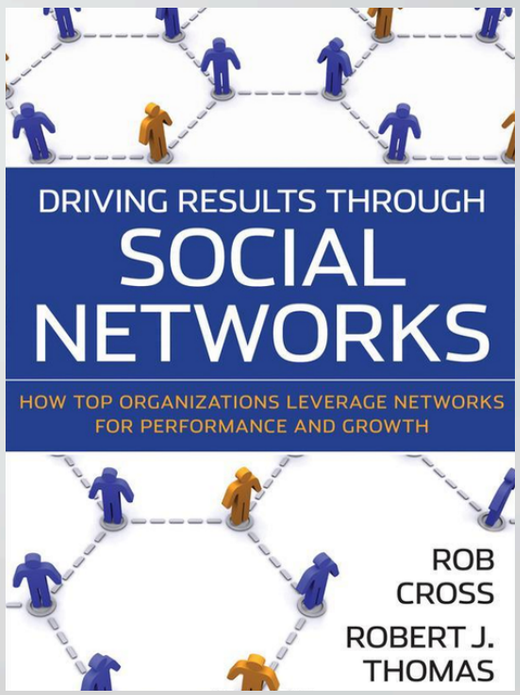
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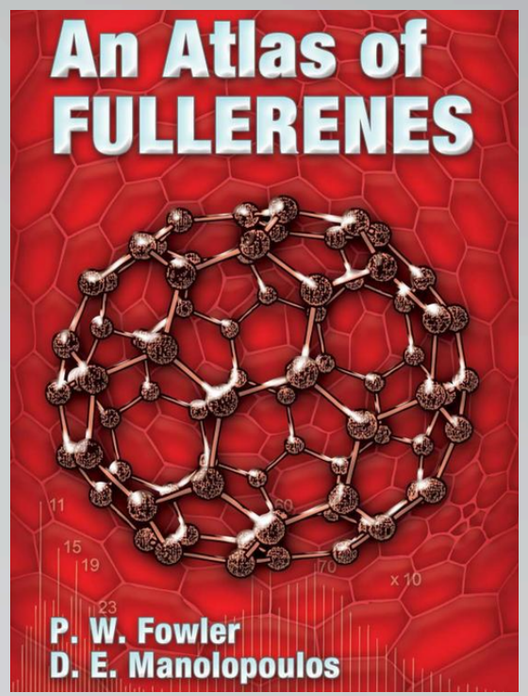
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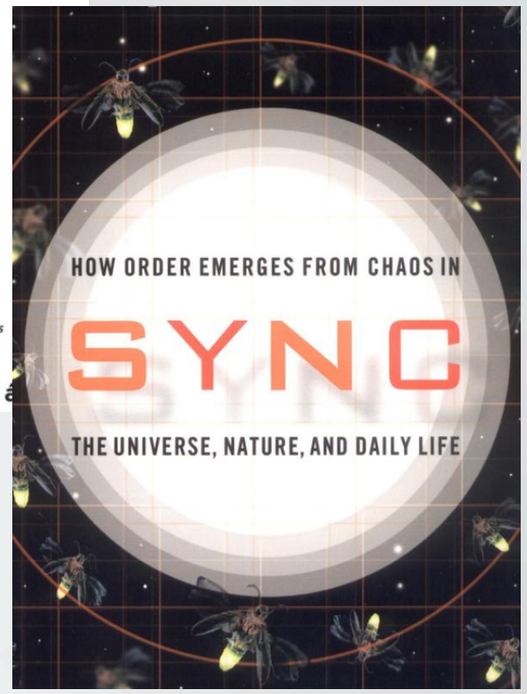

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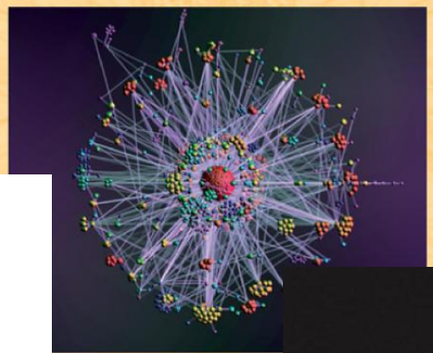

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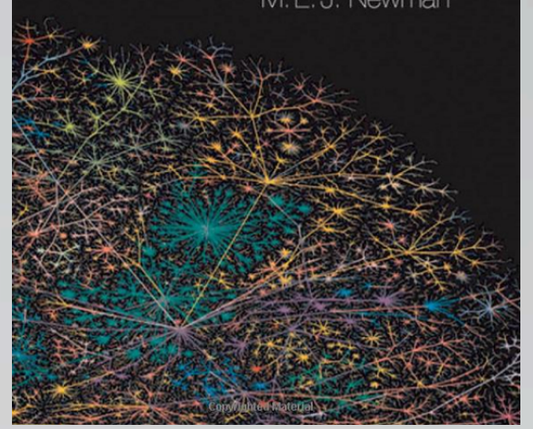
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