Imitation Games

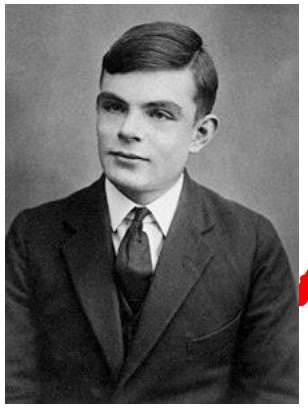
Avi Wigderson
Institute for Advanced Study

Plan

The original Imitation Game
Intelligence
The main idea, generalizations, speculations

Modern Imitation Games
Cryptography
Randomness
Combinatorics and number theory
Privacy
Definitions and major consequences

Conclusions



Alan Turing 1912-1954

Computer science

Computing revolution

Enigma machine

Biological modeling

Artificial Intelligence

Intelligence

[Turing'50] *Computing machinery and intelligence*

How to study the question "can machines think?"

1) Define **machine** & **think.** (philosophical/ontological)

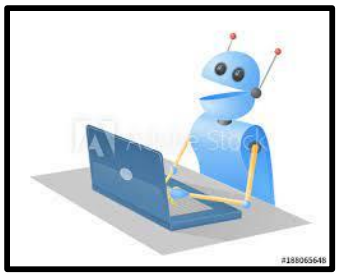
2) Test it!

(operational/behavioral)

Turing's test: the original imitation game

[Turing '50]

H

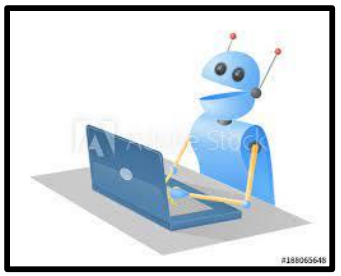


H

"Definition": Robot is intelligent if the referee makes a similar guess in both worlds

Turing's test: the original imitation game

[Turing '50]



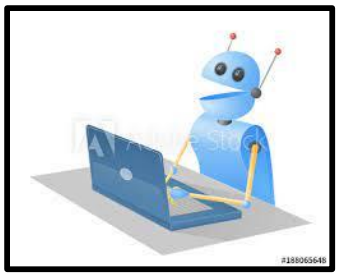
H

R

"Definition": Robot is intelligent if the referee makes a similar guess in both worlds

[Turing '50]

Turing's test: the original imitation game



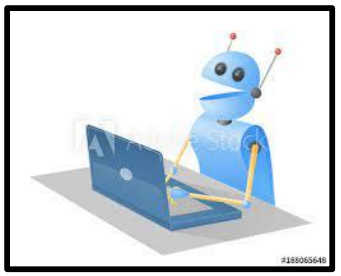
92%

93%

"Definition": Robot is intelligent if the referee makes a similar guess in both worlds

Turing's test: the original imitation game

[Turing '50]



75%

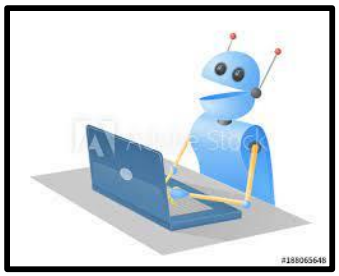
74%

"Definition": Robot is intelligent if every human referee makes a similar guess in both worlds

Turing's test: the original imitation game

[Turing '50]

p_0



p_1

"Definition": Robot is intelligent if for *every* human referee, $p_0 \approx p_1$

Cognition, emotions,...

Can a computer ~~feel~~ behave as if it feels

- Empathy, fear, pain, … ?
- Conscious, self-aware, … ?

How about me? How about my dog?

Objective, ontological definitions may not be testable, falsifiable, have universal meaning, …

Subjective, behavioral definitions may be precise, testable, operational, useful, ..., revolutionary

Precise Imitation Games
- Theory of Computation
- Discrete Mathematics

Paradigm: two things are the *same* if they cannot be told apart by any reasonable test

Formal definitions of central notions - primary

Theorems, proofs, constructions, theories,…

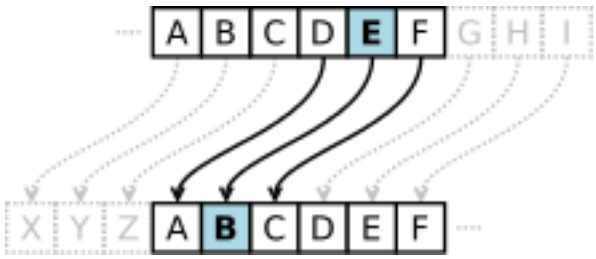
Power of the Imitation Game paradigm - enable math, science, technology, policy!

Cryptography

Encryption:
the first 2000 years

Enc(ATTACK) = XQQXZH
Enc(RETREAT) = OBQOBXQ

Caesar's cipher



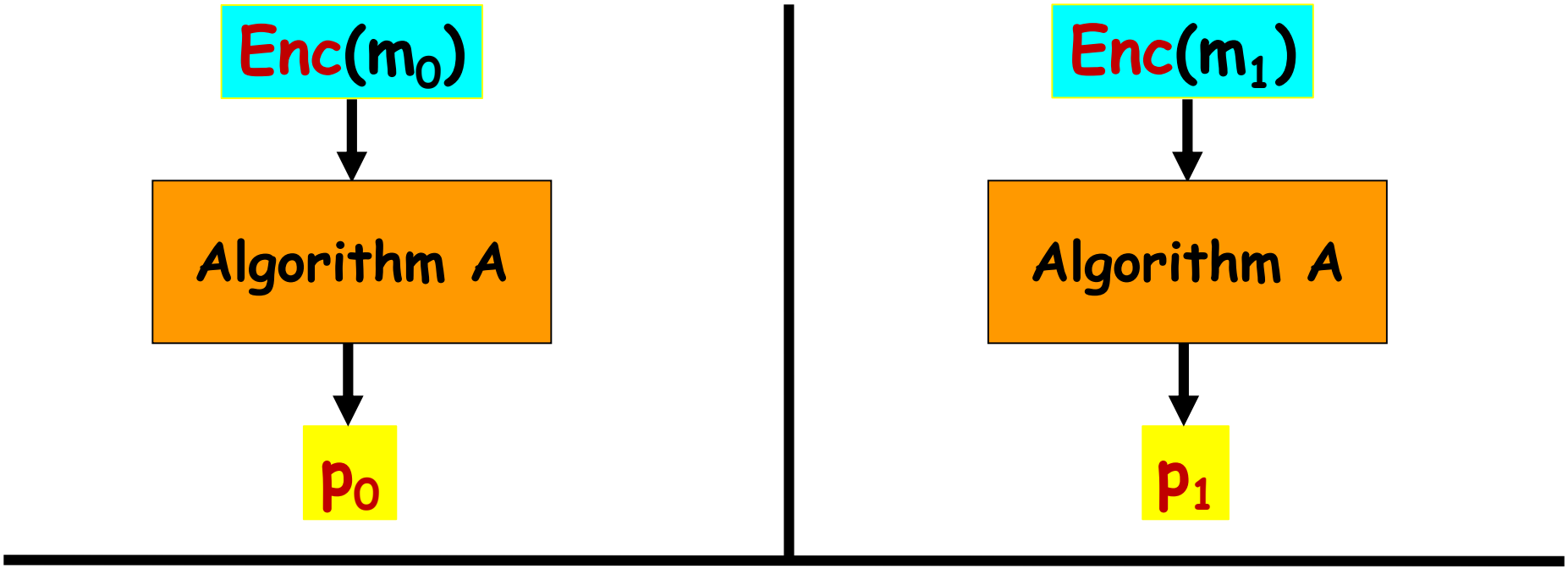
Enigma machine

Is Enc secure?

What is "secure"?

[Goldwasser-Micali '81]

Secure encryption



Definition: Enc is secure if for *every* m_0 & m_1 and for *every* efficient algorithm $p_0 \approx p_1$

Theory: Shooting for the moon (and getting there!) Defining *secret*. Shows Enc must be probabilistic!

Modern cryptography
last 4 decades

Public-key Encryption
On-line shopping
Contract signing
Secret exchange
Zero-knowledge proofs
Internet elections
Poker on telephone
Blockchains & digital currency

.....

Everything (w/out physical implements!)

Is a given protocol secure?

What is "secure"?

protocol ←→ imitation game

Randomness

The amazing utility of randomness

Nature seems to supply us perfect randomness

Unbiased, independent bits

which we use for numerous applications

- Sampling
- Scientific experiments & simulations
- Probabilistic algorithms
- Cryptography
- Game theory
- Gambling
- …

Seemingly much faster than deterministic ones for many problems

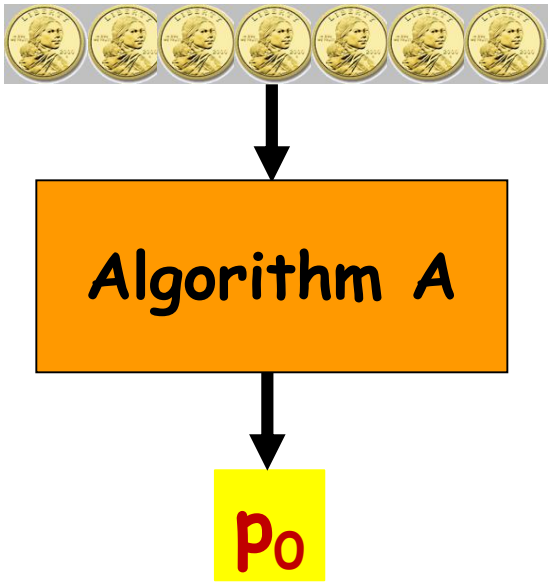
Where are the random bits from?

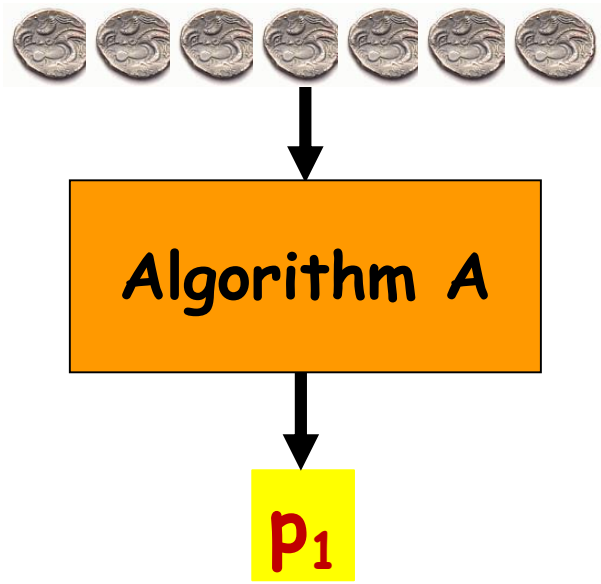
Is this power real?

Universe has:	Applications
- Perfect randomness 	Everything!
- Weak random sources     Biased, dependent bits 	??
- No randomness	??

[Blum-Micali '81
Yao'82]

Computational pseudo-randomness





Definition:  is **pseudo-random** if for *every* efficient algorithm,

$p_0 \approx p_1$

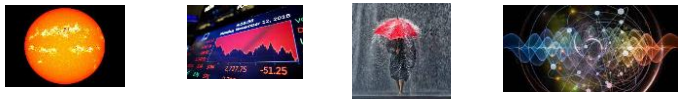
Theory: Composition, Amplification, Hardness vs. Randomness paradigm

Practice: Pseudo-random generators, Crypto

Universe has:

- Perfect randomness

- Weak random sources



Biased, dependent bits

- No randomness

Assuming "P≠NP": there are hard problems

Applications

Probabilistic algorithms

Probabilistic algorithms

Extractor theory

[B,SV,NZ,T,…,GUV,DW,…]

purifying randomness

Probabilistic algorithms

Hardness vs. Randomness

[BM,Y,…NW,IW,…]

Every fast prob alg has a deterministic counterpart

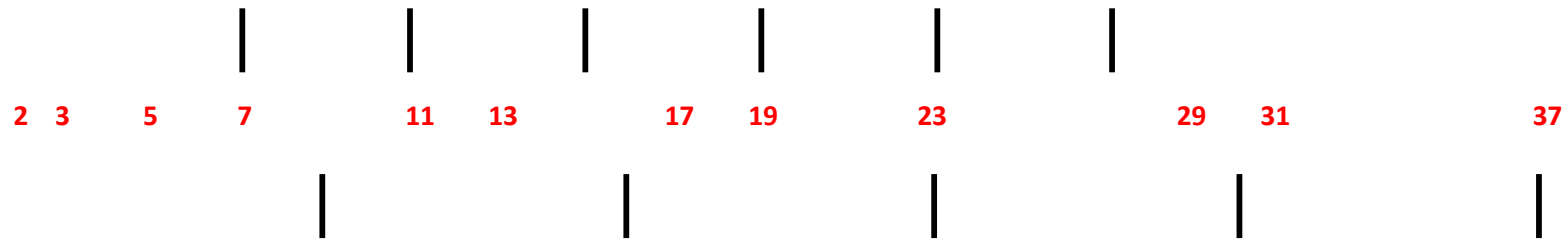
Major theories

Unexpected benefits

Structural pseudo-randomness
(discrete math, number theory,…)

[Ramsey '30] *"Every large enough system must have some structure"*

Periodic sequences



Which subsets contains long periodic sequences?

[Szemeredi '75] All "dense" subsets do!

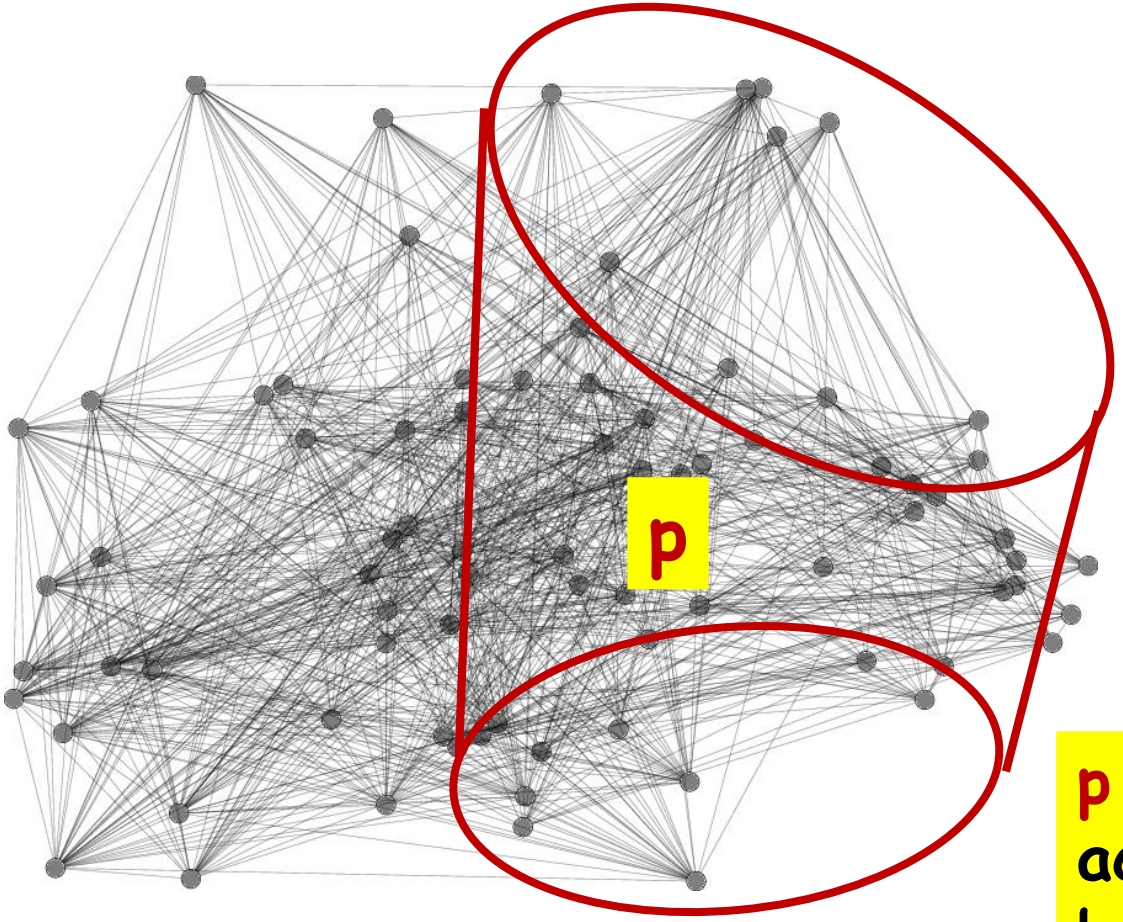
[Green-Tao '04] The primes numbers do!

[Easy] Random subsets do!

Which subsets "look" random?

[Szemeredi '75] Every "dense" network does!!

Networks, Clusters, Bonds

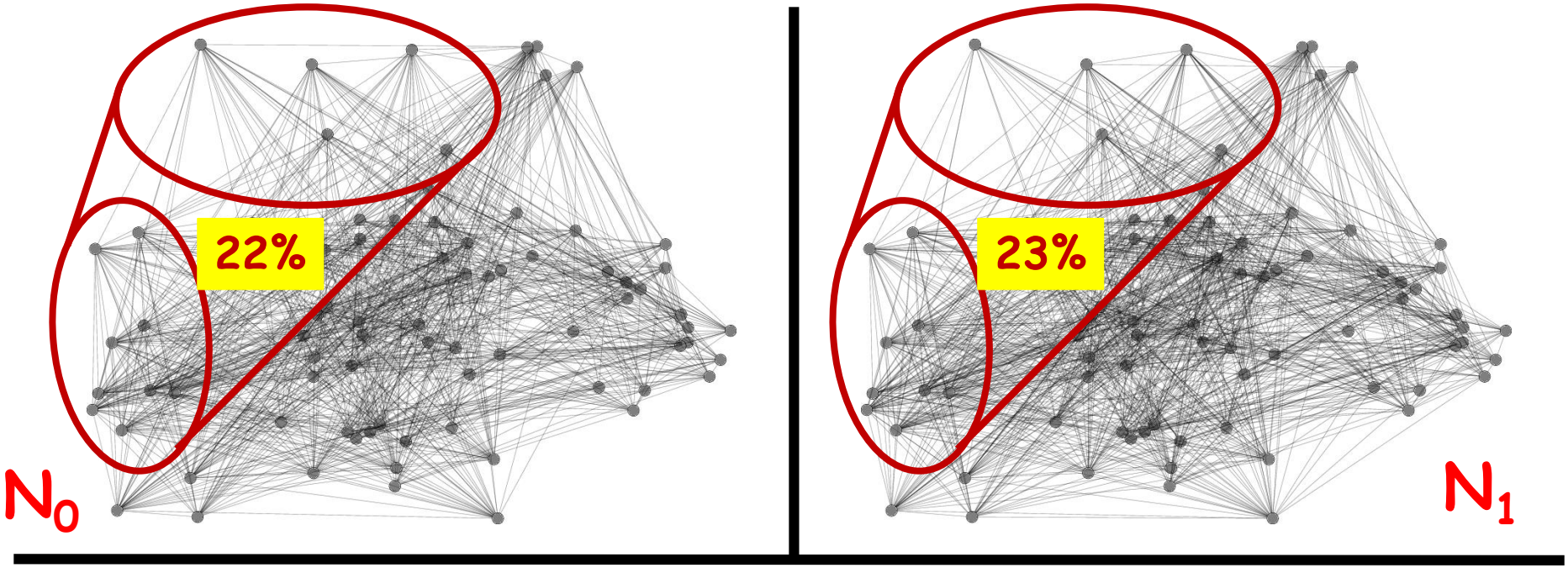


Roads, Internet, Facebook,...

p = bond: fraction o
actual connections
between clusters,
out of all possible

[Szemeredi'75]

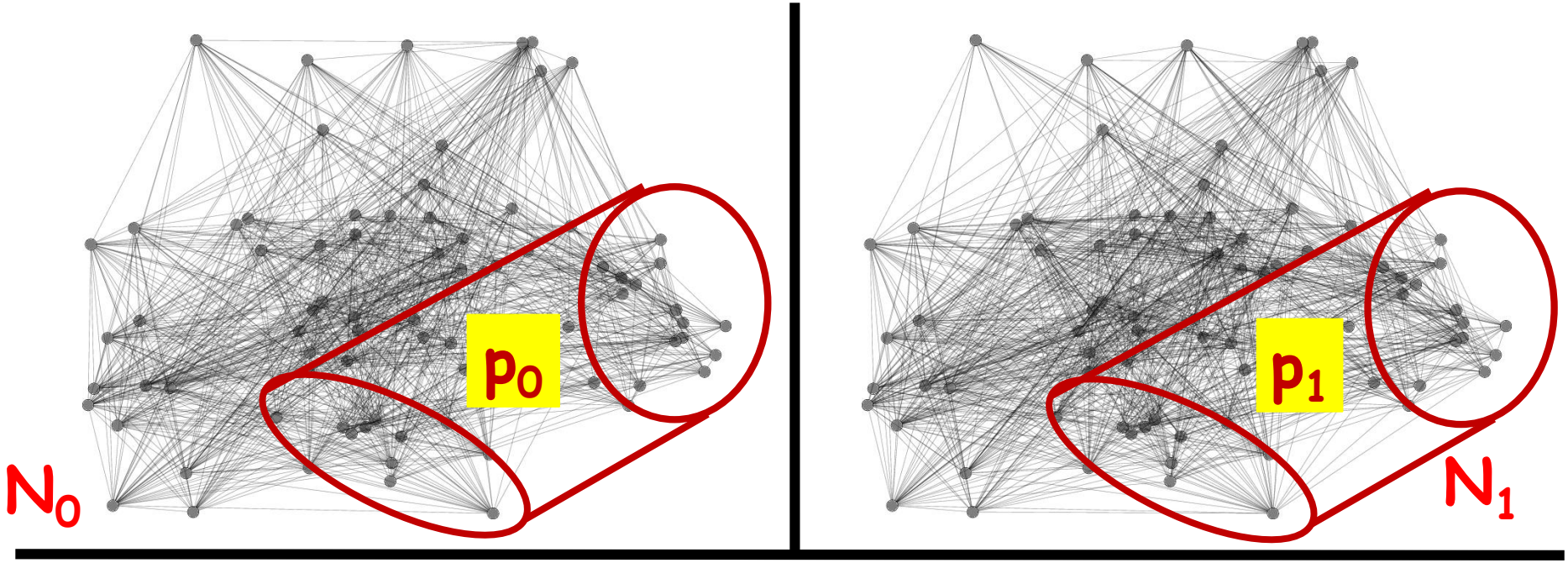
Bond-similarity of networks



Definition: N_0 & N_1 are bond-similar if *every* two communities are equally bonde $p_0 \approx p_1$

[Szemeredi'75]

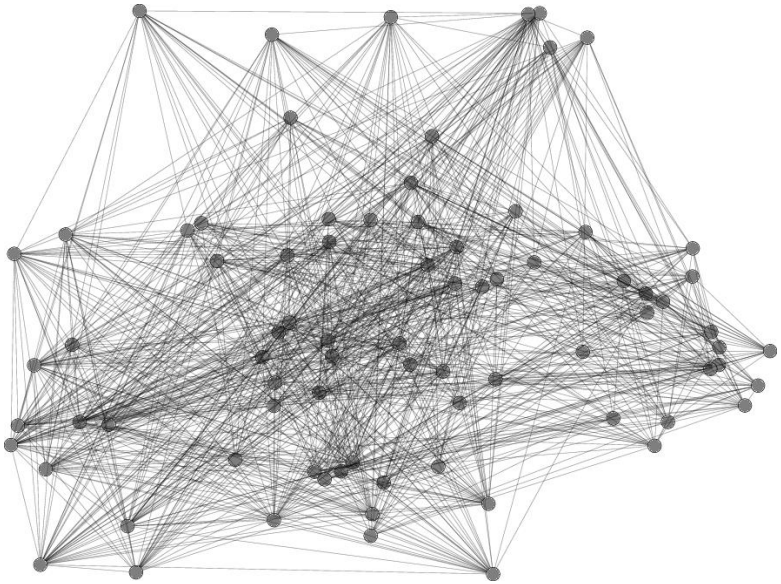
Bond-similarity of networks



Definition: N_0 & N_1 are bond-similar if *every* two communities are equally bonde $p_0 \approx p_1$

[Szemeredi'75]

Regularity



N_0

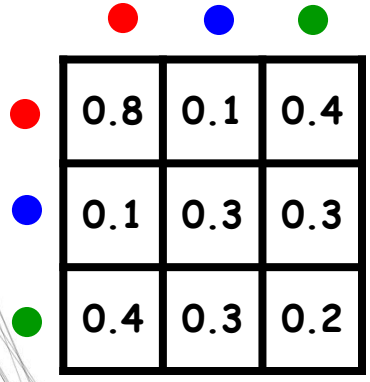
Szemeredi's Regularity Lemma:

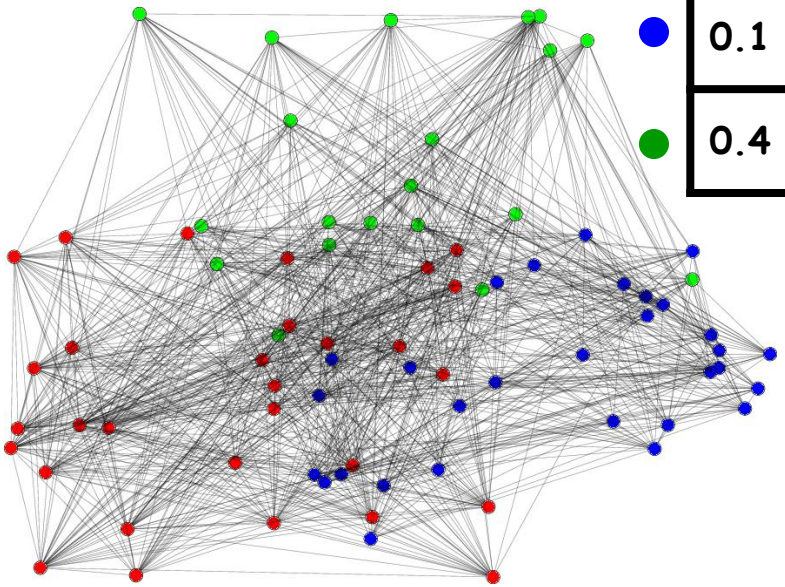
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

[Szemeredi'75]

Regularity





N_0

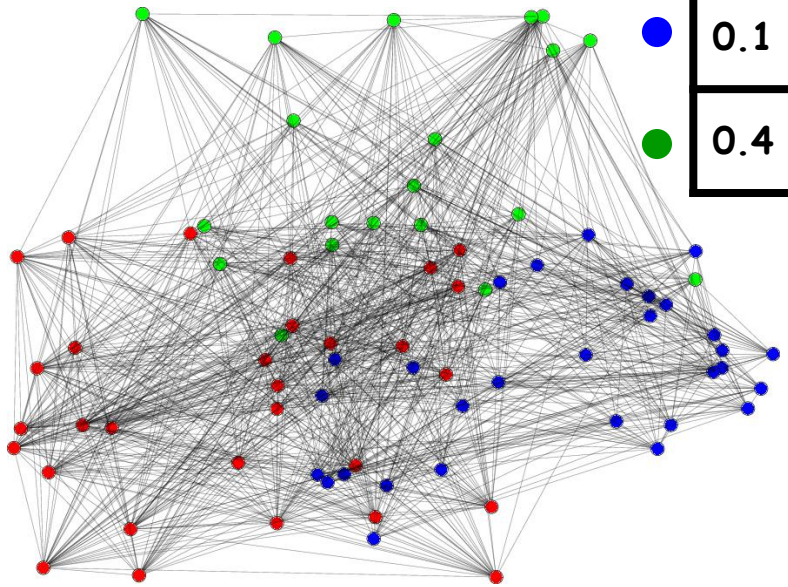
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

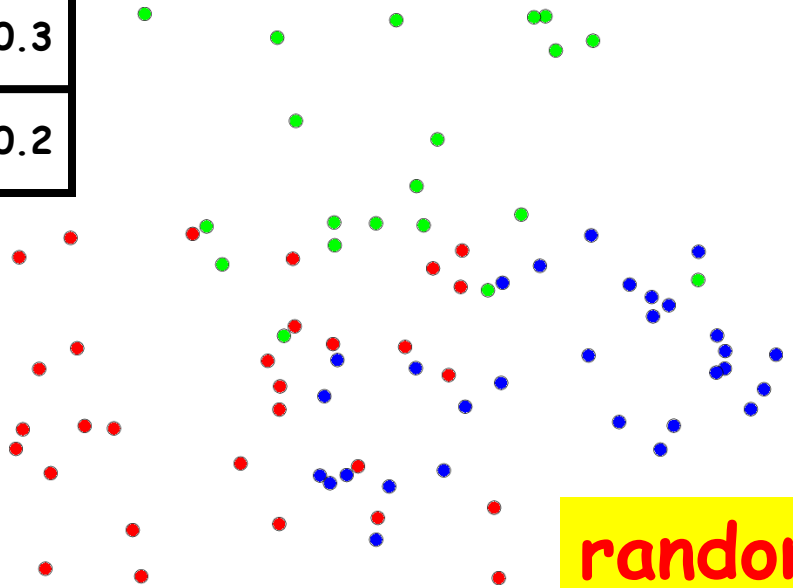
[Szemeredi'75]

Regularity

●	0.8	0.1	0.4
●	0.1	0.3	0.3
●	0.4	0.3	0.2



N_0



random

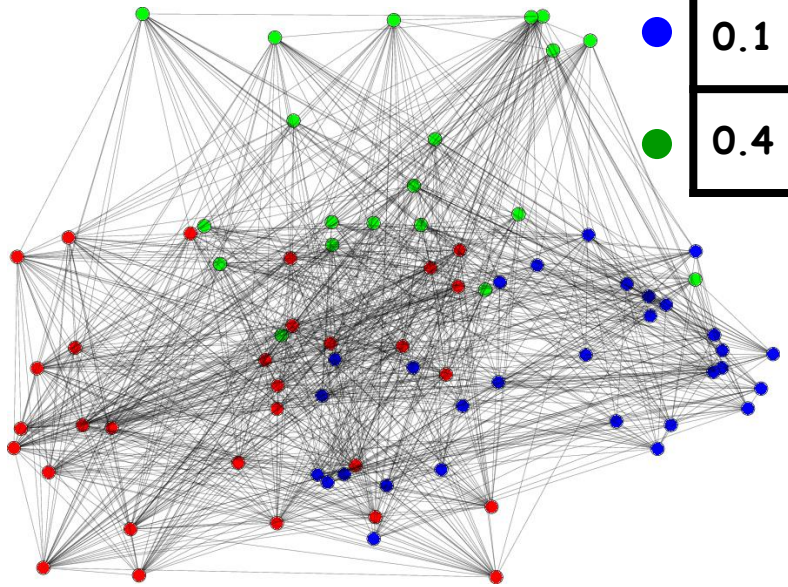
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

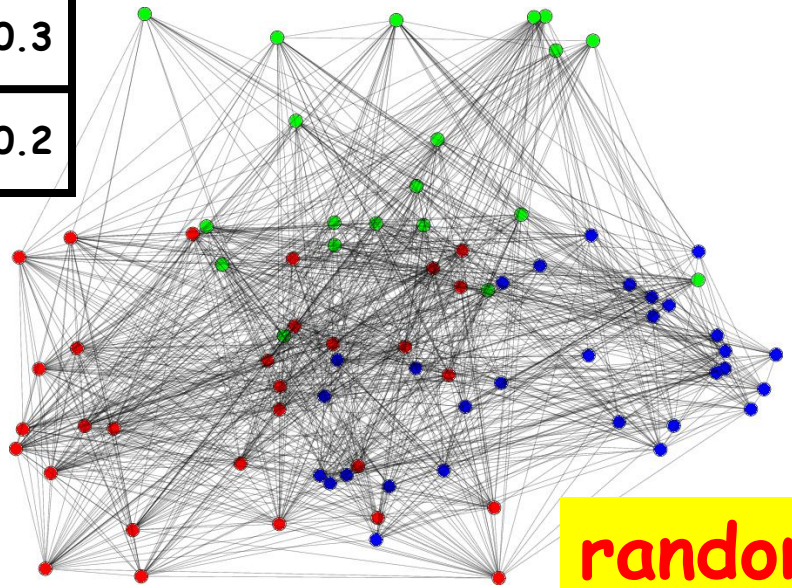
[Szemeredi'75]

Regularity

●	0.8	0.1	0.4
●	0.1	0.3	0.3
●	0.4	0.3	0.2



N_0



random

Szemeredi's Regularity Lemma:

Every network is bond-similar to a random network

Proof: ***Every*** network has a tiny model

Regularity Galore

Dense graphs, sequences "look" random

True for other objects, any set of tests!

Math: [Szemeredi, Thomasson, Chung-Graham-Wilson, Green-Tao-Ziegler, Gowers,…] Transference principle

CS: [Impagliazzo, Reingold-Trevisan-Tulisani-Vadhan,…] Dense model theorem (Boosting, Multip. Weights…)

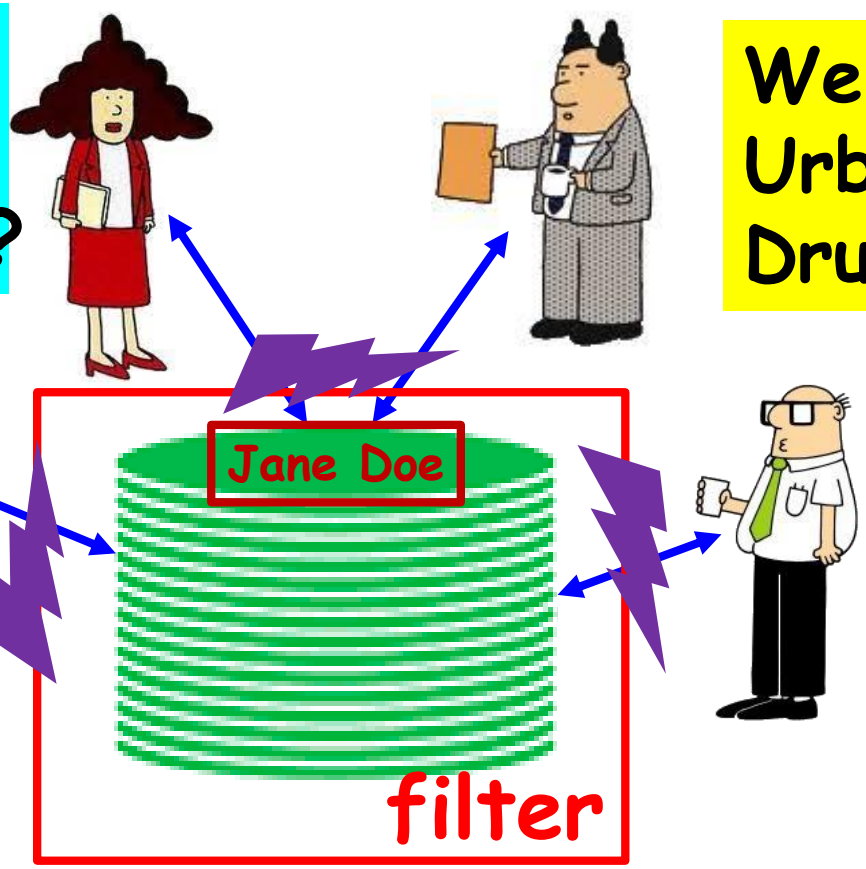
Structure vs. Randomness dichotomy

- Discrete Math
- Number Theory
- Complexity Theory
- ……
- PDEs
- Ergodic Theory
- Analysis

Privacy

Privacy versus Utility

Why should I
- Participate?
-Tell the truth?



Data analysts

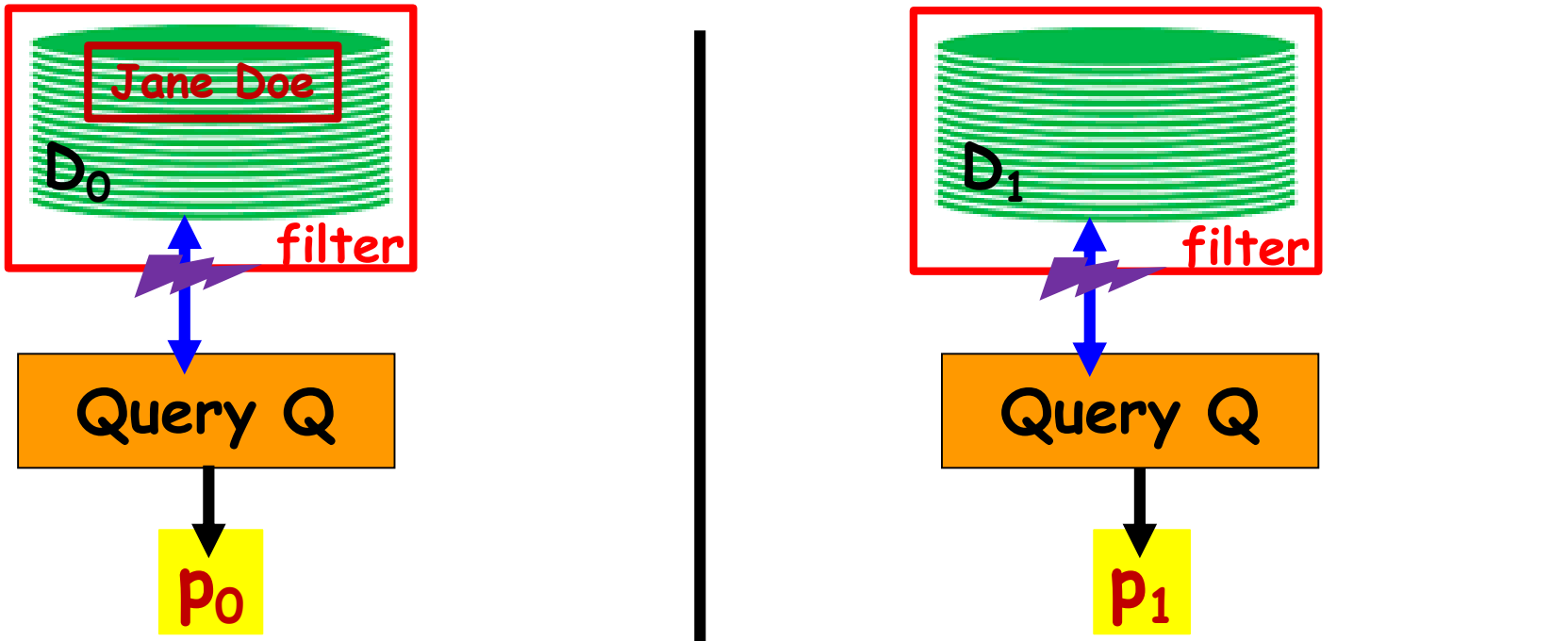
Welfare gaps
Urban planning
Drug/treatment

- Restrict queries
- Filter answers

Database D: Many individual records, e.g. census/medical data

[Dwork-McSherry-Nissim-Smith'06]

Differential Privacy



Definition: A **filter** is **differentially private** if

for *every* adjacent D_0 & D_1 and *every* legal query

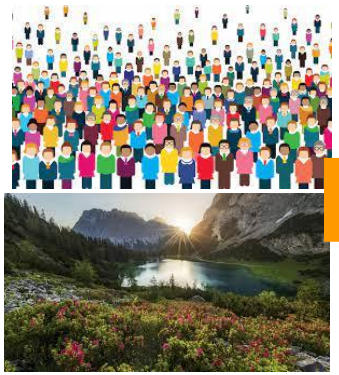
$p_0 \approx p_1$

Theory: Composition, many queries, higher accuracy,

resistance to future knowledge

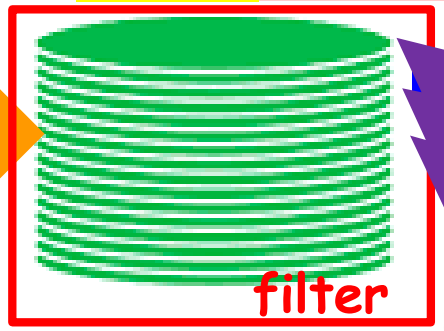
[Dwork-Feldman-Hardt-Pitassi-Reingold-Roth'14,15,…]

Adaptive data analysis



sample

Data expensive!



Science/ML

Adaptively:
- Tune parameters
- Form hypotheses
- Generate queries

- Data reuse
- Overfitting
- No generalization

Crisis: "Why most published research findings are wrong"
Ioannidis'05 PLoSMed

Theorem: Using a differentially private filter can prevent overfitting, ensure statistical validity and generalization, despite data reuse

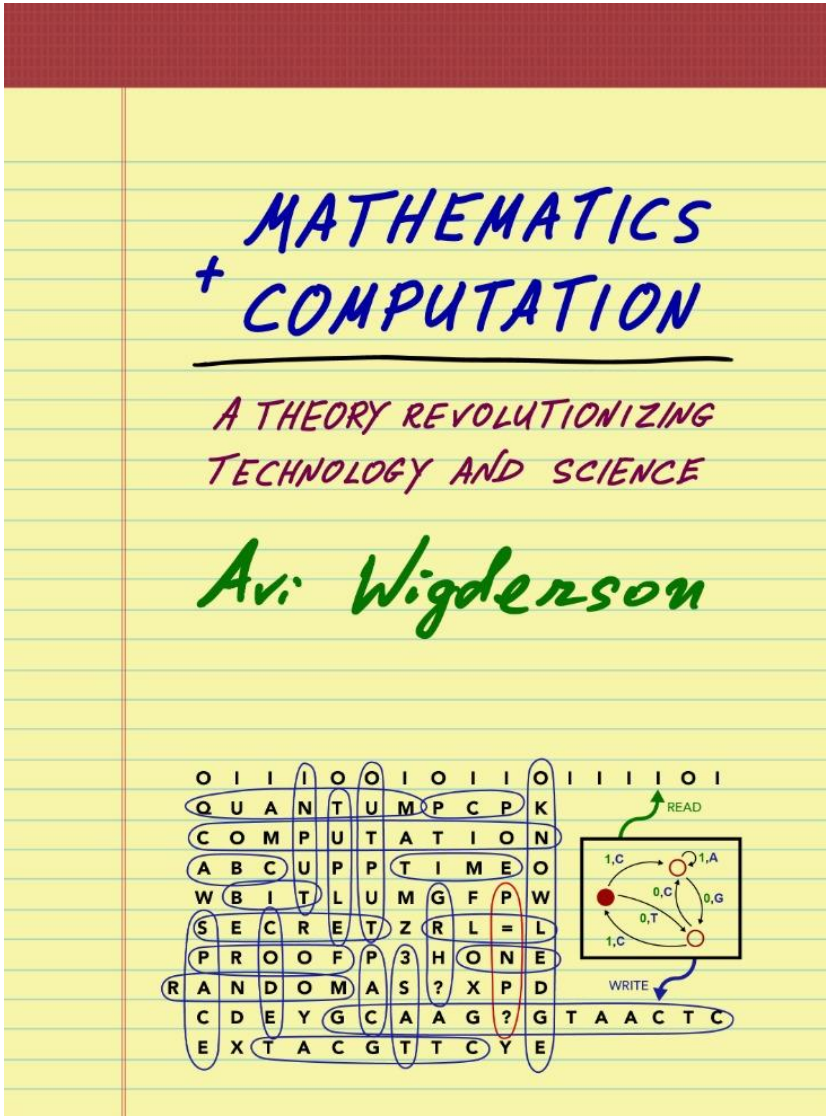
Summary

Things are identical unless you can tell them apart (eg diamonds, Picassos, news… real/fake)

Behavioral, "subjective" definitions (like Imitation Games) are extremely powerful. May be useful in philosophical and operational understanding other fundamental notions.

ToC is a modeling science, essentially tuned to the underlying process and its resources. Definitions of central notions are primary -

Book ad



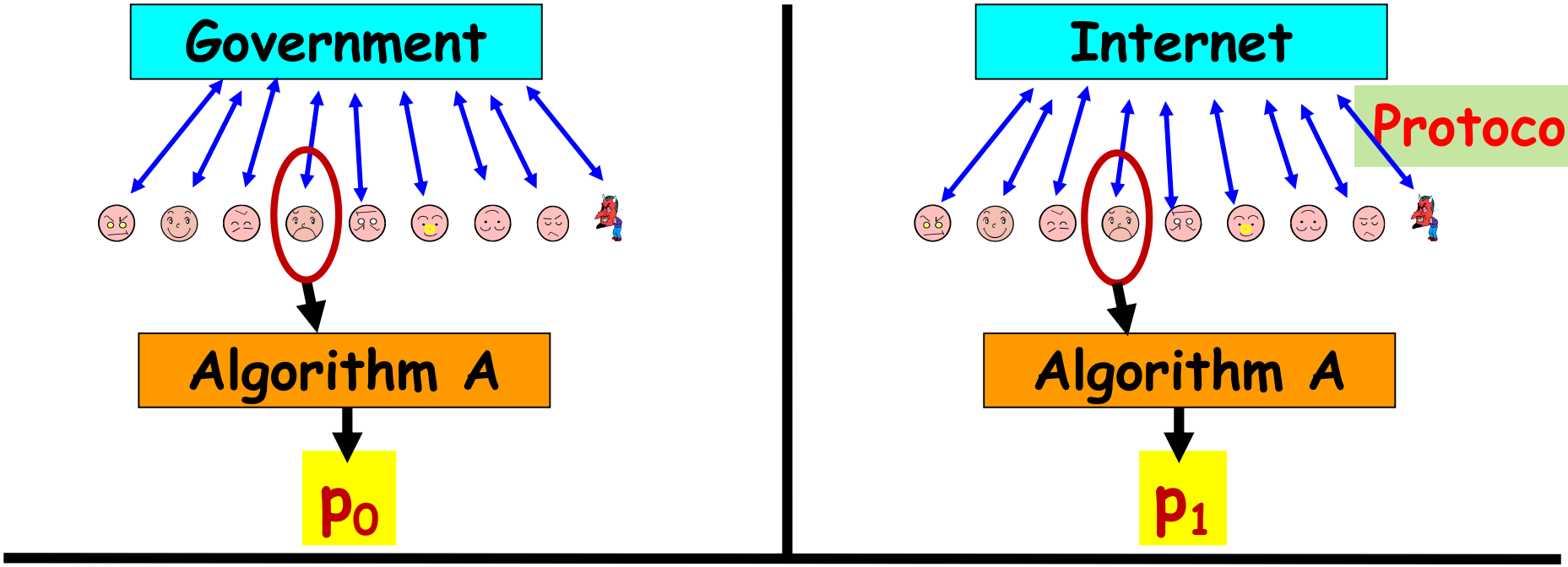
- Published by Princeton University Press

- Free (forever) on my website

- Comments welcome!

[Yao'86, Goldreich -Micali-W '87]

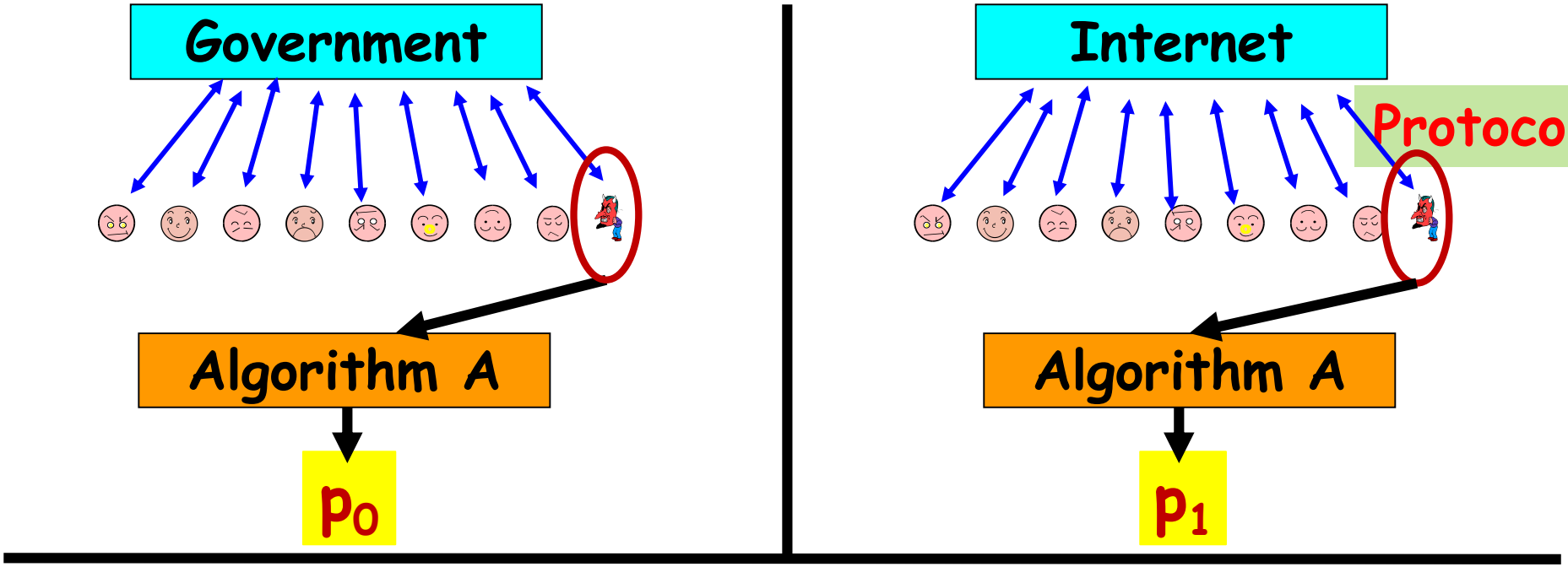
(e.g.) Secure elections



Definition: Protocol is secure if for every efficient algorithm, and ev[illegible] $p_0 \approx p_1$ [illegible]yer

[Yao'86, Goldreich -Micali-W '87]

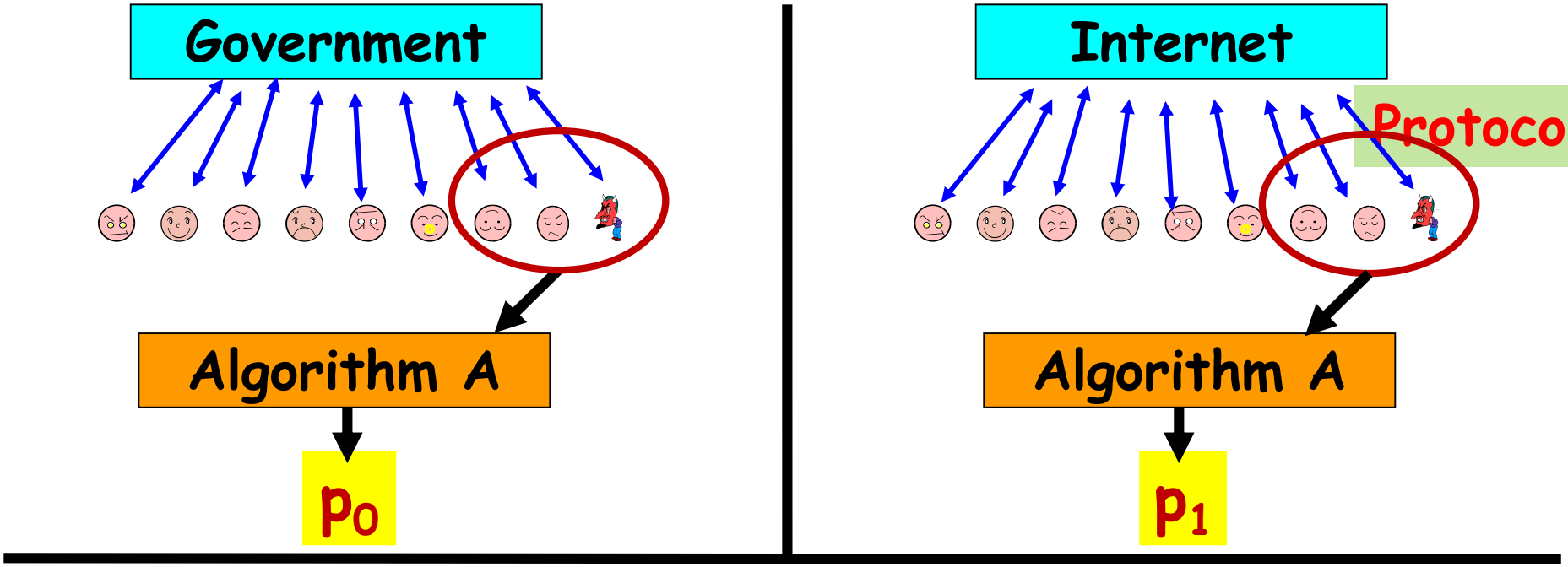
Secure elections



Definition: Protocol is secure if for every efficient algorithm, and ev $p_0 \approx p_1$ yer

[Yao'86, Goldreich -Micali-W '87]

Secure elections



Definition: **Protocol** is **secure** if for ***every*** efficient algorithm, and ***every*** subset p_0 ≠ p_1 ers,

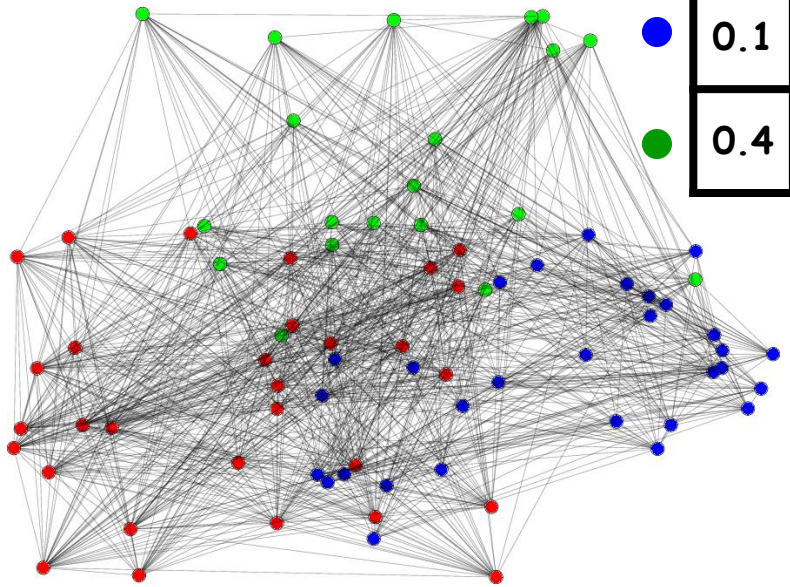
Theory: Crypto! Zero-Knowledge, Secure protocol design for any problem, under simple assumptions

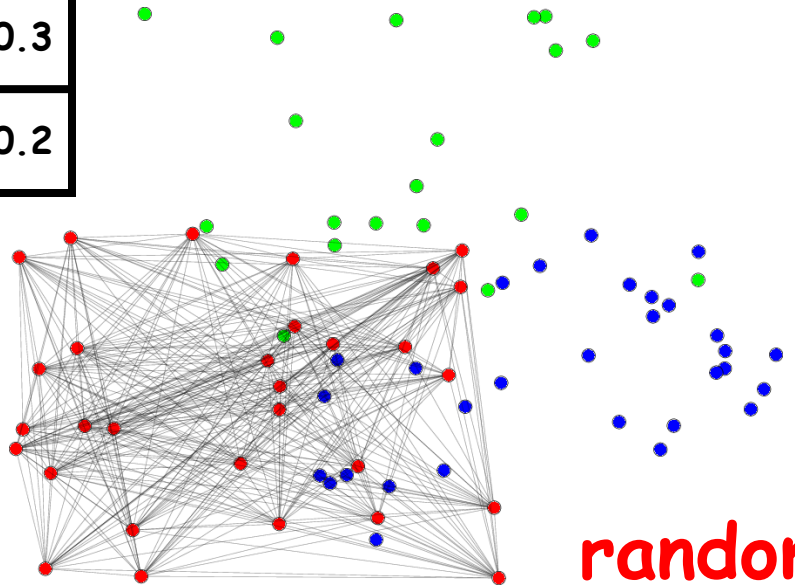
Practice: **Internet security, shopping,**

[Szemeredi'75]

Regularity

●	0.8	0.1	0.4
●	0.1	0.3	0.3
●	0.4	0.3	0.2





N_0

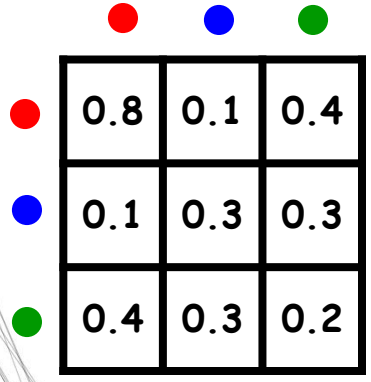
random

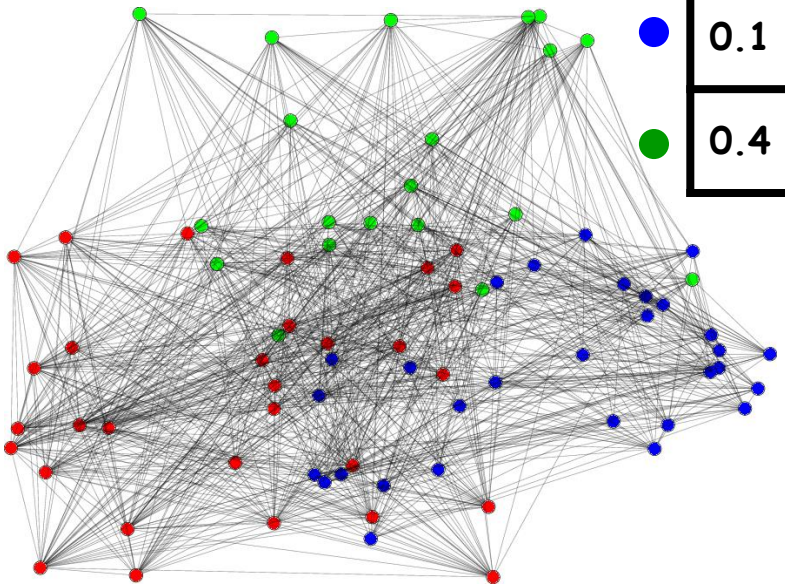
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

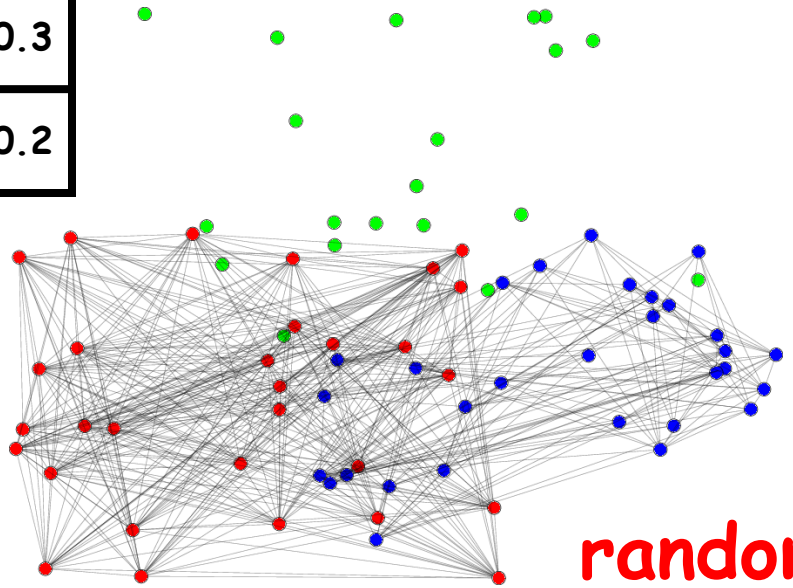
[Szemeredi'75]

Regularity





N_0



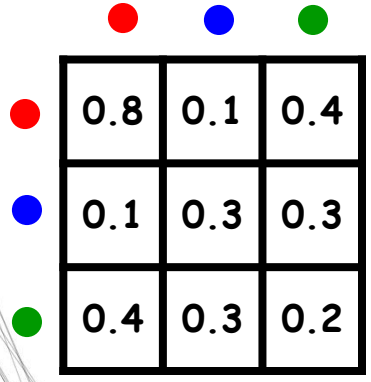
random

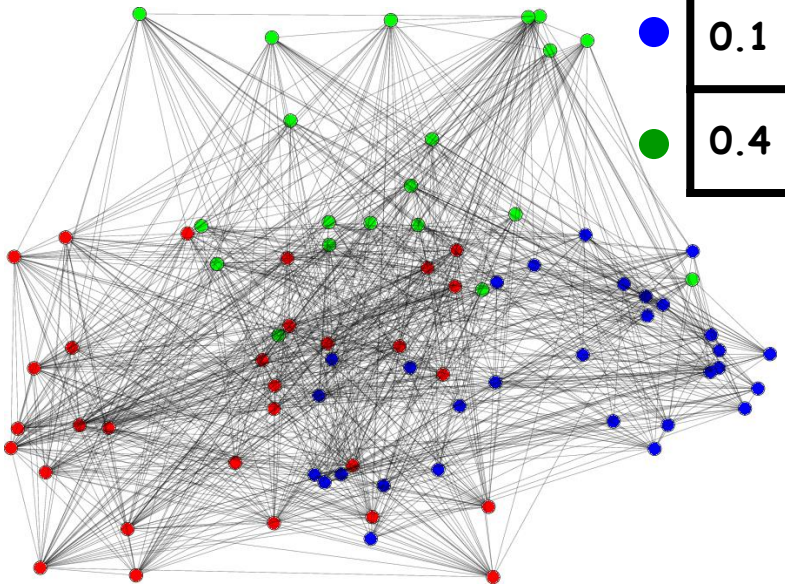
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

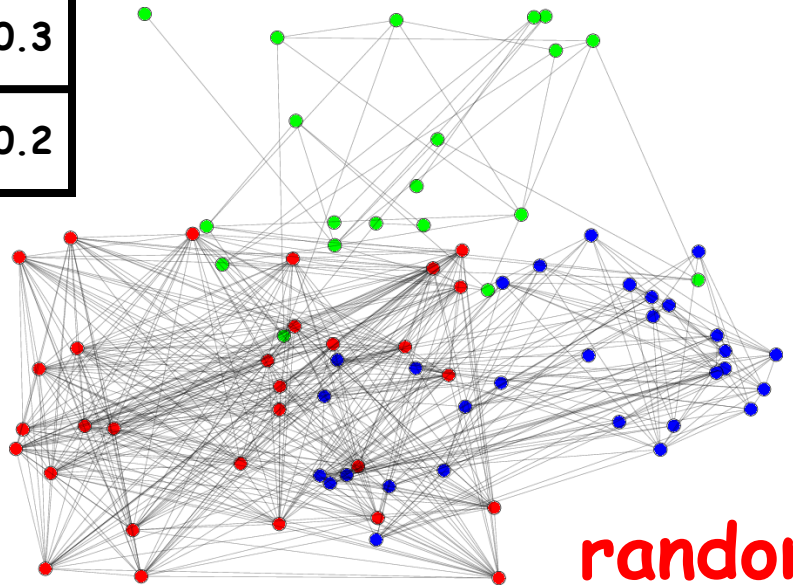
[Szemeredi'75]

Regularity





N_0



random

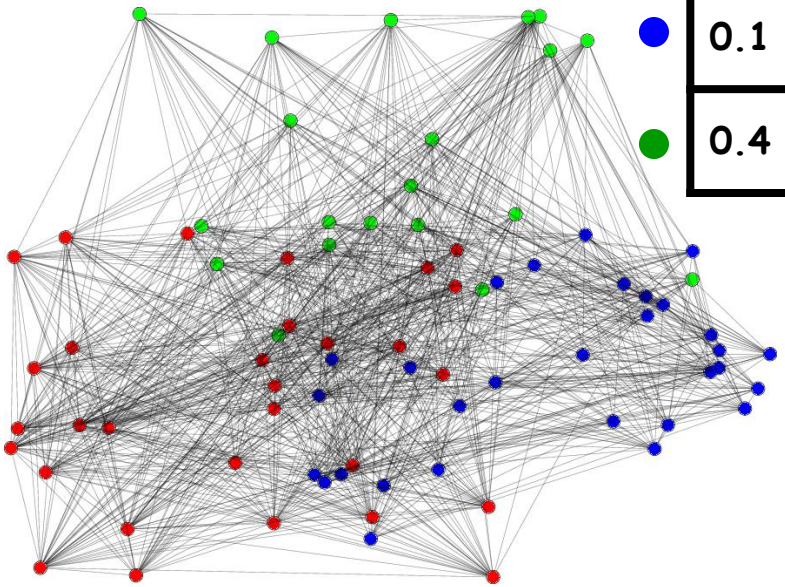
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

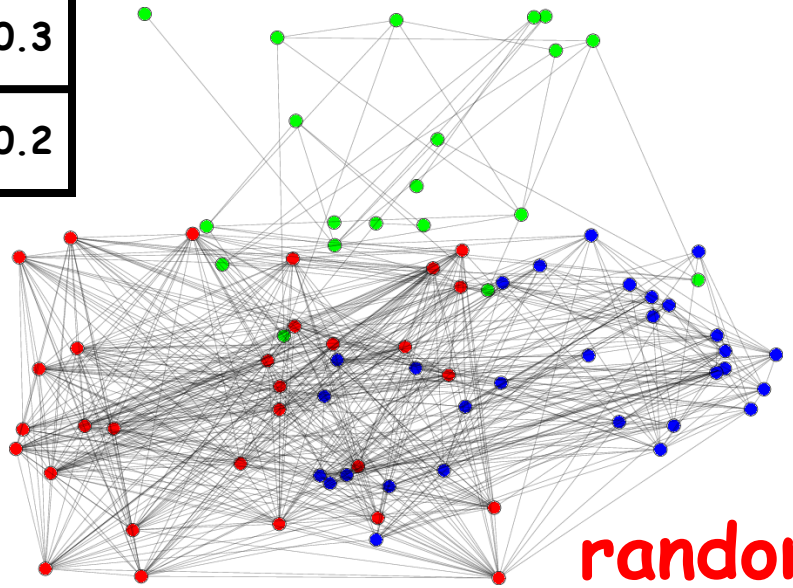
[Szemeredi'75]

Regularity

●	0.8	0.1	0.4
●	0.1	0.3	0.3
●	0.4	0.3	0.2



N_0



random

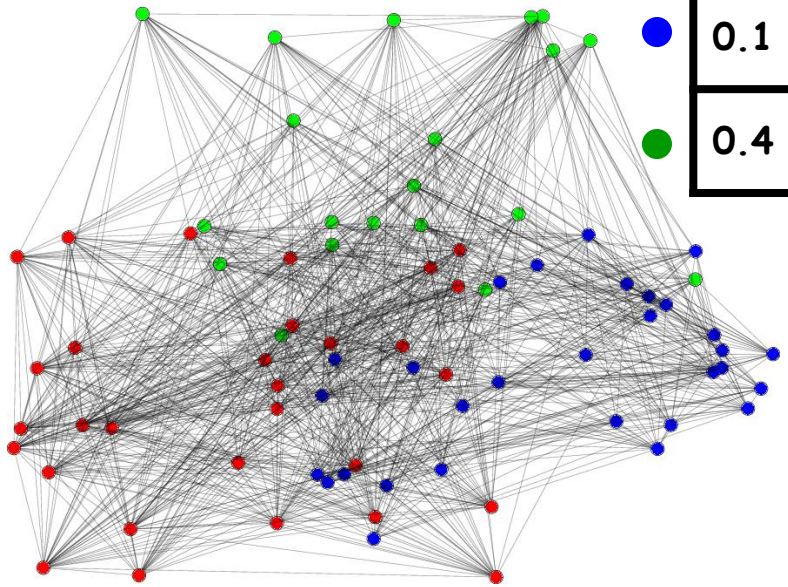
Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model

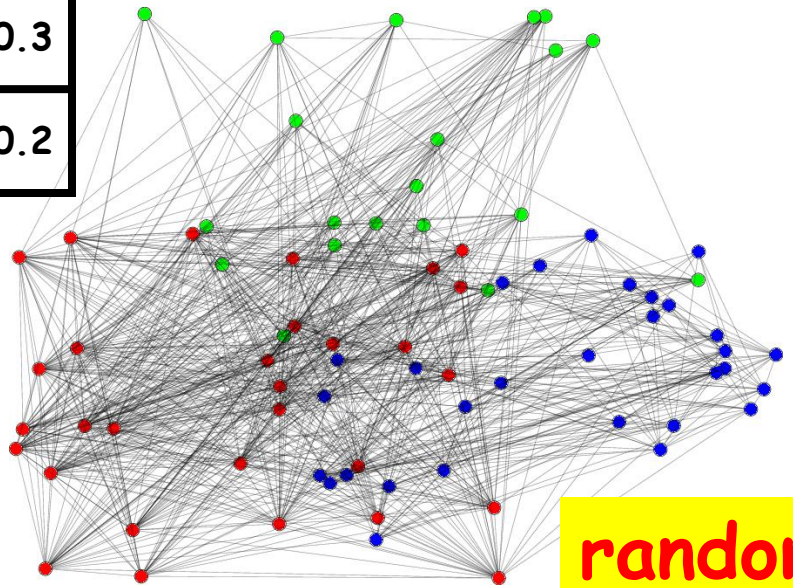
[Szemeredi'75]

Regularity

●	0.8	0.1	0.4
●	0.1	0.3	0.3
●	0.4	0.3	0.2



N_0



random

Szemeredi's Regularity Lemma:
Every network is bond-similar to a random network

Proof: *Every* network has a tiny model