Let's get ***Physical!***

Spot the Differences

Too Many!

Spot the Differences

Still Many!

Spot the Differences

Better Screen

Bigger Disk

More RAM

Cooler Design

...

Better Screen

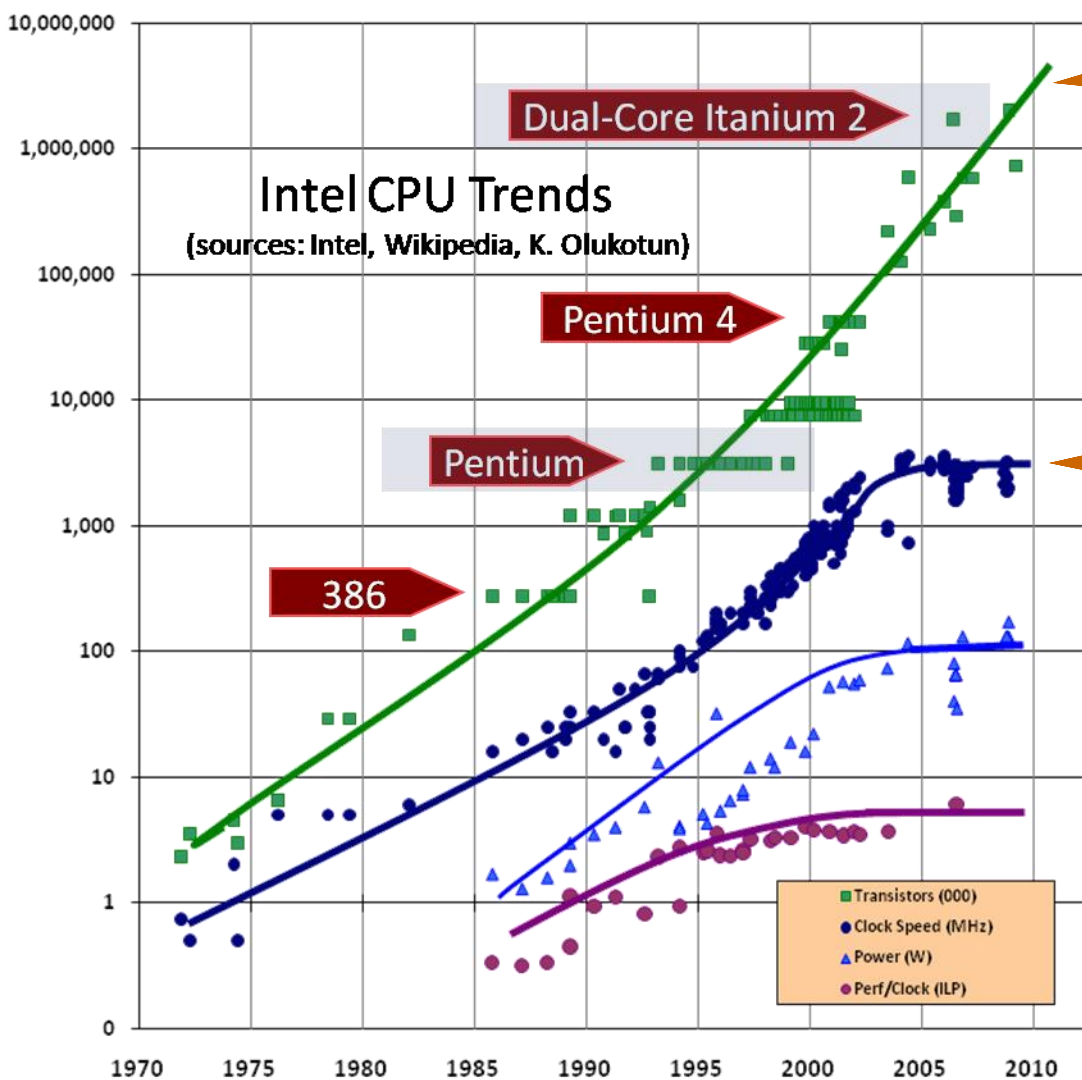
Bigger Disk

More RAM

Cooler Design

...

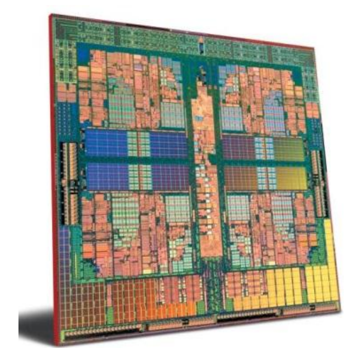
Same CPU Clock Speed



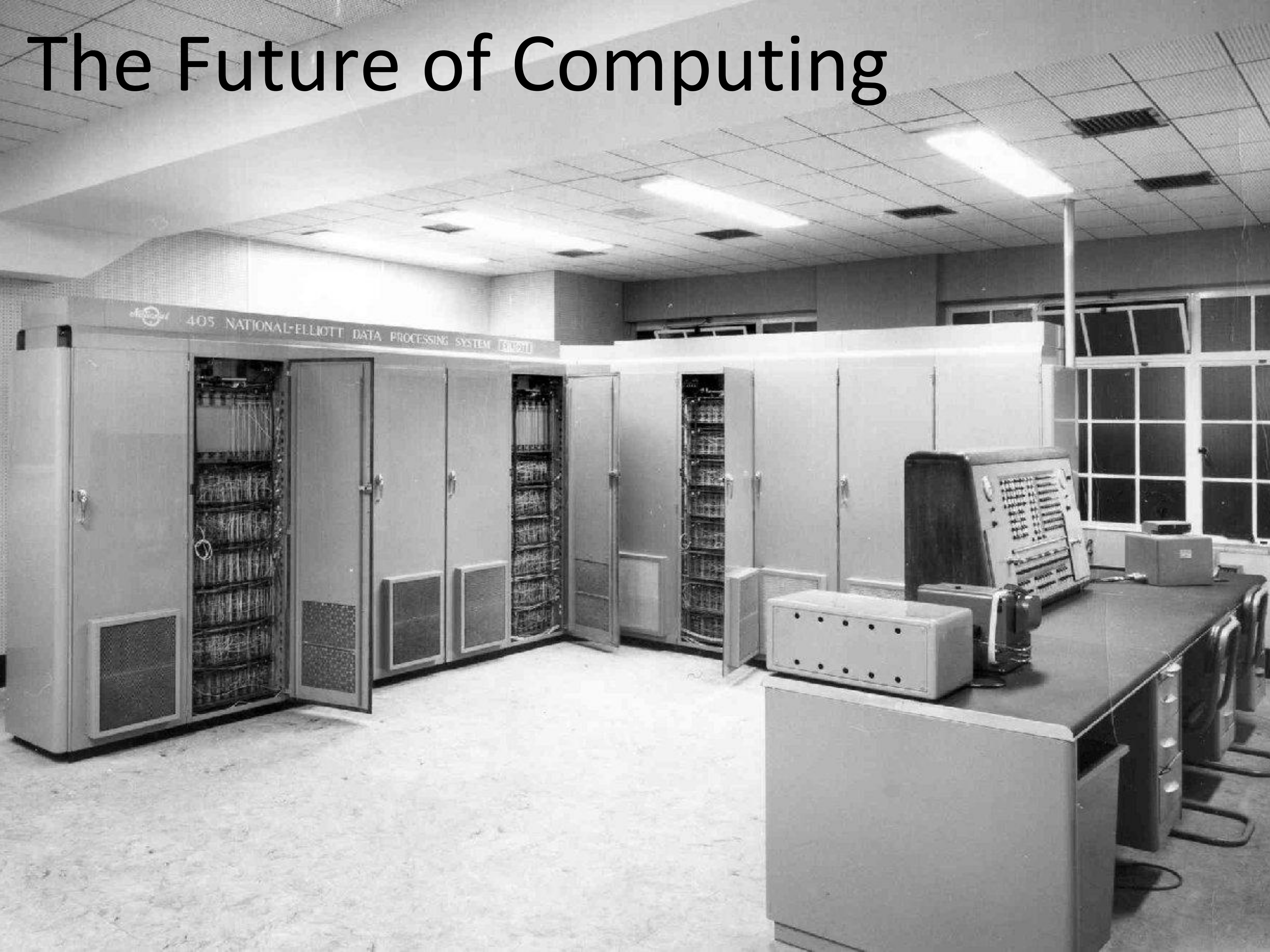
Transistor count still rising

Clock speed flattening sharply

Advent of multi-core processors!



The Future of Computing

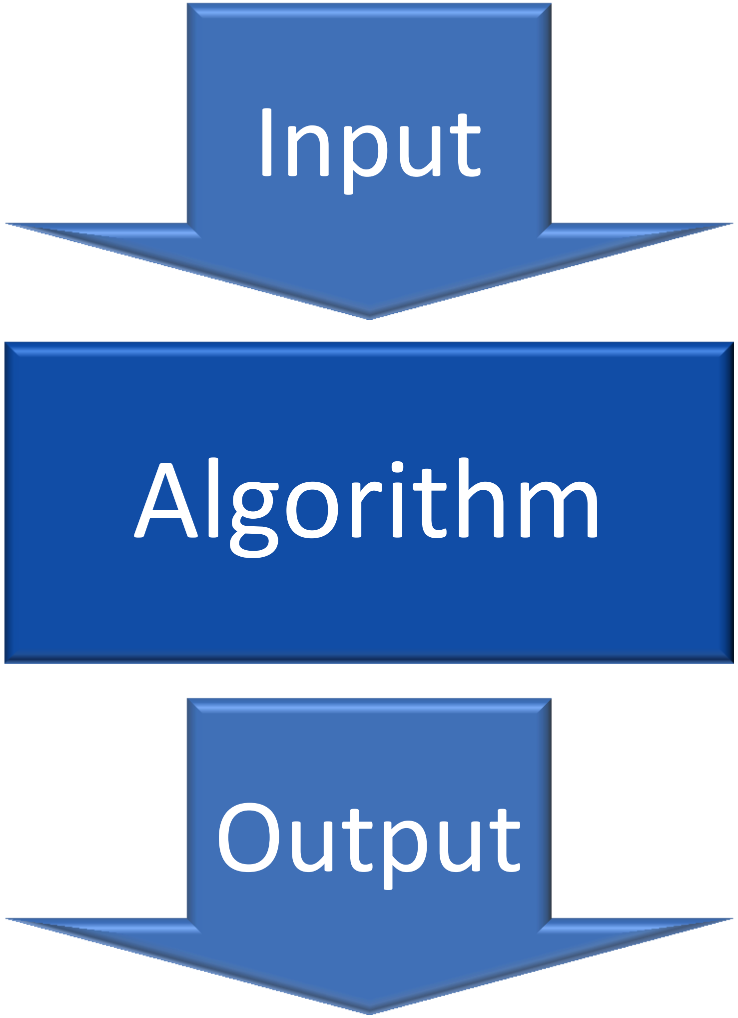


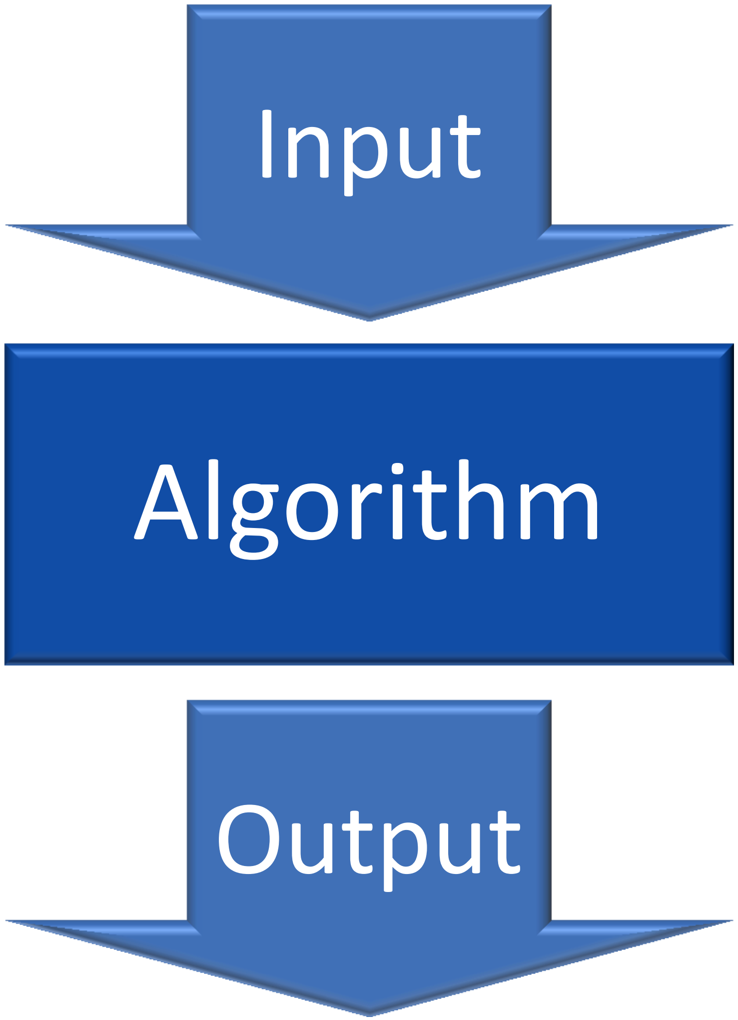
Why Should I Care?

Computer Science → Washing Machine Science

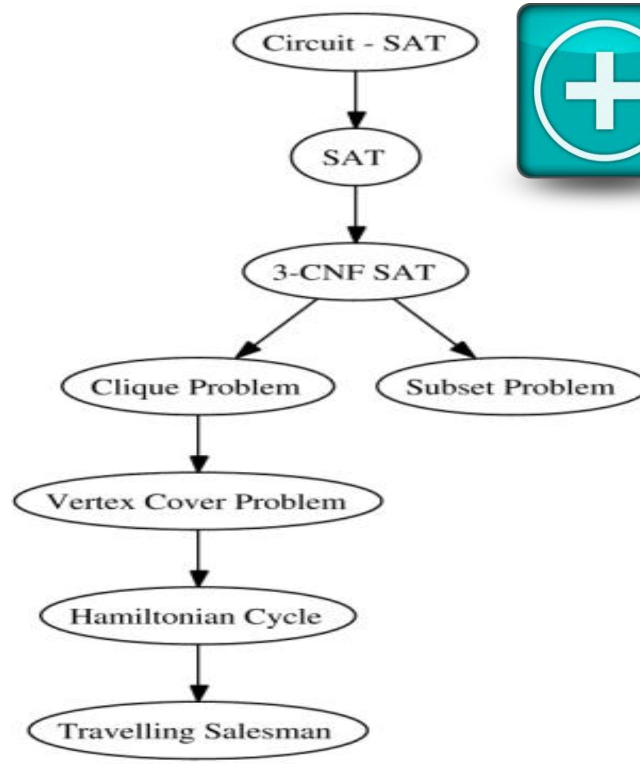
[Roger Boyle, Maurice Herlihy]

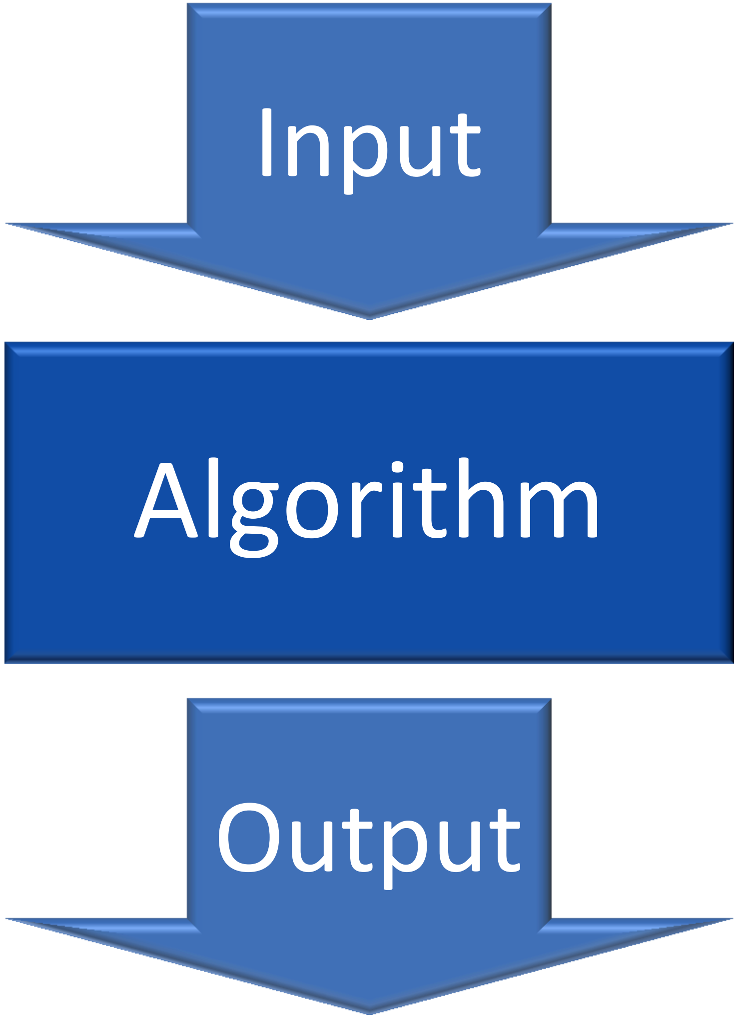
Algorithms


Input
Algorithm
Output

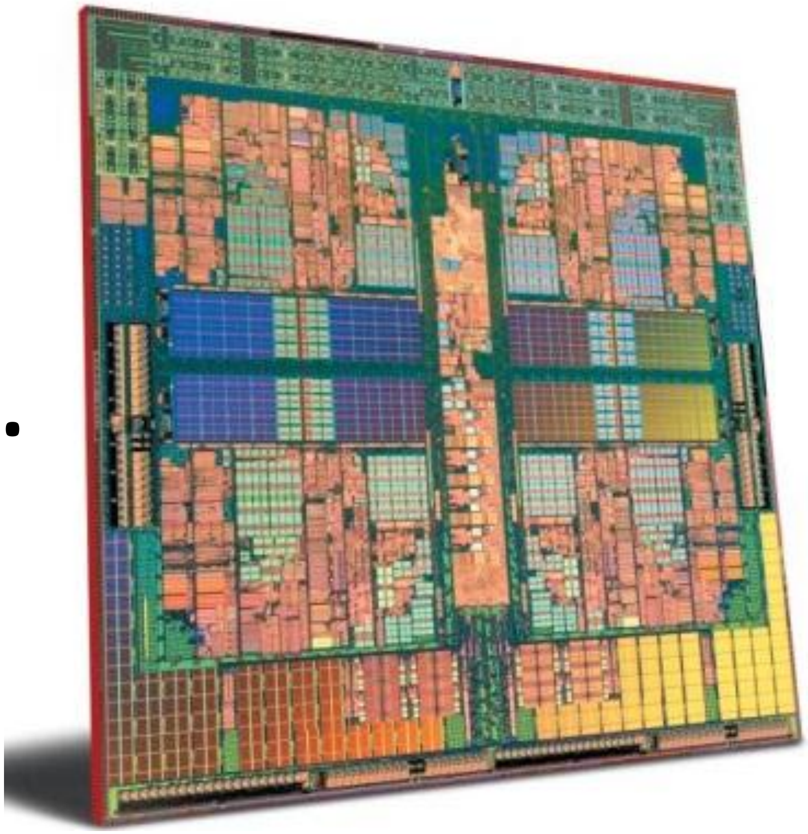


simple and robust model
comparable results
complexity theory

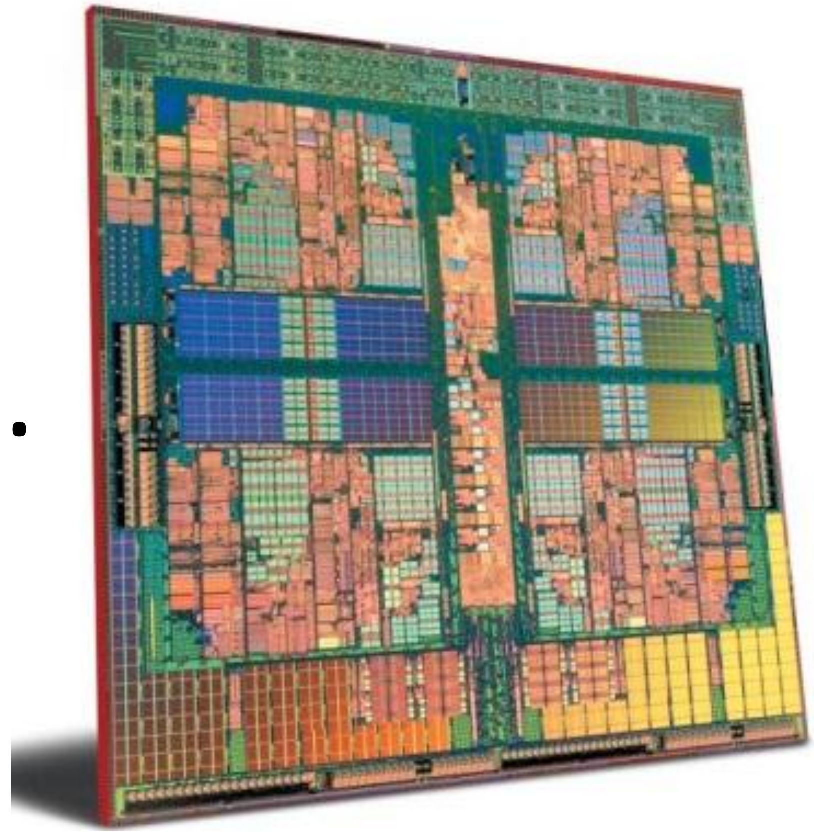




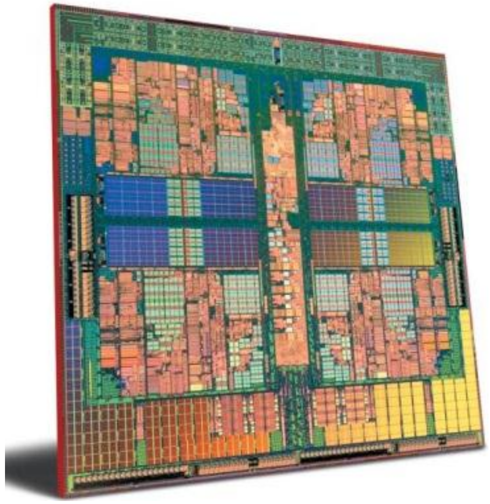
vs.

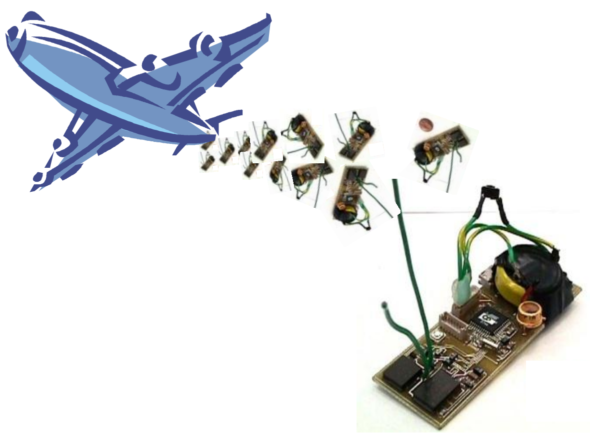


vs.



The Future of Computing?





Talk Overview

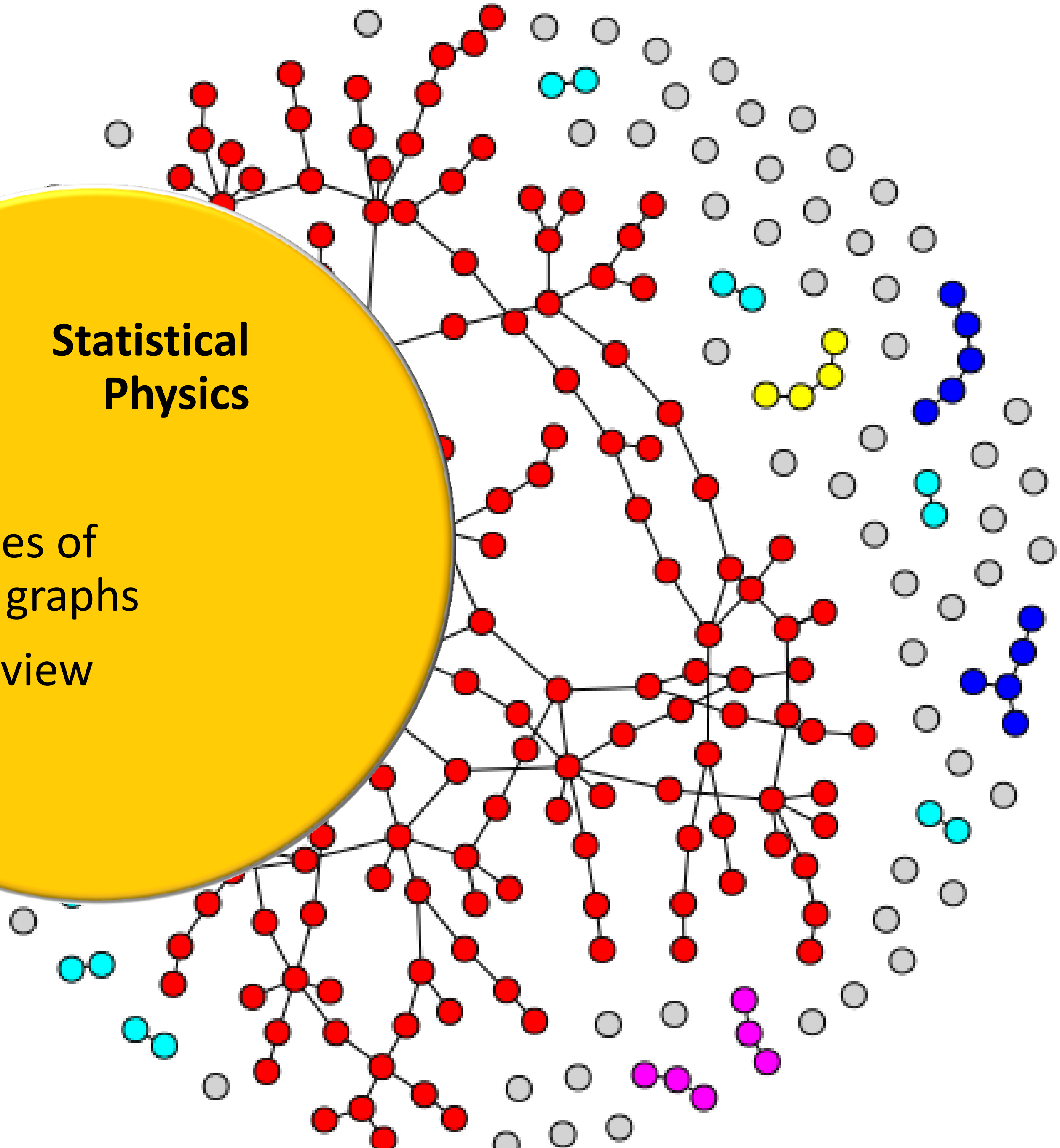
Introduction & Motivation

Some Examples for Physical Algorithms

What are Physical Algorithms?

Well-Known Examples

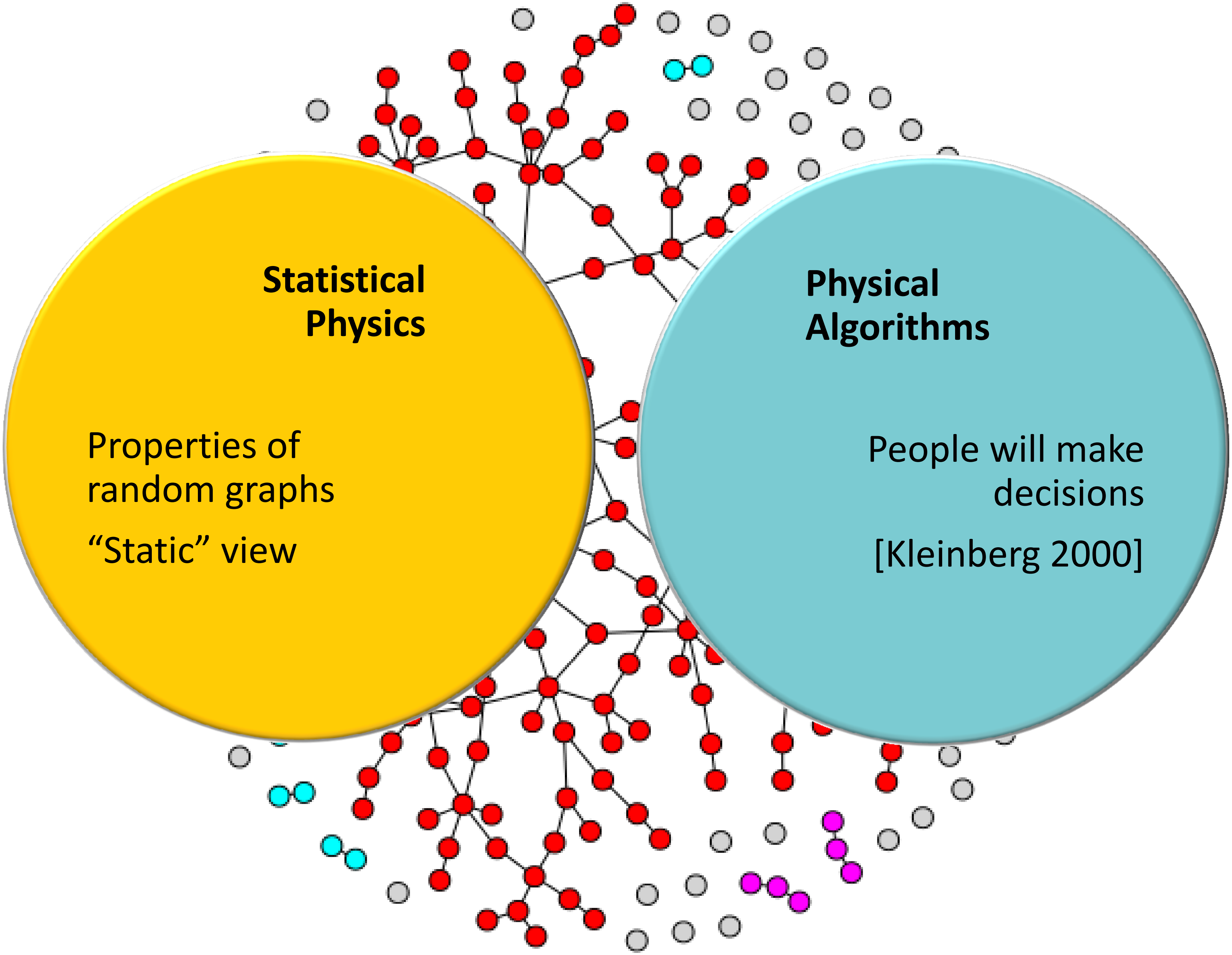
Small World Phenomenon



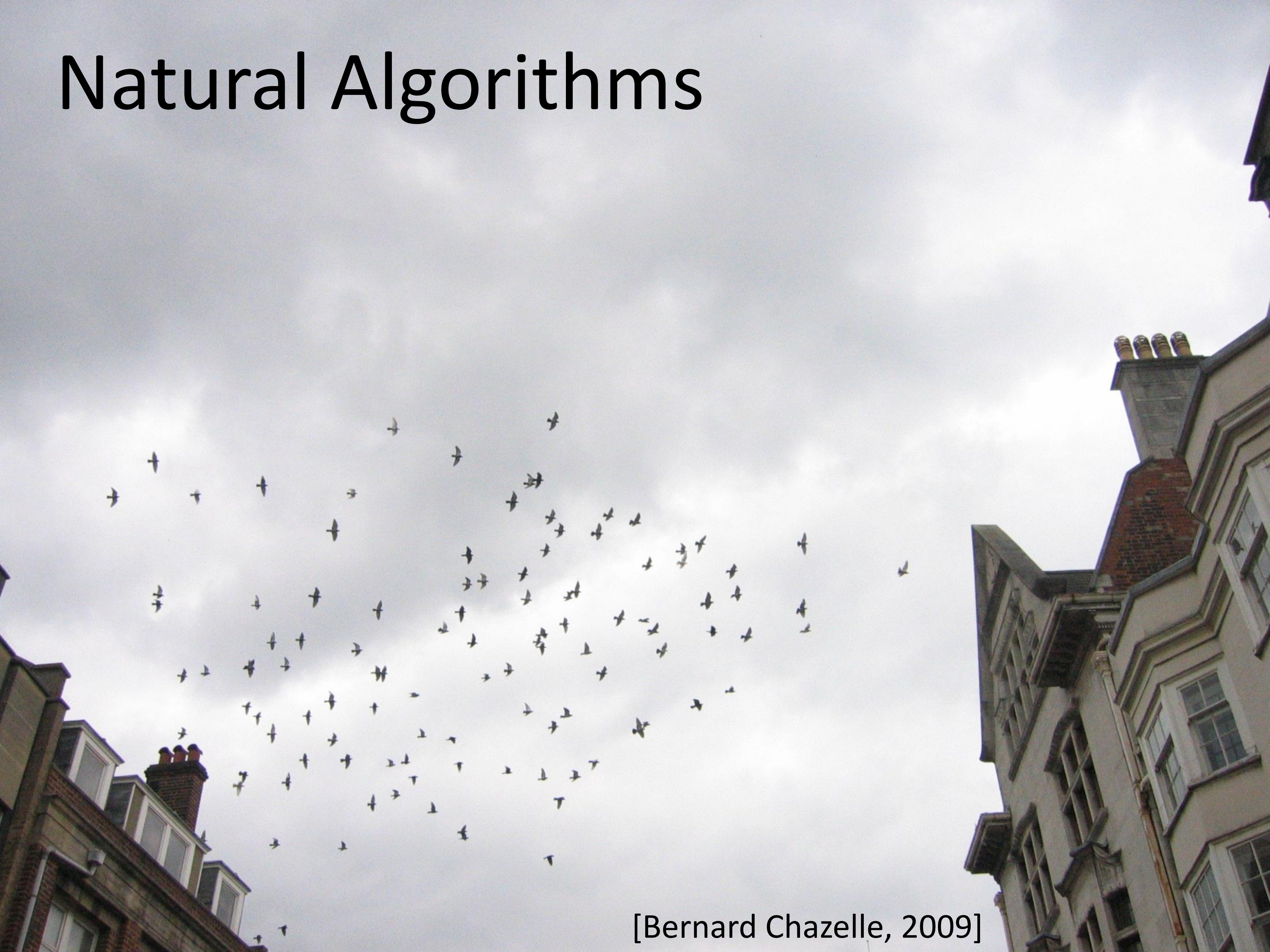
Statistical Physics

Properties of random graphs

“Static” view


Statistical Physics
Properties of random graphs
"Static" view
Physical Algorithms
People will make decisions
[Kleinberg 2000]

Natural Algorithms



[Bernard Chazelle, 2009]

game theory


BitThief-Worded T-shirt from Zazzle.com - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://www.zazzle.com/bitthief_worded_shirt-235172699316920973
Stats eDoz ConfSearch Libra TG dvd
Shopping Cart | Help | MyZazzle | Login
ZAZZLE
infinite one-of-a-kind-ness
WHAT'S HOT
CATEGORIES
PARTICIPATE
CREATE
search
Go
BitThief-Worded T-shirt
by bit_thief
(0 votes)
Views: Model Product Design
BitThief
front
back
Ladies Basic T-Shirt
(starting at $21.00)
The classic t-shirt, made specifically for women. Pre-shrunk, 5.0 ounce 100% super-soft cotton, baby jersey knit. Coverstitched 3/4" bottom hem and sleeve opening. Custom contoured fit. Made by Bella.
Men Women Kid Baby
All Classic Fashion Sport Sustainable (info)
12 colors
6 colors
6 colors
1 color
5 colors
Color: Yellow (+$2.55)
(info for dark colors)
Size: Adult 2X
(view size chart)
S M L XL 2X
Model: Lindsay
Qty: 1
(save in bulk)
$23.55
Add to cart
Customize: Change the design, add your own ideas!
Customize it
Email this | Link to this | Add to favorites | Bookmark this | Report violation
Marketplace Categories:
Arts, Design, Fashion > Graphic Design > Graffiti > Digital Graffiti
Find: henz
Next Previous Highlight all Match case
Done
Adblock

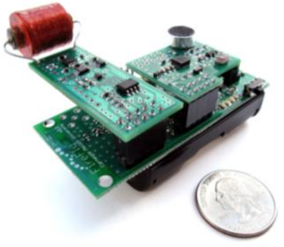
Clock Synchronization

Clock Synchronization in Networks

Global Positioning System (GPS)

Radio Clock Signal

AC-power line radiation



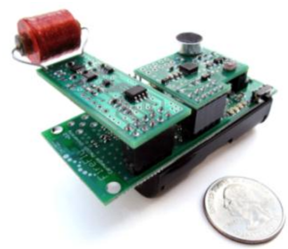
Synchronization messages

Clock Synchronization in Networks

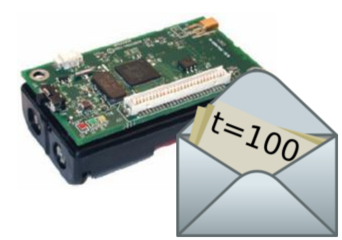
Global Positioning System (GPS)

Radio Clock Signal

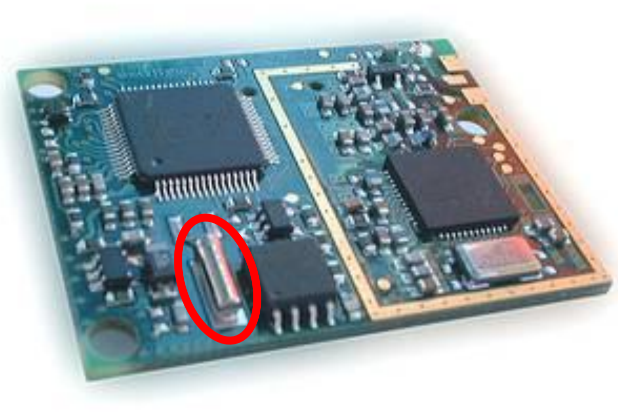
AC-power line radiation

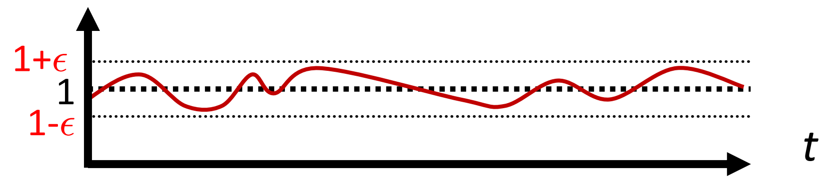


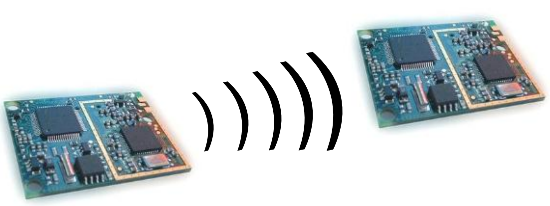
Synchronization messages

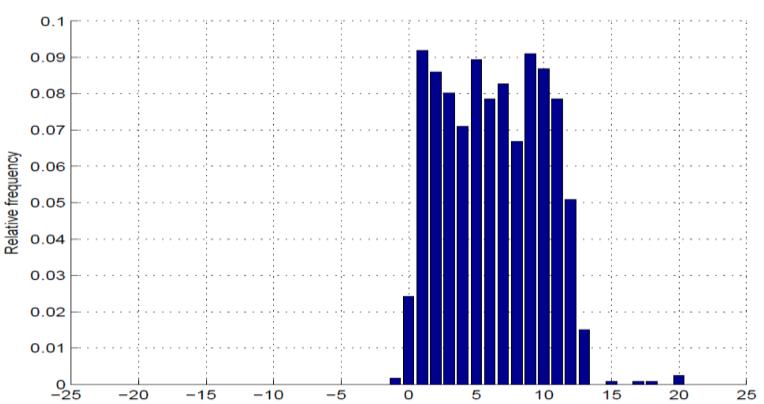


Problem: Physical Reality







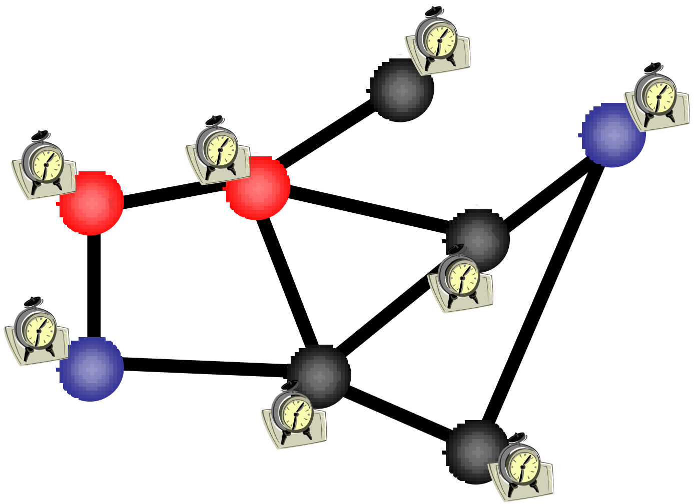


Clock Synchronization in Theory?

Given a communication network

1. Each node equipped with hardware clock with drift
2. Message delays with jitter

worst-case (but constant)



Goal: Synchronize Clocks ("Logical Clocks")

- Both global and local synchronization!

Time Must Behave!

- Time (logical clocks) should not be allowed to stand still or jump

Time Must Behave!

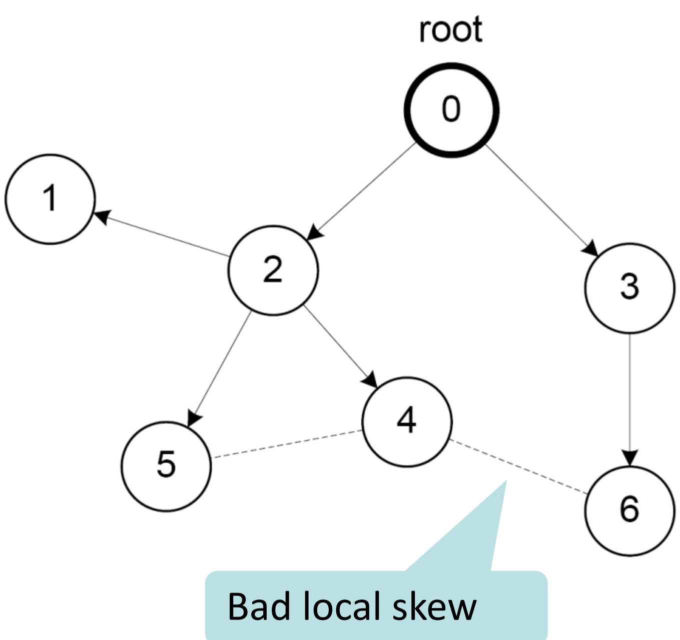
- Time (logical clocks) should not be allowed to stand still or jump

- Let's be more careful (and ambitious):
- Logical clocks should always move forward
  - Sometimes faster, sometimes slower is OK.
  - But there should be a minimum and a maximum speed.
  - As close to correct time as possible!

Local Skew

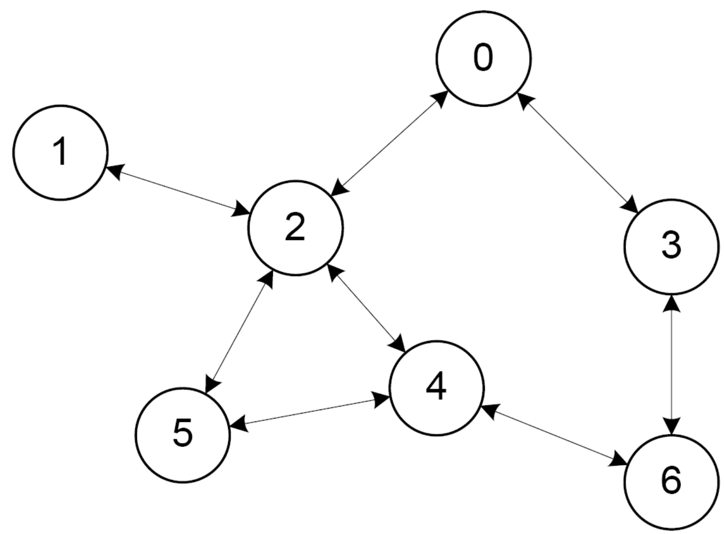
Tree-based Algorithms

e.g. FTSP



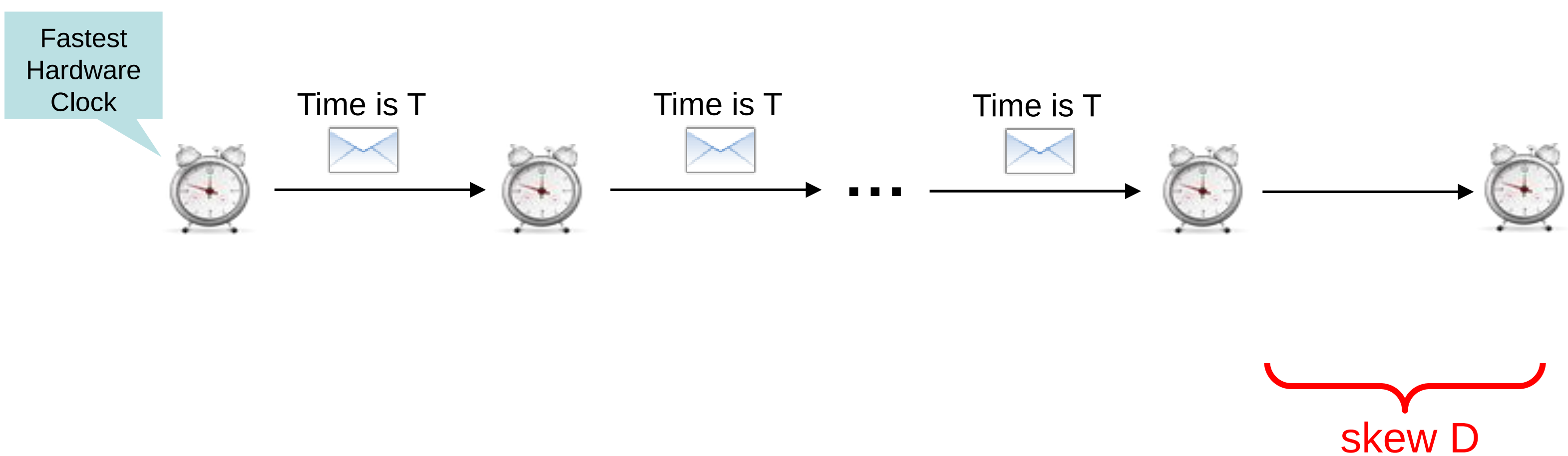
Neighborhood Algorithms

e.g. GTSP

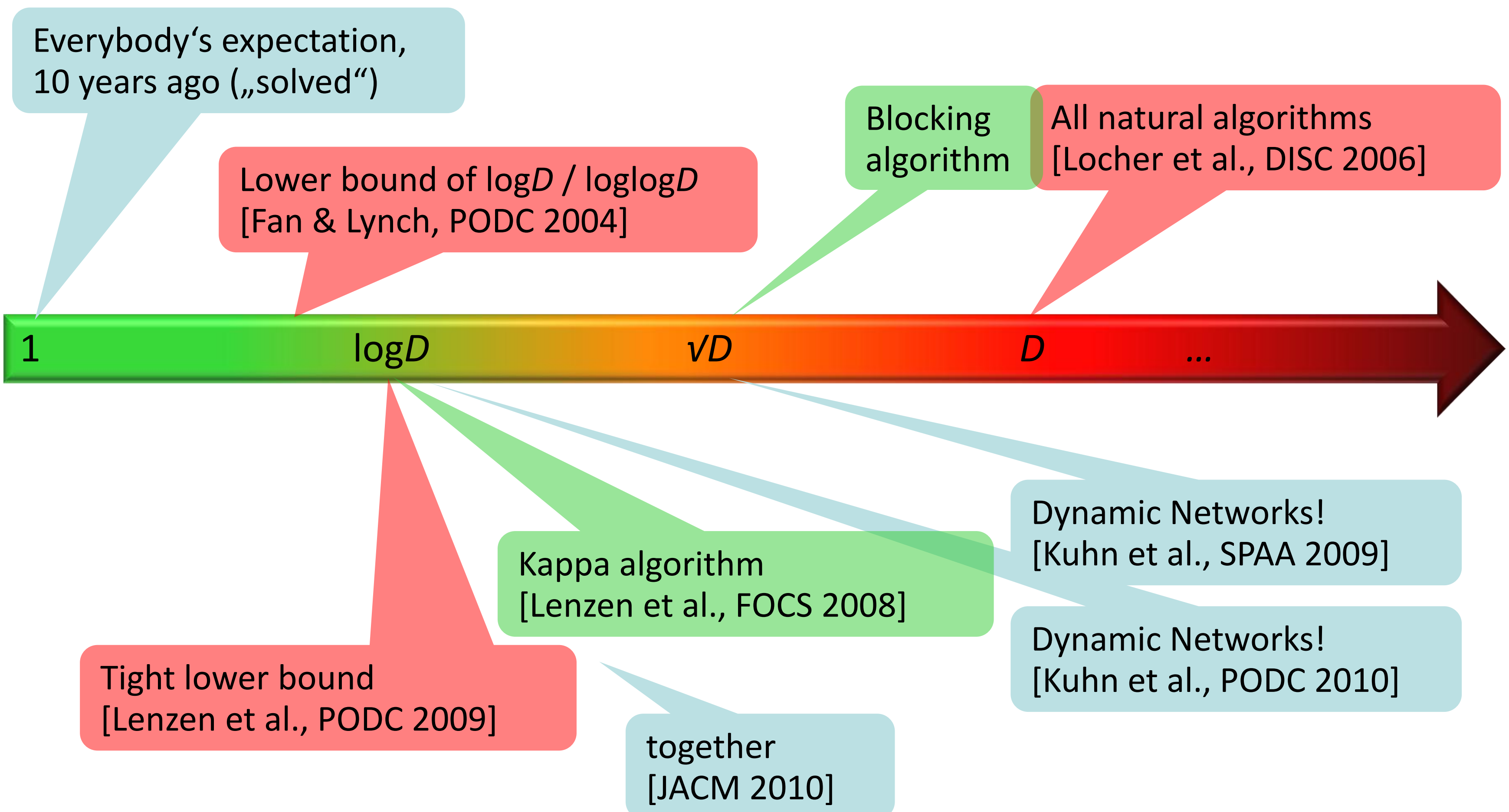


Synchronization Algorithms: An Example (“A^{max}”)

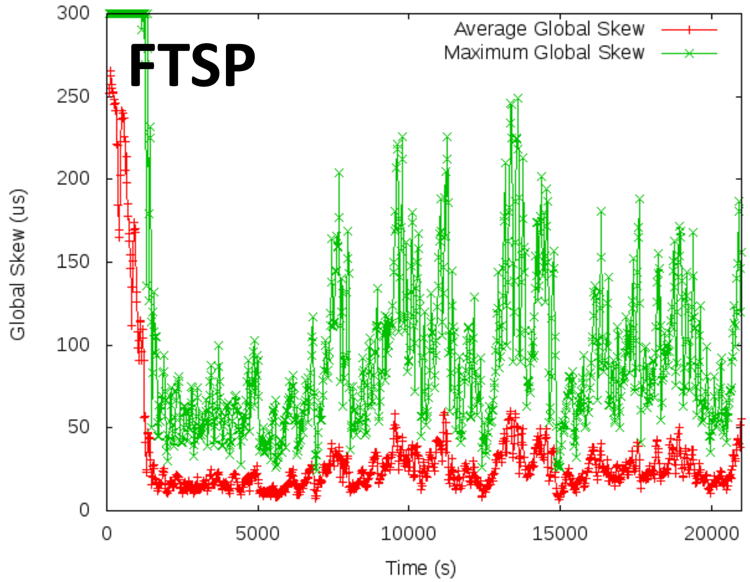
- Question: How to update the logical clock based on the messages from the neighbors?
- Idea: Minimizing the skew to the fastest neighbor
  - Set clock to maximum clock value you know, forward new values immediately
- First all messages are slow (1), then suddenly all messages are fast (0)!

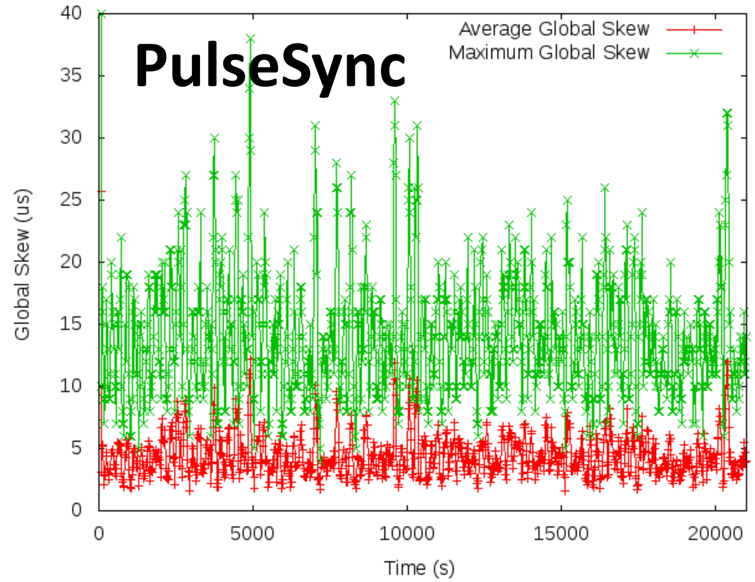


Local Skew: Overview of Results



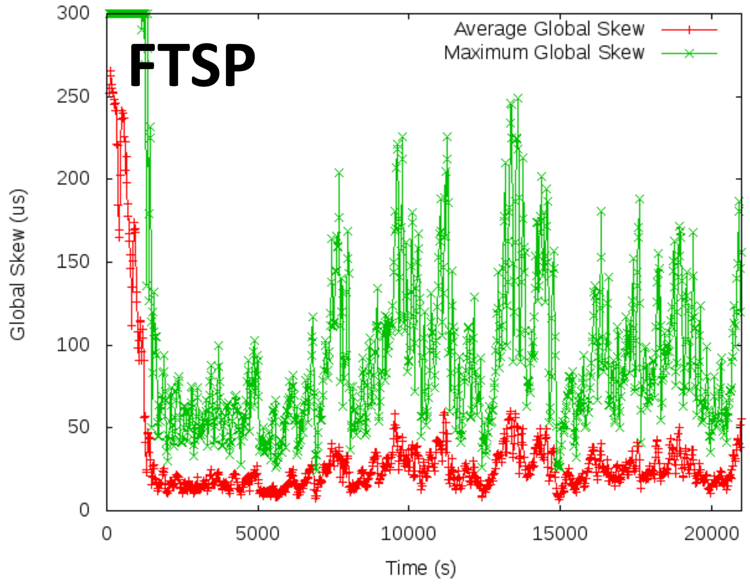
Experimental Results for Global Skew

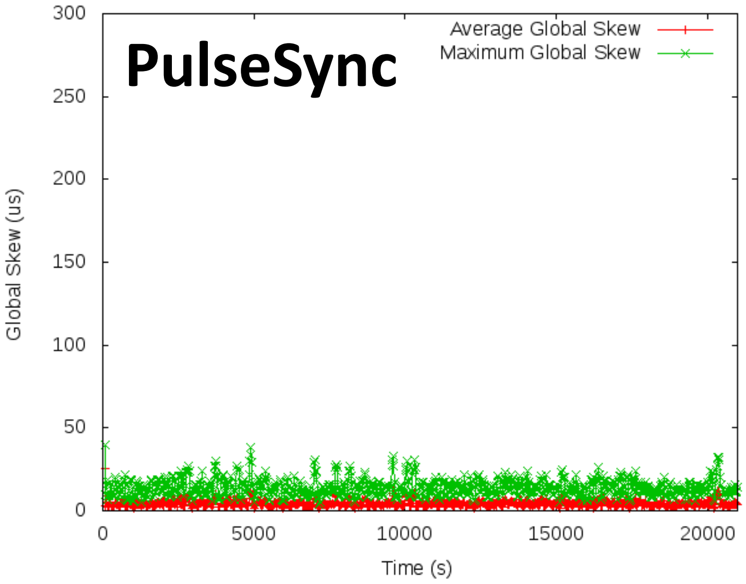




[Lenzen, Sommer, W, SenSys 2009]

Experimental Results for Global Skew





[Lenzen, Sommer, W, SenSys 2009]

Clock Synchronization vs. Car Coordination

- In the future cars may travel at high speed despite a tiny safety distance, thanks to advanced sensors and communication

Clock Synchronization vs. Car Coordination

- In the future cars may travel at high speed despite a tiny safety distance, thanks to advanced sensors and communication

- How fast & close can you drive?

- Answer possibly related to clock synchronization
  - clock drift ↔ cars cannot control speed perfectly
  - message jitter ↔ sensors or communication between cars not perfect

Wireless Communication

Wireless Communication

EE, Physics

Maxwell Equations

Simulation, Testing

‘Scaling Laws’

Network Algorithms

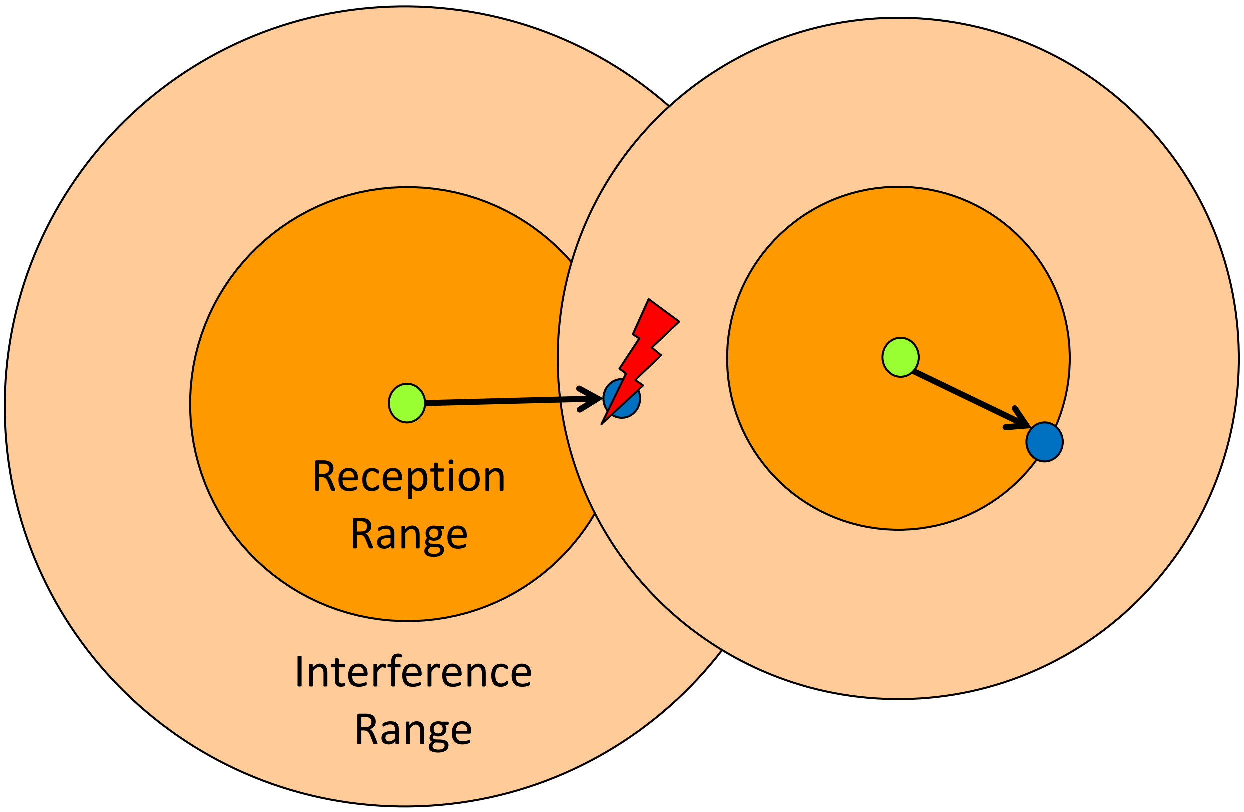
CS, Applied Math

[Geometric] Graphs

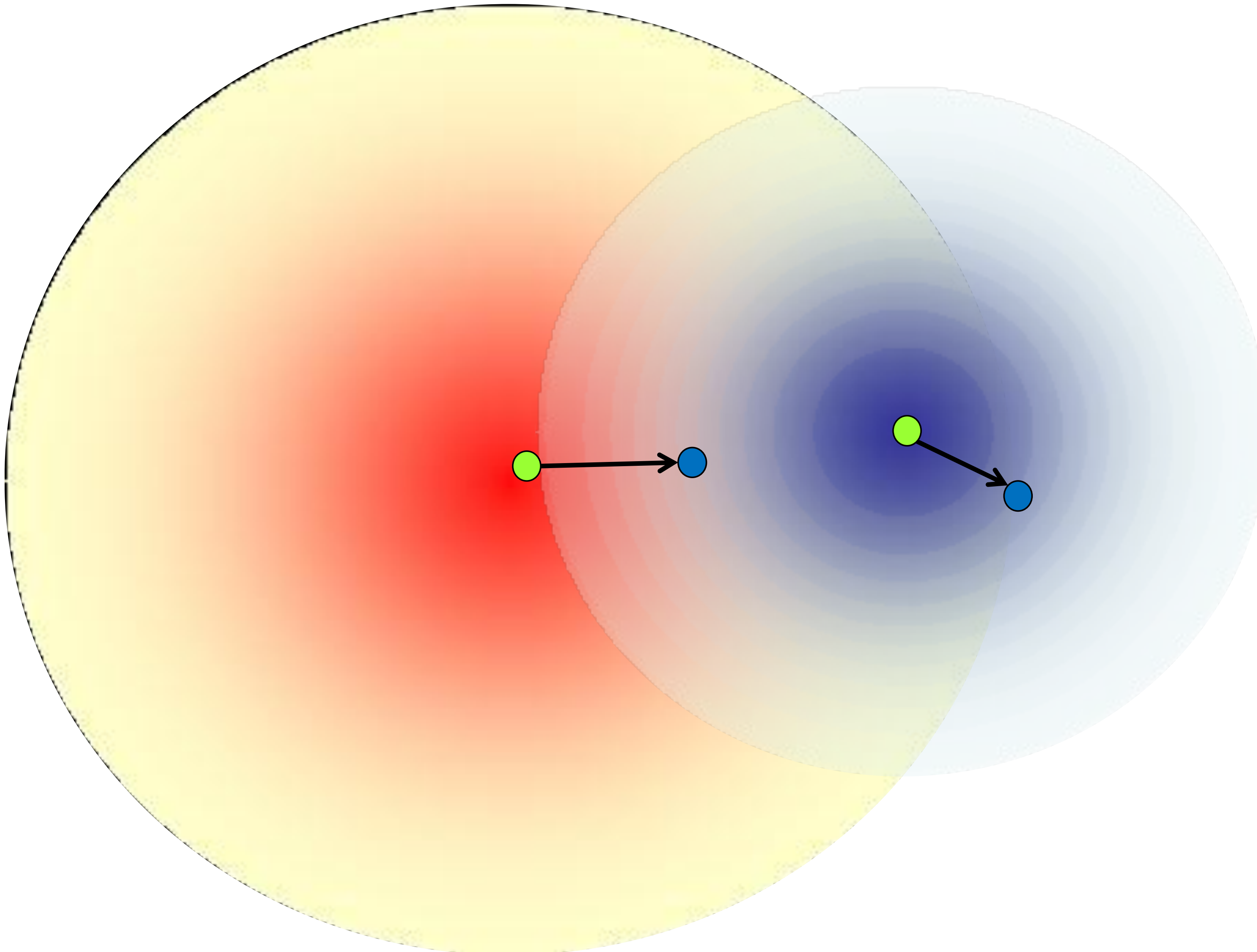
Worst-Case Analysis

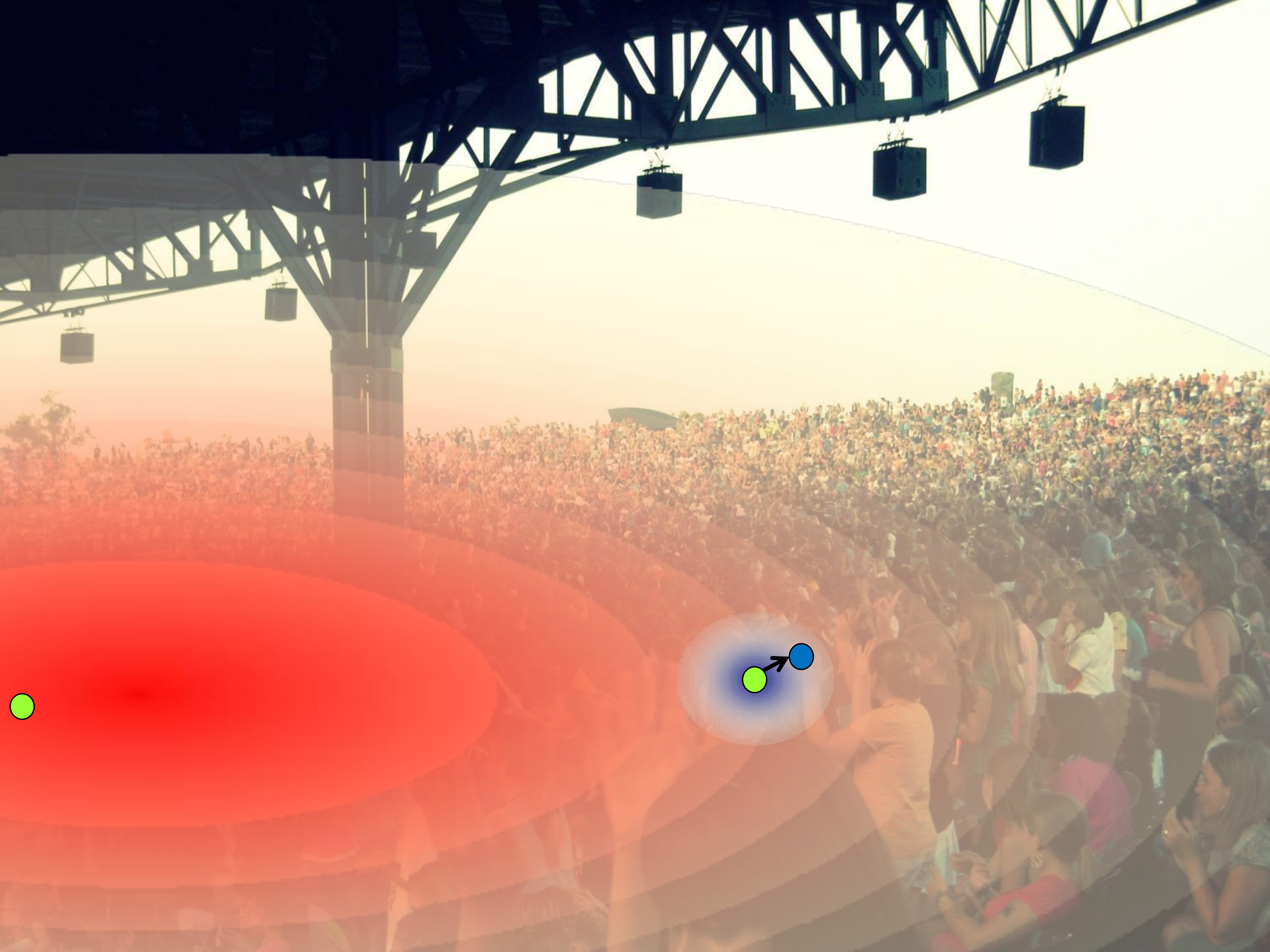
Any-Case Analysis

CS Models: e.g. Disk Model (Protocol Model)



EE Models: e.g. SINR Model (Physical Model)



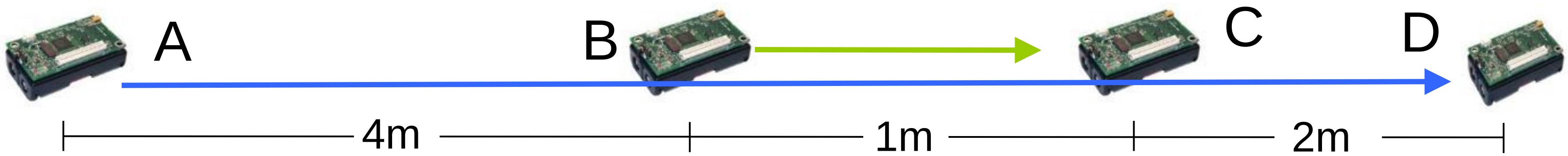


Signal-To-Interference-Plus-Noise Ratio (SINR) Formula

$$\frac{\frac{P_u}{d(u,v)^\alpha}}{N + \sum_{w \in V \setminus \{u\}} \frac{P_w}{d(w,v)^\alpha}} \geq \beta$$

- Received signal power from sender
- Power level of sender *u*
- Path-loss exponent
- Minimum signal-to-interference ratio
- Noise
- Received signal power from all other nodes (=interference)
- Distance between two nodes

Example: Protocol vs. Physical Model



Assume a single frequency (and no fancy decoding techniques!)

Is spatial reuse possible?

- NO — Protocol Model
- YES — With power control

Let α=3, β=3, and N=10nW

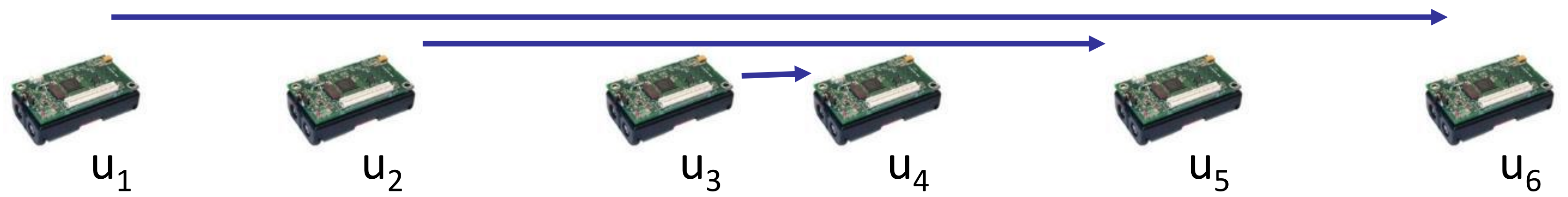
Transmission powers: P_B= -15 dBm and P_A= 1 dBm

SINR of A at D: $$\frac{1.26mW/(7m)^3}{0.01\mu W + 31.6\mu W/(3m)^3} \approx 3.11 \geq \beta$$

SINR of B at C: $$\frac{31.6\mu W/(1m)^3}{0.01\mu W + 1.26mW/(5m)^3} \approx 3.13 \geq \beta$$

This works in practice!

… even with very simple hardware (sensor nodes)



Time for transmitting 20‘000 packets:

	Time required	
	standard MAC	“SINR-MAC”
Node u_1	$721s$	$267s$
Node u_2	$778s$	$268s$
Node u_3	$780s$	$270s$

	Messages received	
	standard MAC	“SINR-MAC”
Node u_4	19999	19773
Node u_5	18784	18488
Node u_6	16519	19498

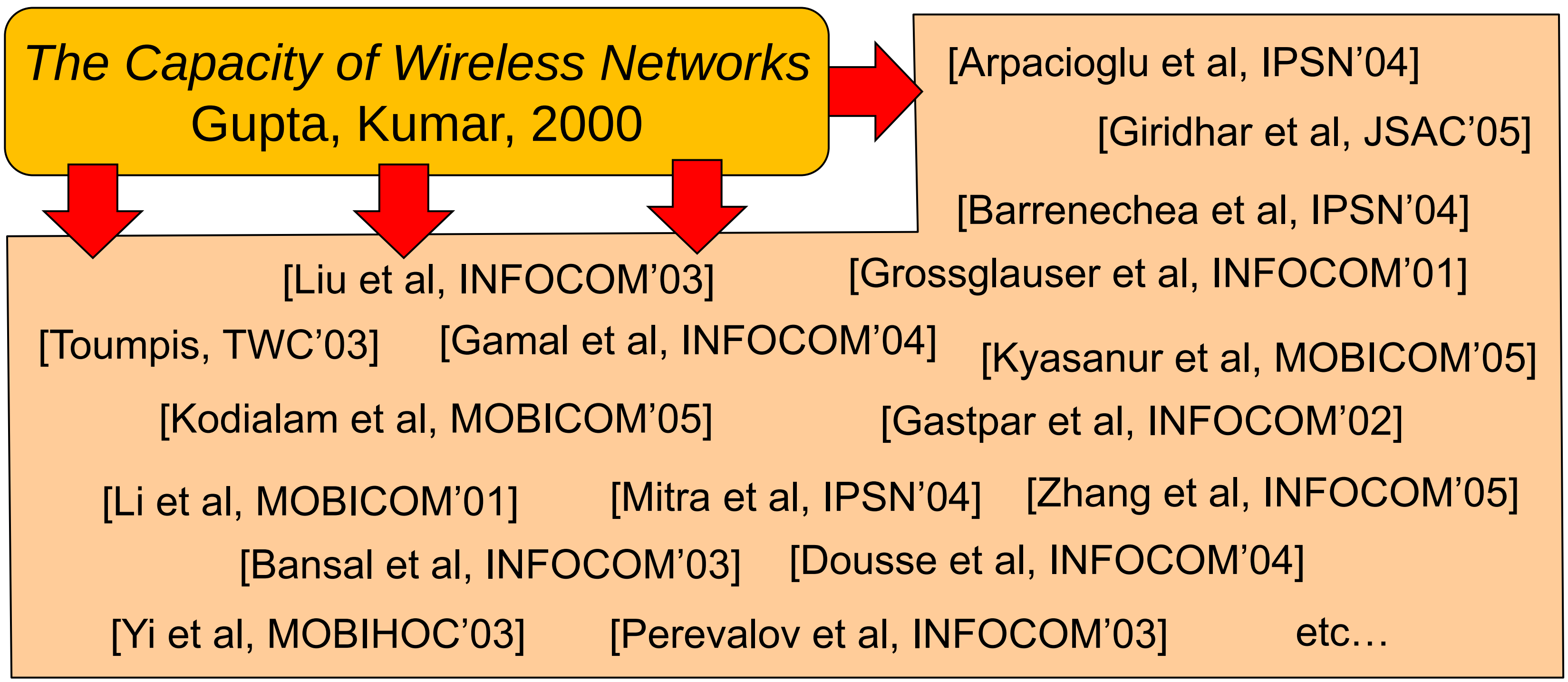
Speed-up is almost a factor 3

[Moscibroda, W, Weber, Hotnets 2006]

The Capacity of a Network

(How many concurrent wireless transmissions can you have)

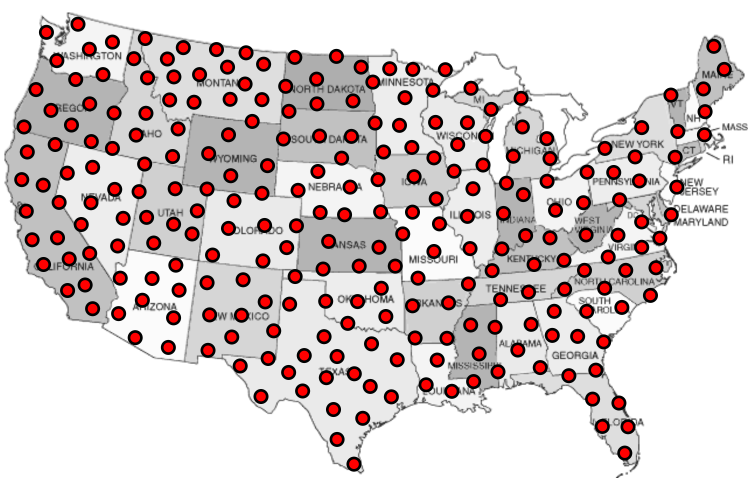
… is a well-studied problem in Wireless Communication

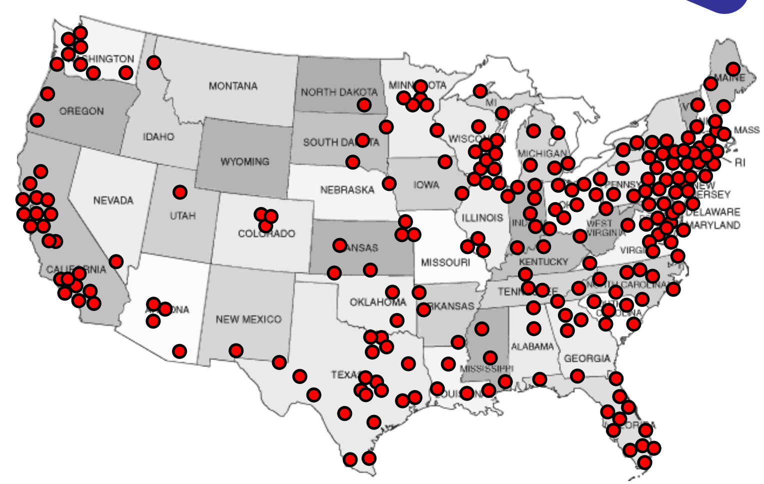


Network Topology?

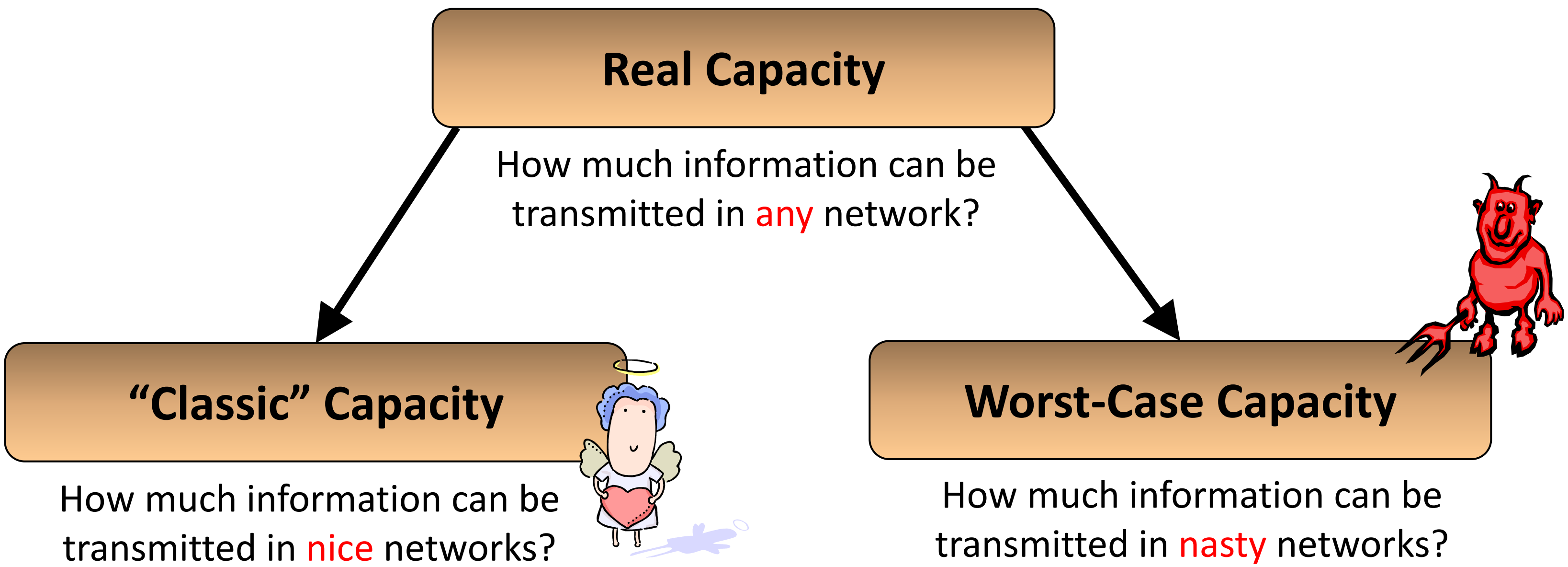
- All these capacity studies make very strong assumptions on node deployment, topologies
  - randomly, uniformly distributed nodes
  - nodes placed on a grid
  - etc.

What if a network looks differently…?





Physical Algorithms



"Convergecast Capacity" in Wireless Networks

[Moscibroda, W, 2006] — Worst-Case Capacity

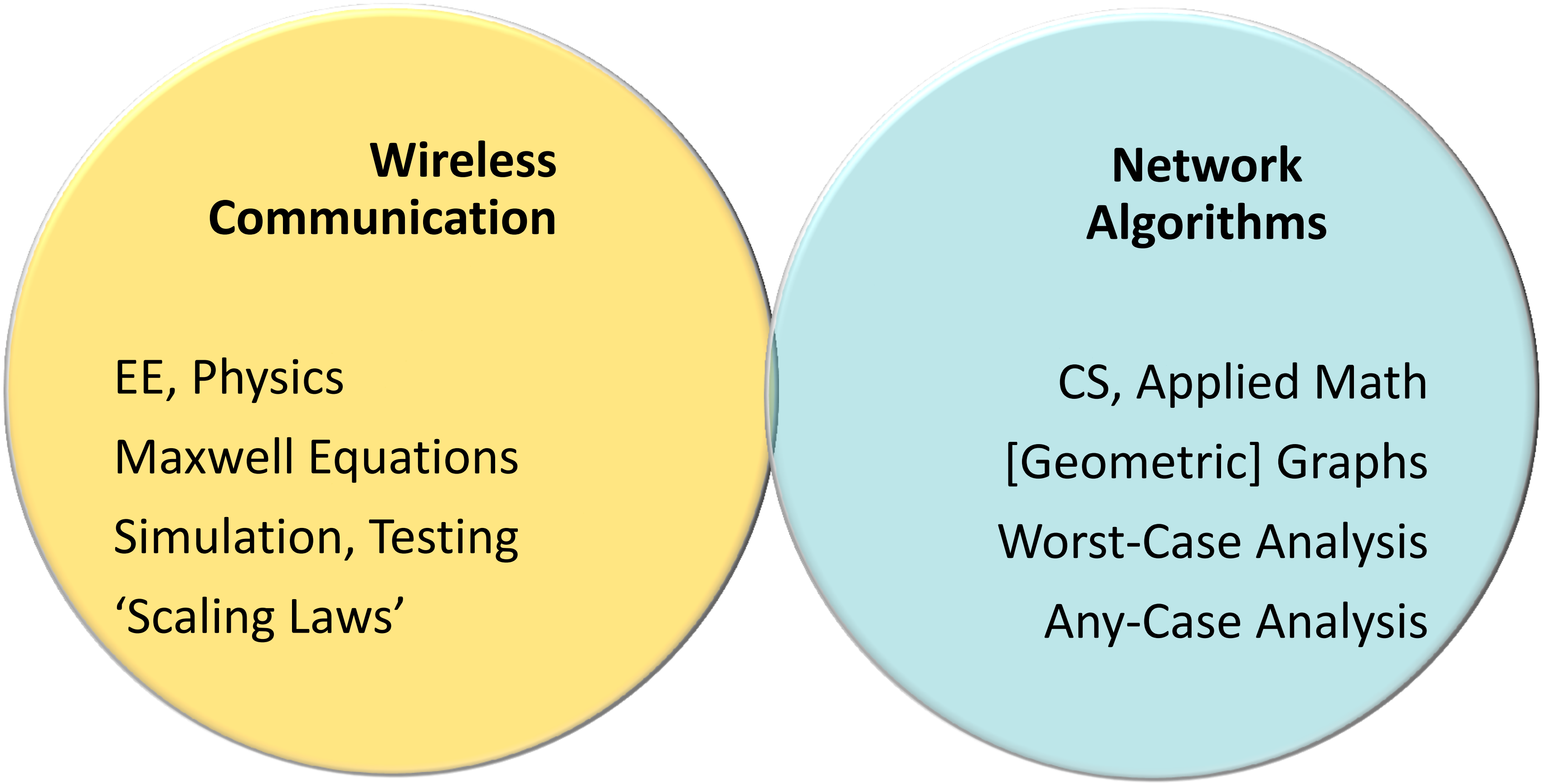
[Giridhar, Kumar, 2005] — Best-Case Capacity

Model/Power \ Networks	Max. rate in arbitrary, worst-case deployment	Max. rate in random, uniform deployment
Protocol Model	$\Theta(1/n)$	$\Theta(1/\log n)$
Physical Model (power control)	$\Omega(1/\log^3 n)$	$\Omega(1/\log n)$

Exponential gap between protocol and physical model!

<u>The Price of Worst-Case Node Placement</u>

- Exponential in protocol model
- Polylogarithmic in physical model (almost no worst-case penalty!)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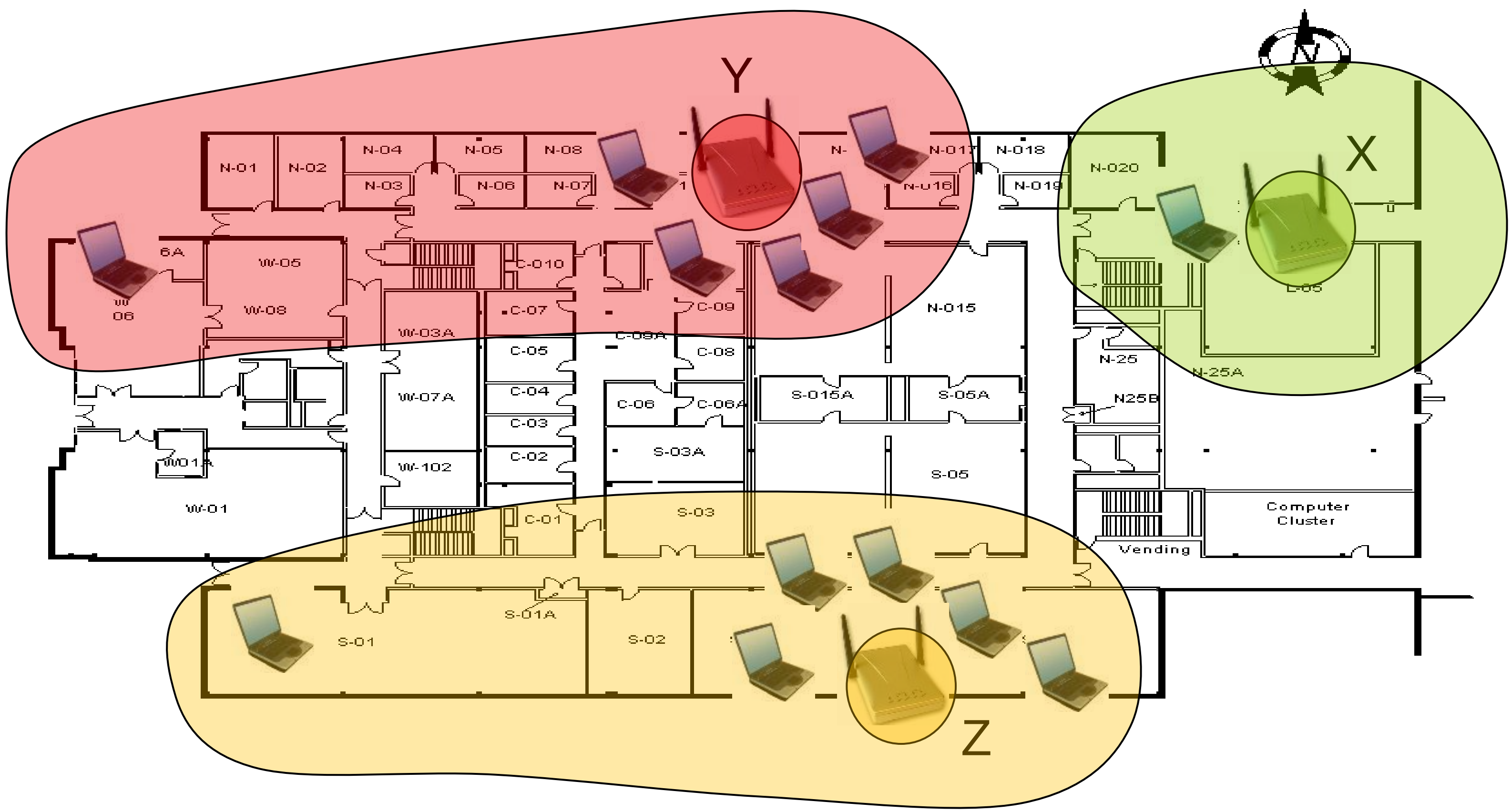
Possible Application – Hotspots in WLAN



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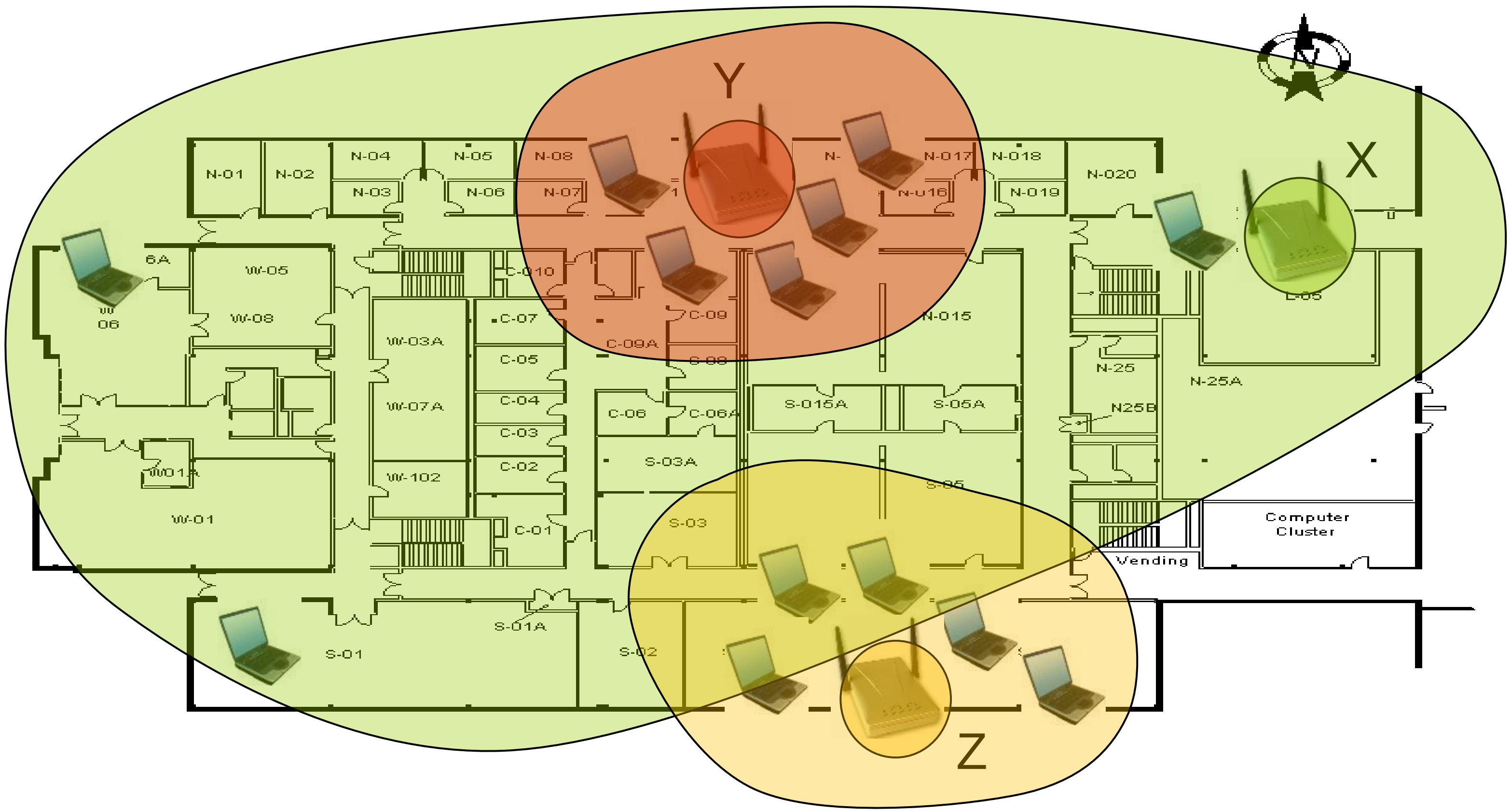
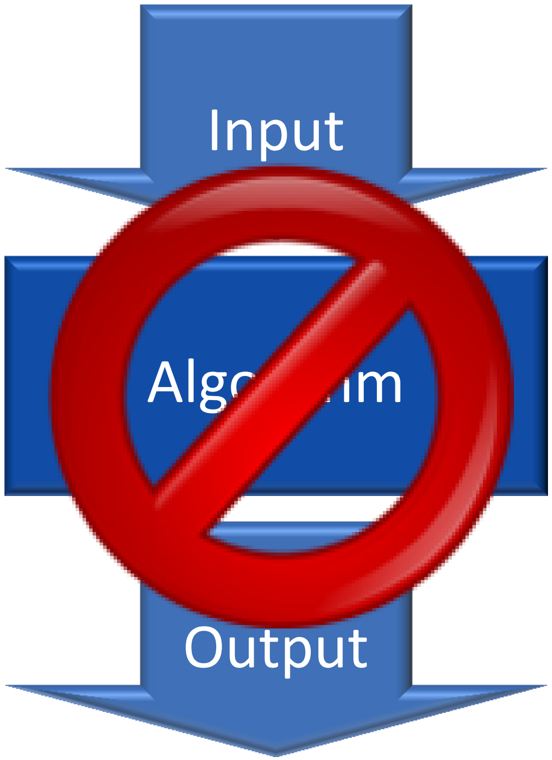


Physical Algorithms?

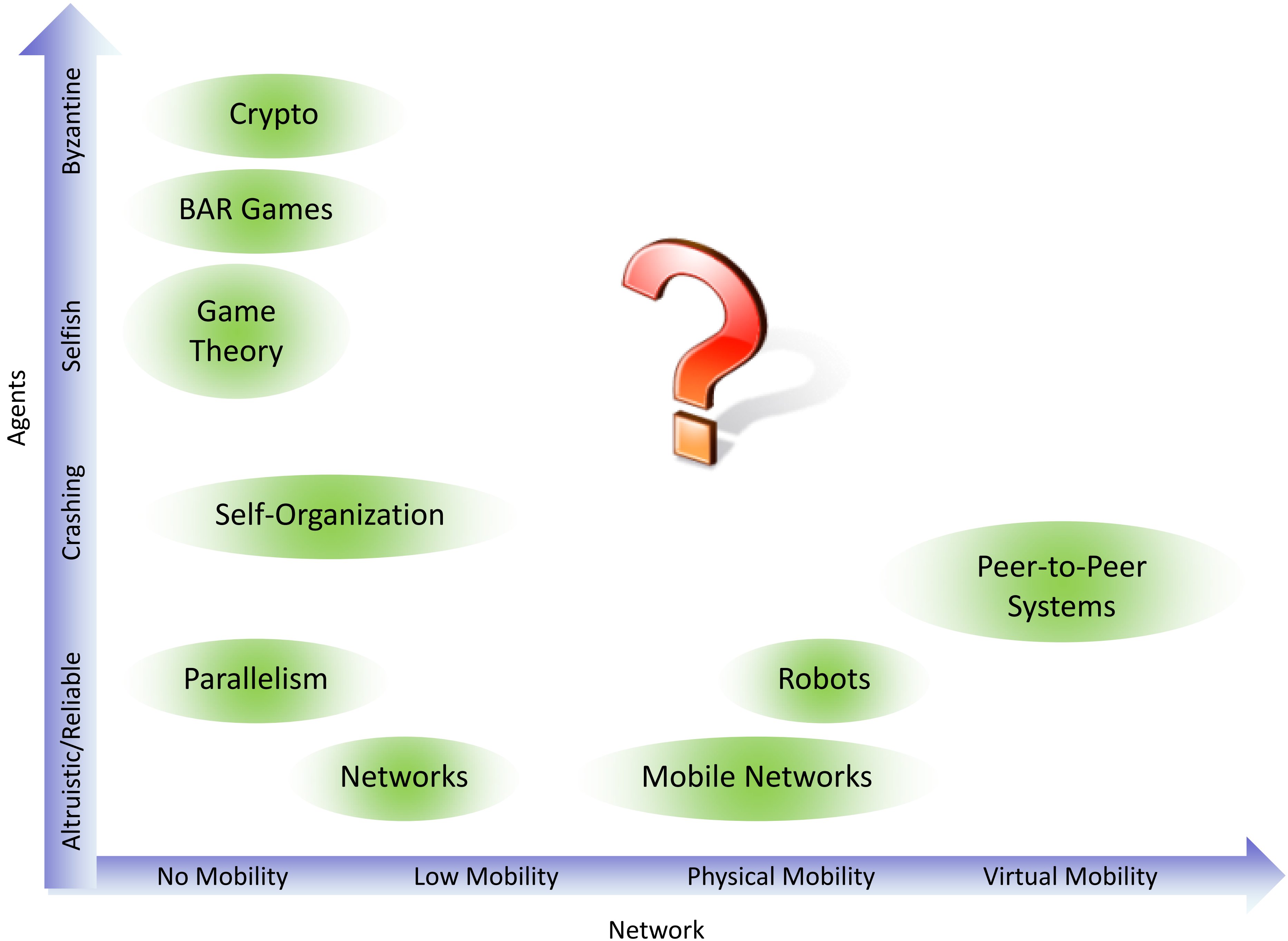
Physical Algorithms



no seq. input/output

beyond laws of physics


Agents
Byzantine
Selfish
Crashing
Altruistic/Reliable
No Mobility
Low Mobility
Physical Mobility
Virtual Mobility
Network
YouTube
upcoming
last.fm
share

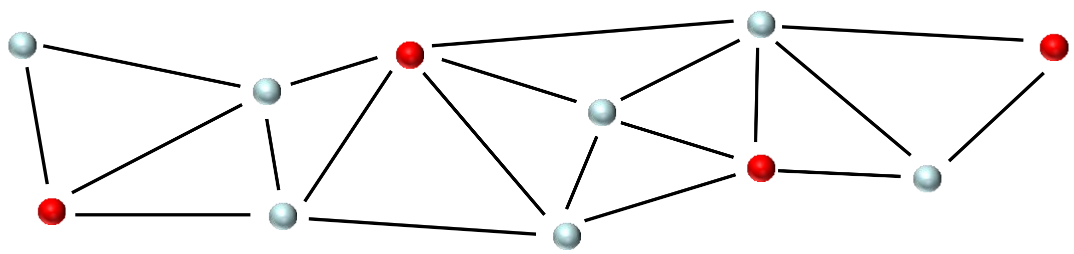


Agents
Byzantine
Selfish
Crashing
Altruistic/Reliable
Crypto
BAR Games
Game Theory
Self-Organization
Peer-to-Peer Systems
Parallelism
Robots
Networks
Mobile Networks
No Mobility
Low Mobility
Physical Mobility
Virtual Mobility
Network

Some Unifying Theory?

Example: Maximal Independent Set (MIS)

- Given a mobile network, nodes with unique IDs.
- Maintain a Maximal Independent Set (MIS)
  - a non-extendable set of pair-wise non-adjacent nodes



- A simple algorithm:

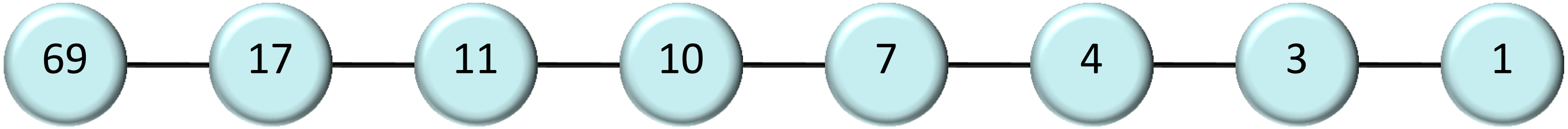
  `IF no higher ID neighbor is in MIS → join MIS`

  `IF higher ID neighbor is in MIS → do not join MIS`

- Can be implemented by constantly sending (ID, in MIS or not in MIS)
- Algorithm is simple, and it will eventually stabilize!

Example

IF no higher ID neighbor is in MIS → join MIS
IF higher ID neighbor is in MIS → do not join MIS



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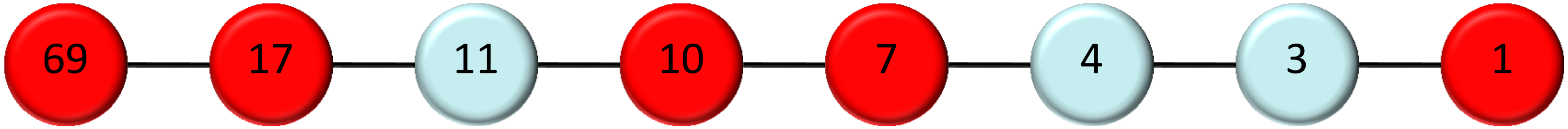

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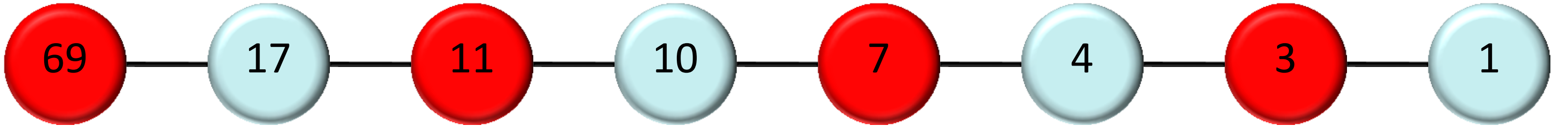

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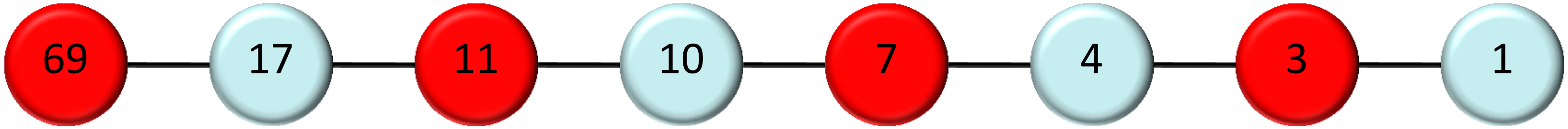
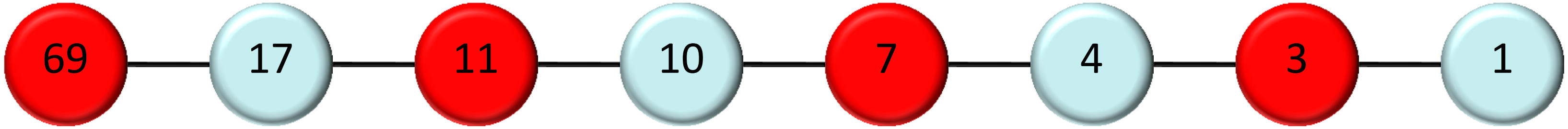


- What if we have minor changes?



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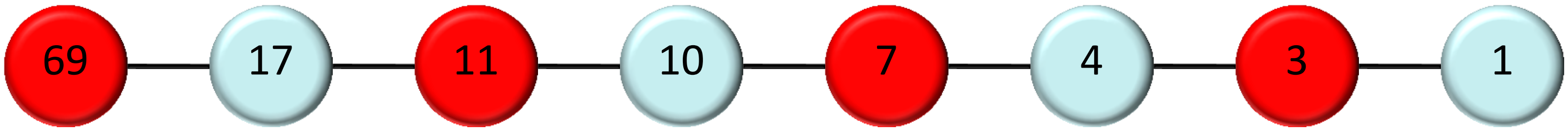
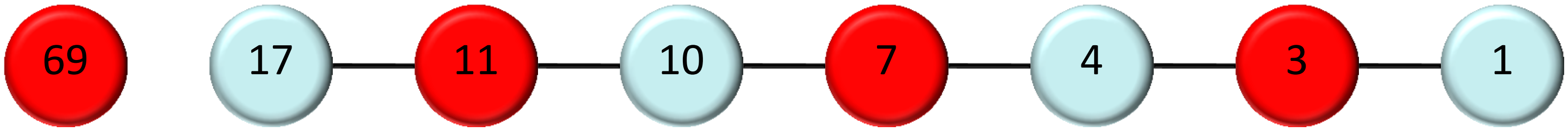
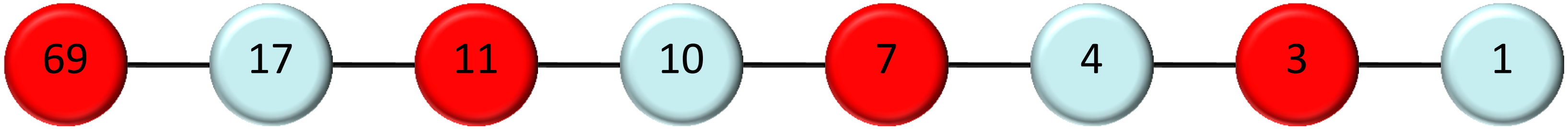


- What if we have minor changes?



Example

```
IF no higher ID neighbor is in MIS → join MIS
IF higher ID neighbor is in MIS → do not join MIS
```



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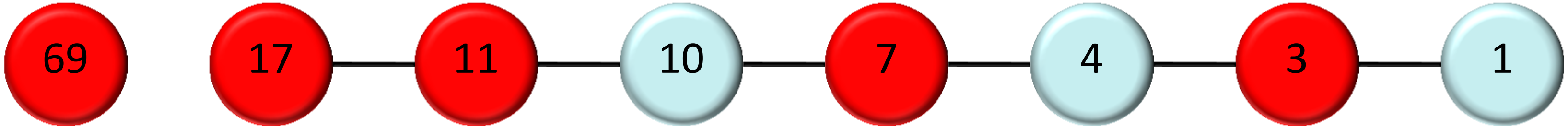

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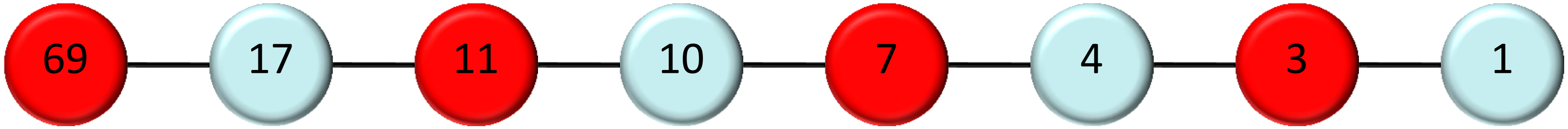

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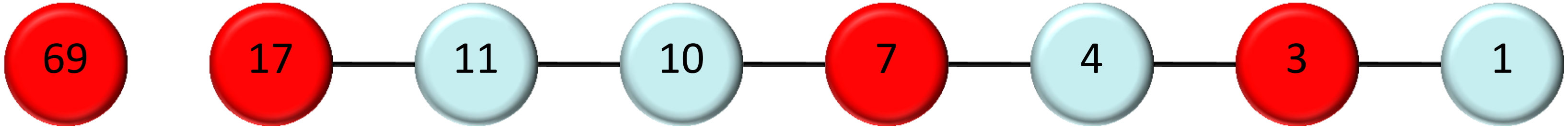

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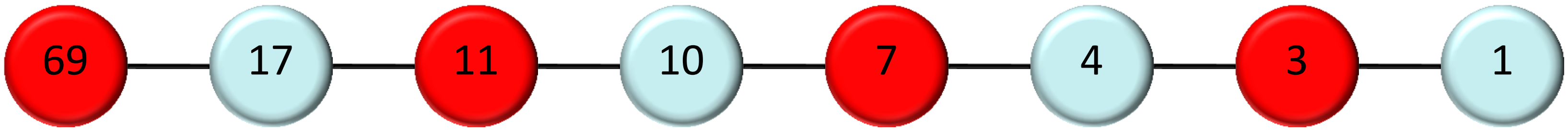

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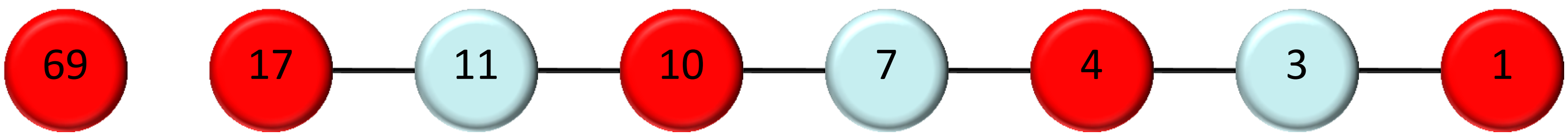

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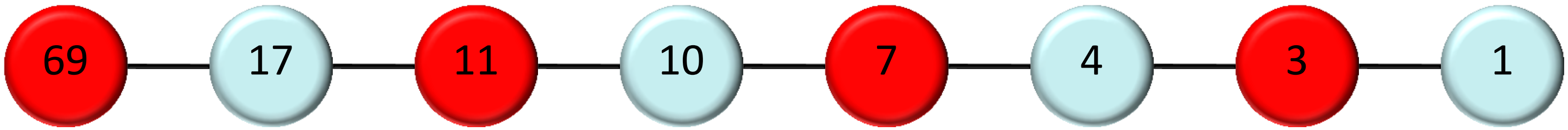

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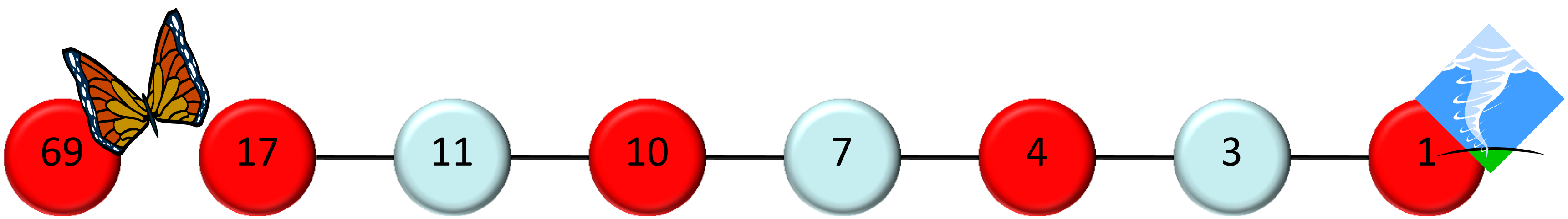
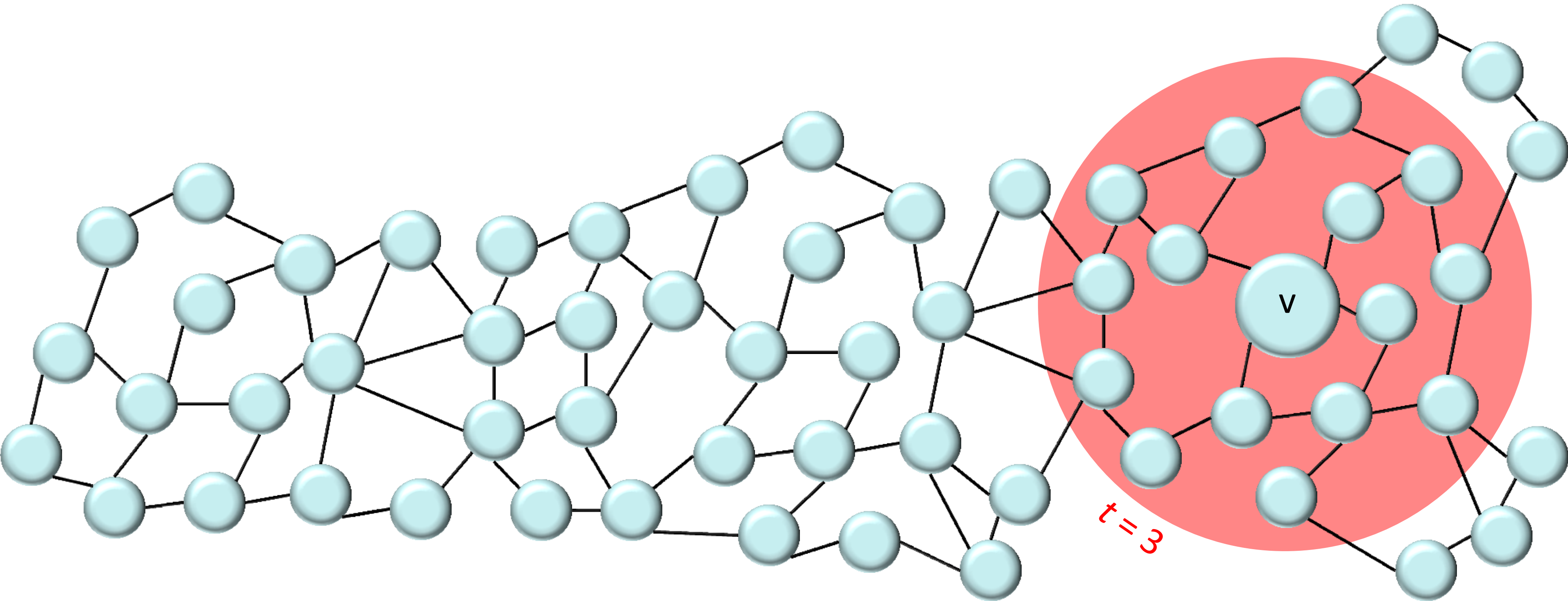


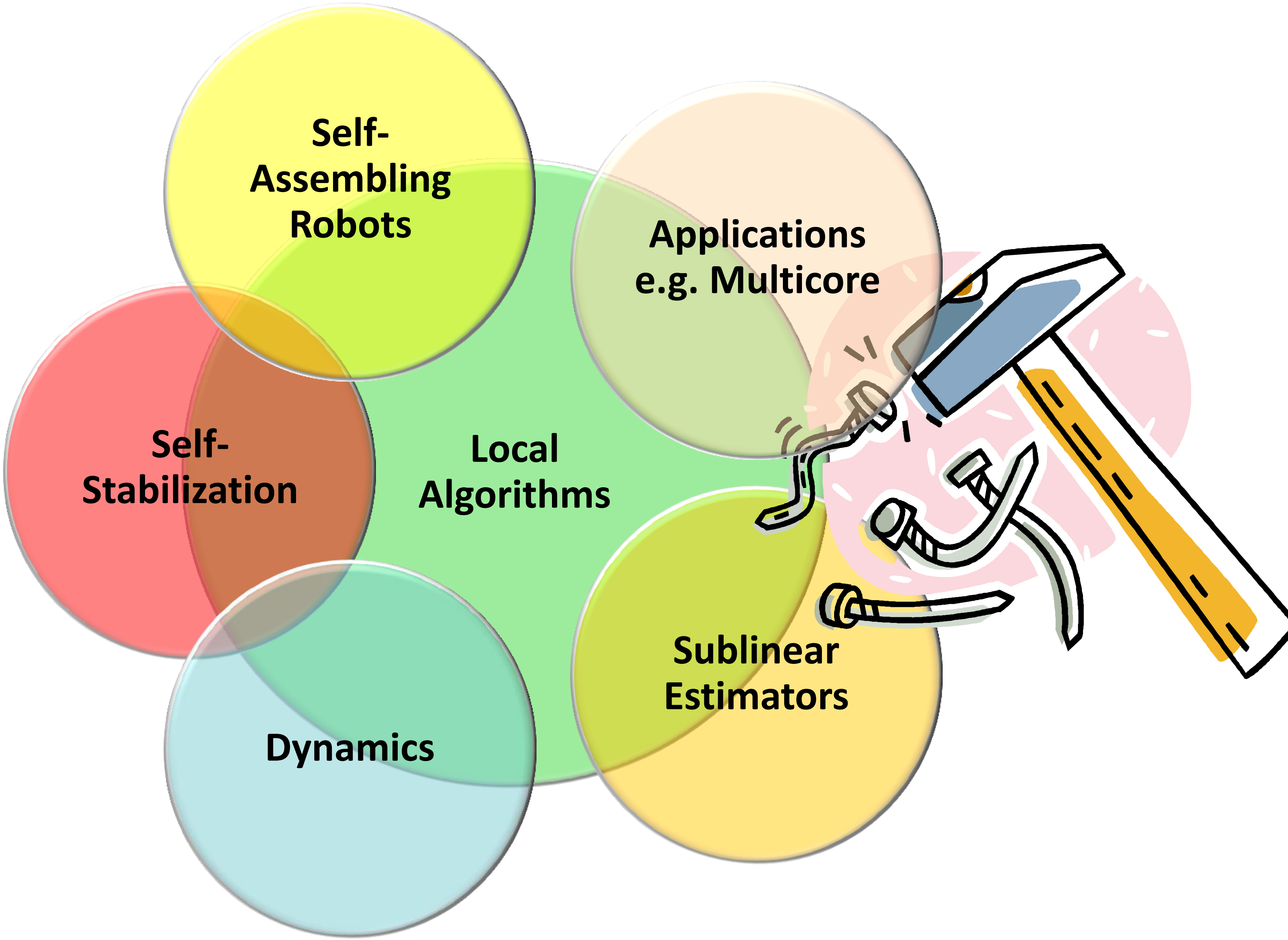
- Proof by animation: Stabilization time is linear in the diameter of the network
  - We need an algorithm that does not have linear causality chain („butterfly effect“)

Local Algorithms

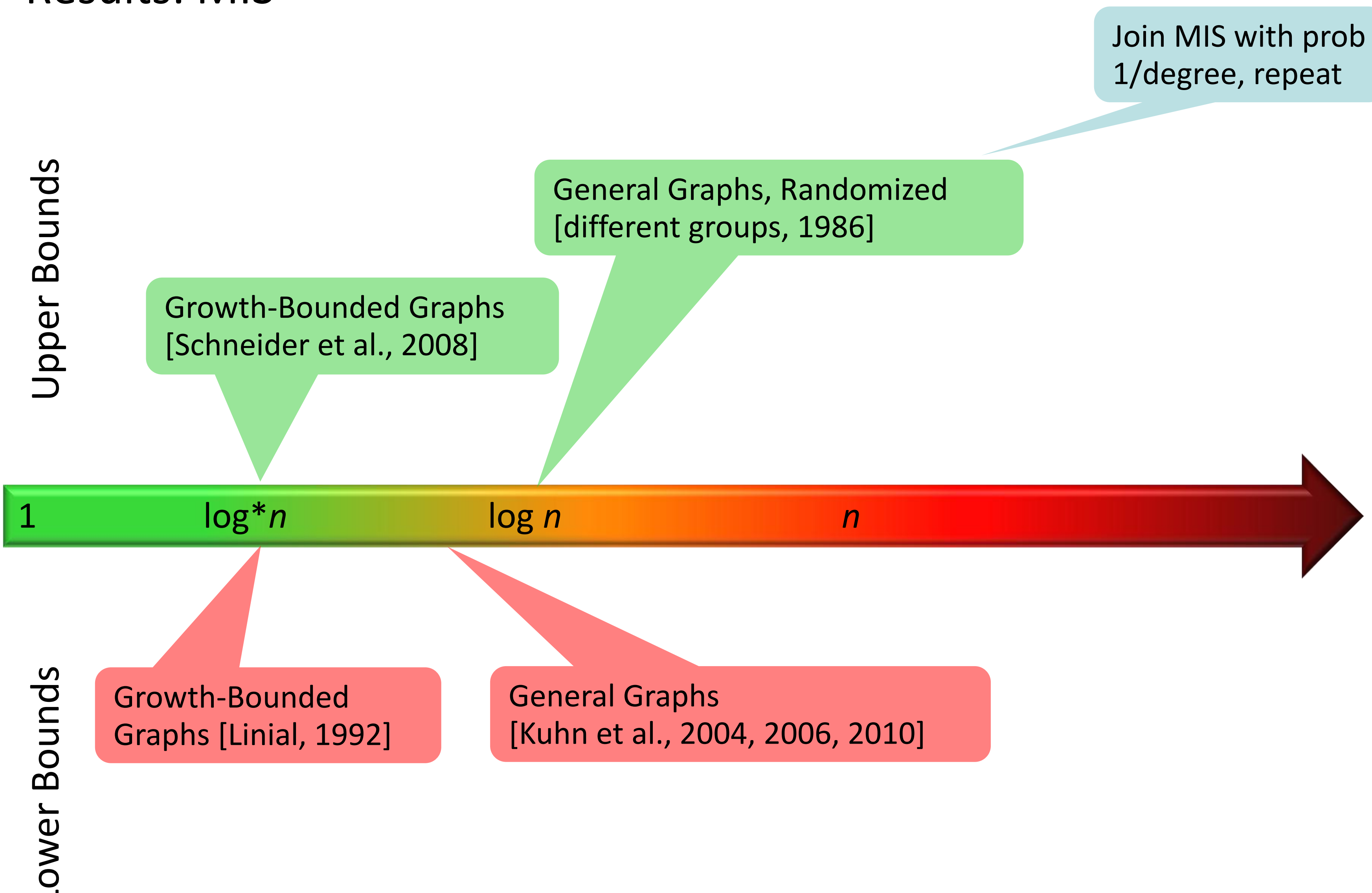
- Given a graph, each node must determine its decision as a function of the information available within radius *t* of the node.
- Or: Each node can exchange a message with all neighbors, for *t* communication rounds, and must then decide.
- Or: Change can only affect nodes in distance *t*. 
- Or: …



Locality is Way to Understand Physical Algorithms



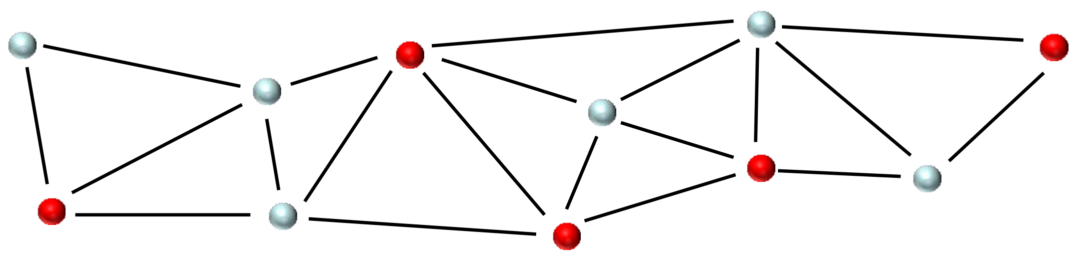
Results: MIS



…similarly connected dominating sets, coloring, matching, covering, packing, max-min LPs, etc.

Lower Bound Example: Minimum Dominating Set (MDS)

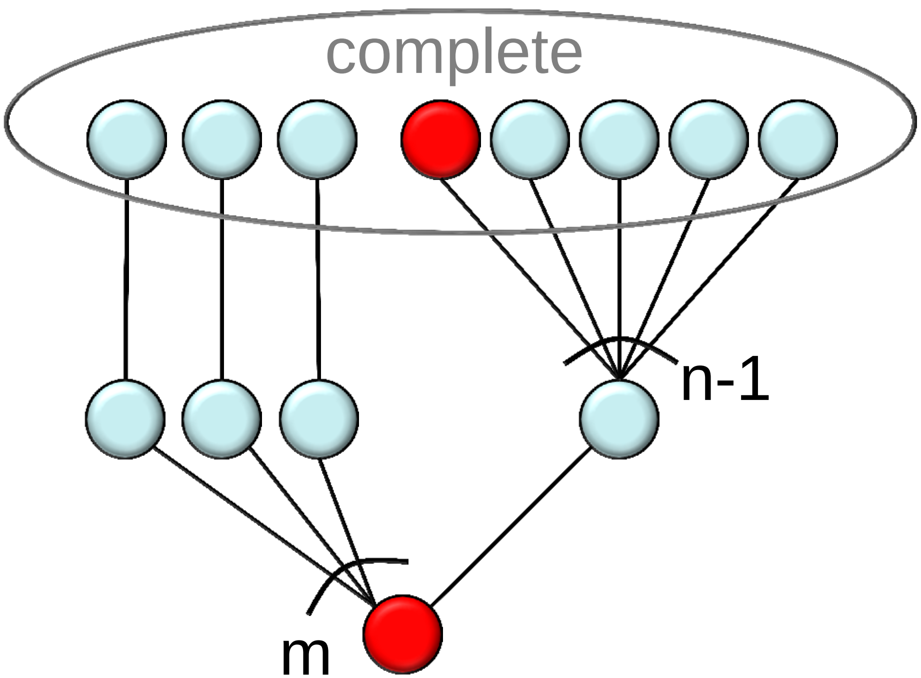
- Input: Given a graph (network), nodes with unique IDs.
- Output: Find a Minimum Dominating Set (MDS)
  - Set of nodes, each node is either in the set itself, or has neighbor in set



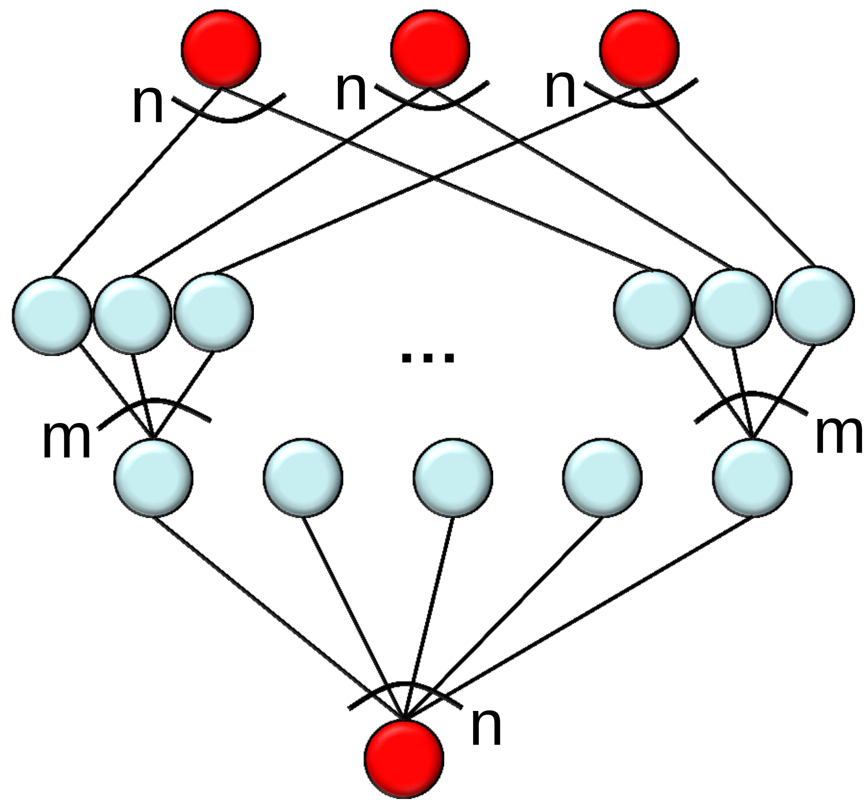
- Differences between MIS and MDS
  - Central (non-local) algorithms: MIS is trivial, whereas MDS is NP-hard
  - Instead: Find an MDS that is “close” to minimum (approximation)
  - Trade-off between time complexity and approximation ratio

Lower Bound for MDS: Intuition

- Two graphs ($m \ll n$). Optimal dominating sets are marked red.



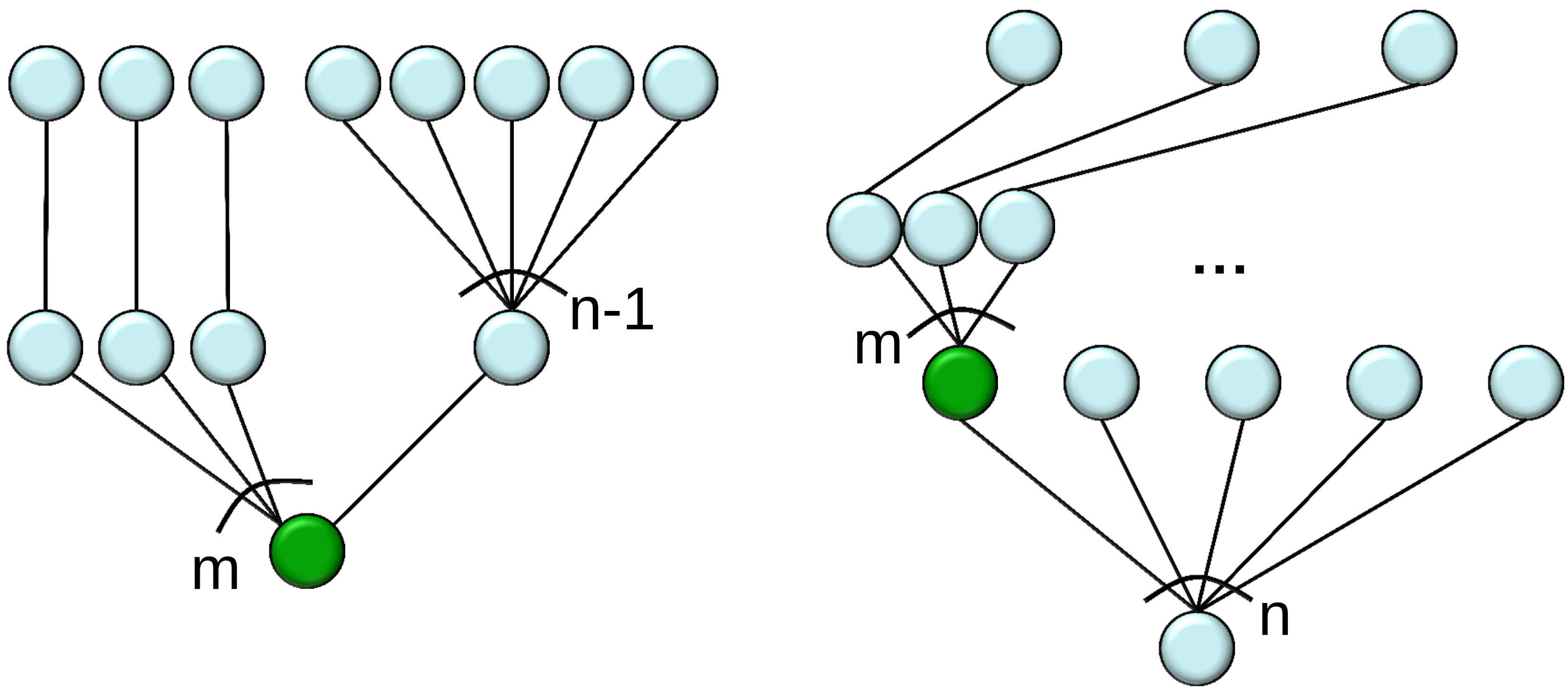
$|DS_{OPT}| = 2.$



$|DS_{OPT}| = m+1.$

Lower Bound for MDS: Intuition (2)

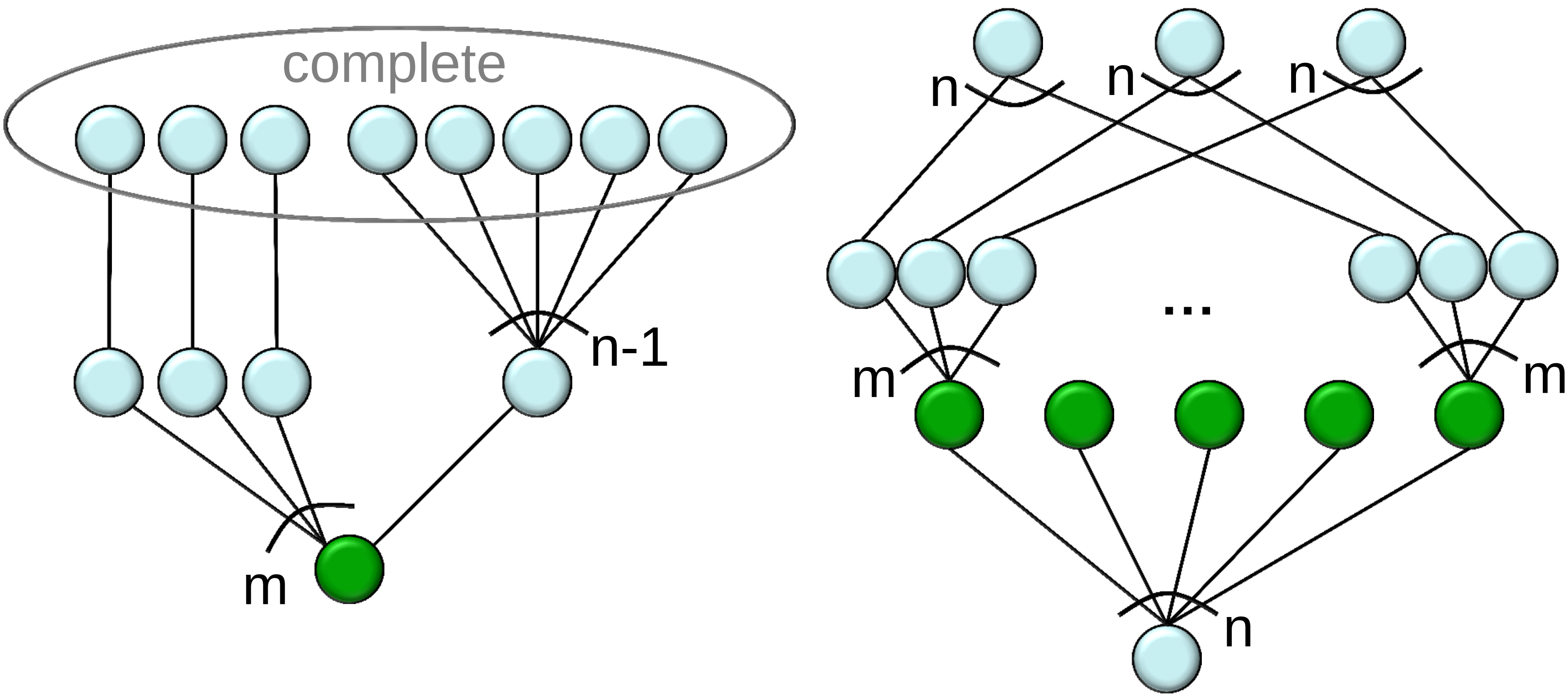
- In local algorithms, nodes must decide only using local knowledge.
- In the example green nodes see exactly the same neighborhood.



- So these green nodes must decide the same way!

Lower Bound for MDS: Intuition (3)

- But however they decide, one way will be devastating (with $n = m^2$)!



$|DS_{OPT}| = 2.$

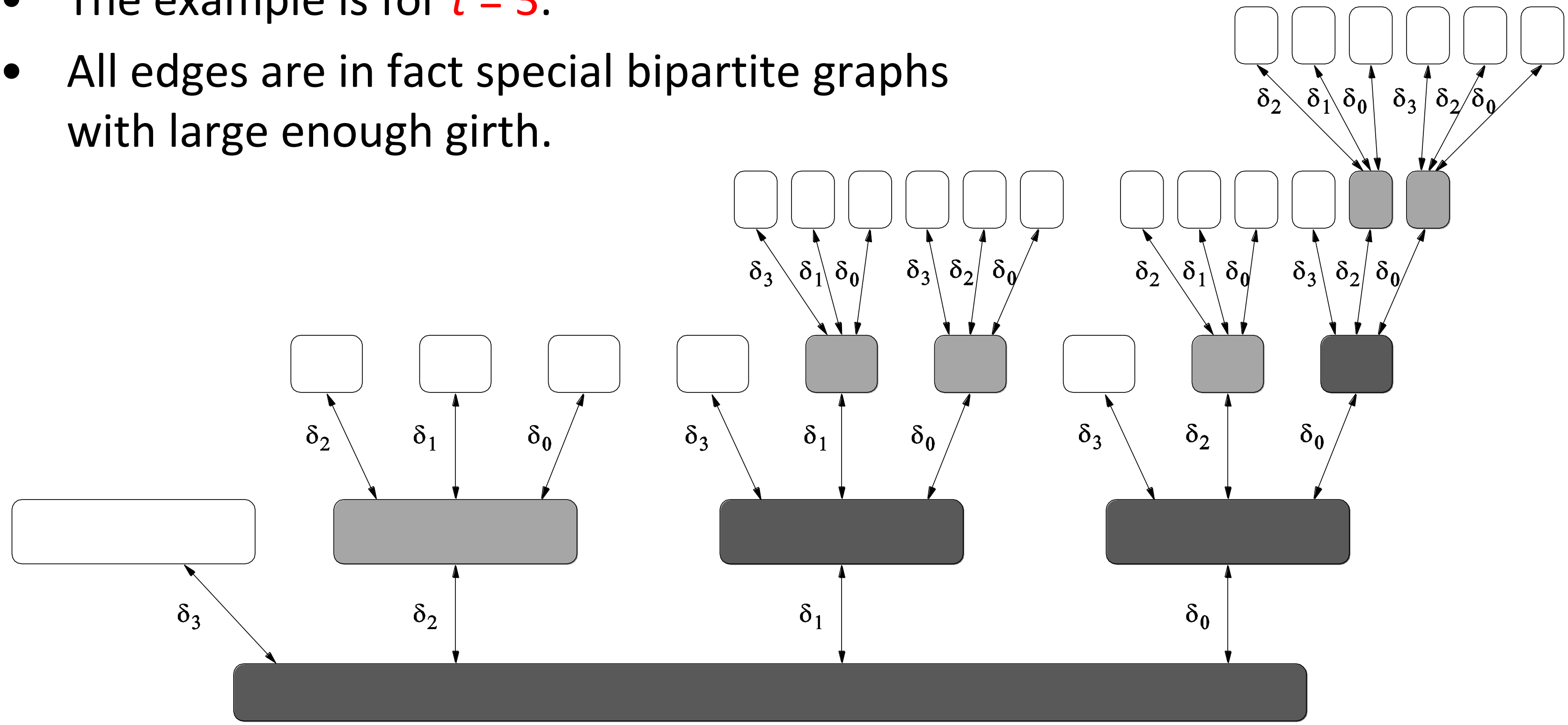
$|DS_{OPT\ without\ green}| \geq m.$

$|DS_{OPT}| = m+1.$

$|DS_{OPT\ with\ green}| > n$

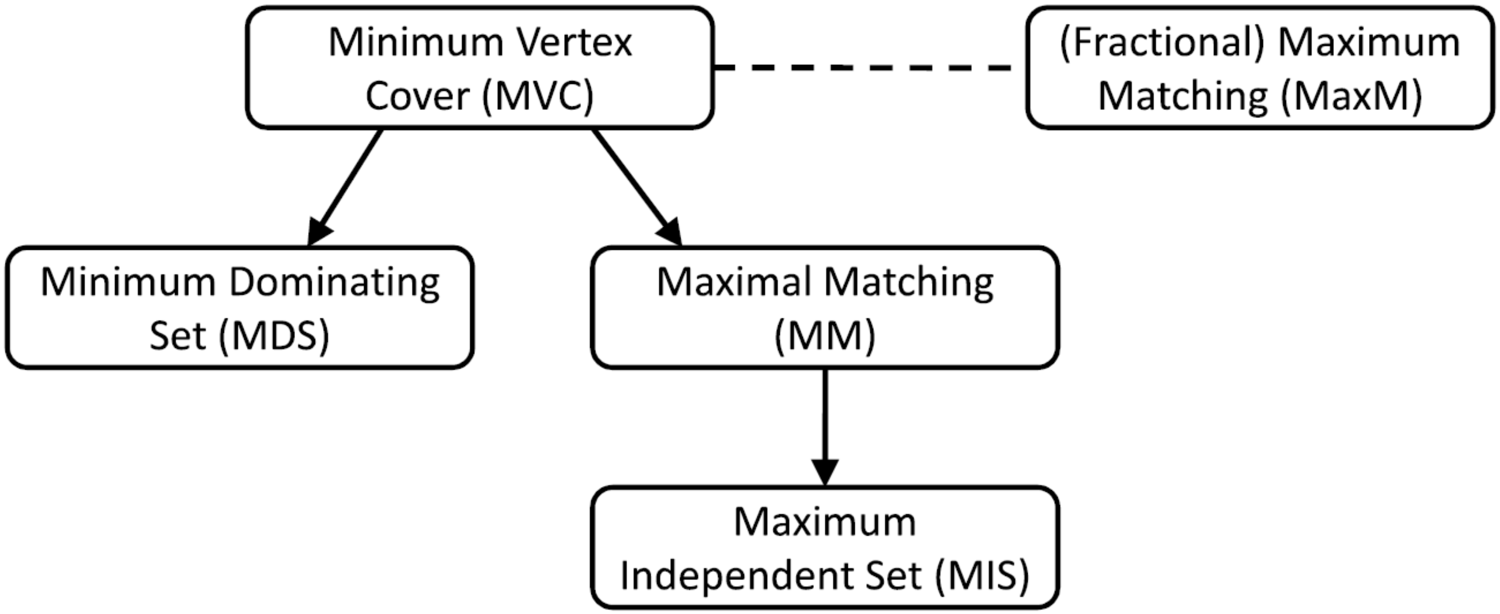
Graph Used in the Lower Bound

- The example is for $t = 3$.
- All edges are in fact special bipartite graphs with large enough girth.



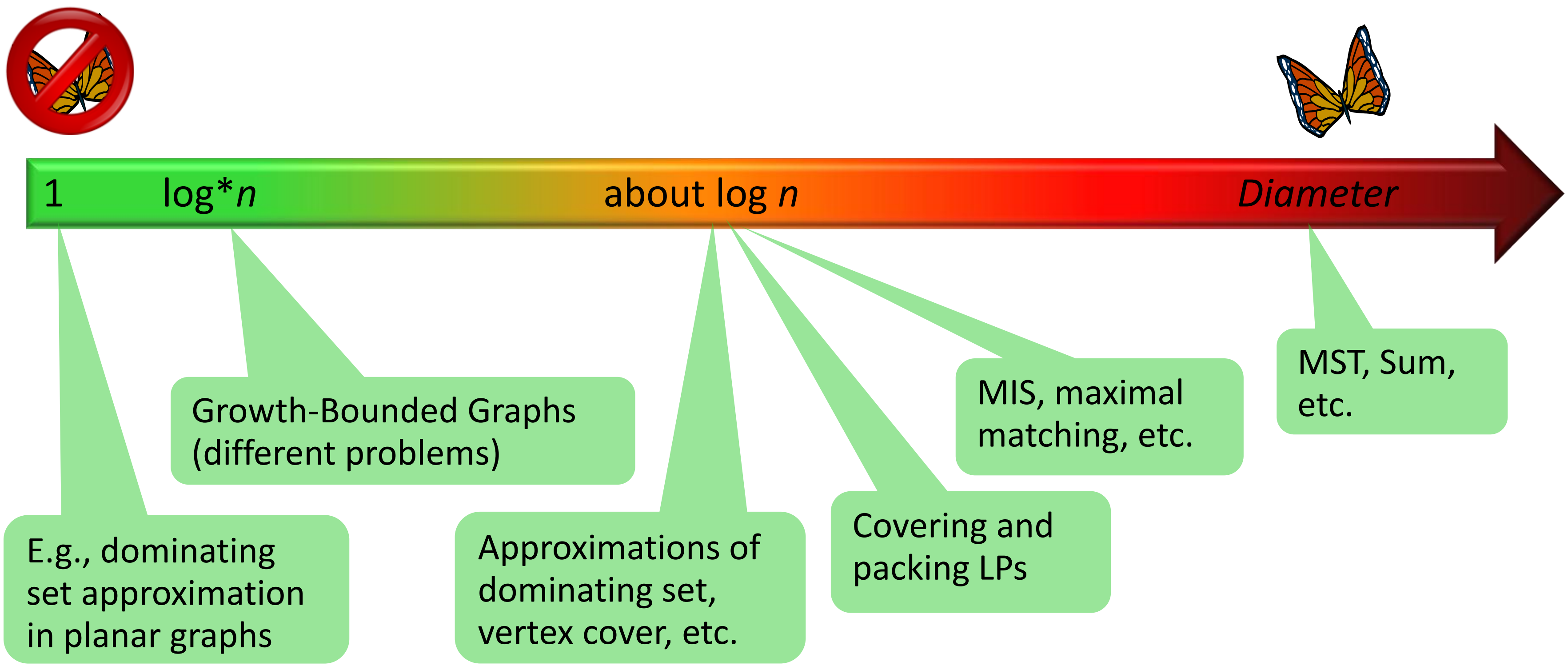
Lower Bounds

- Results: Many "local looking" problems need non-trivial *t*.
- E.g., a polylogarithmic dominating set approximation (or a maximal independent set, etc.) needs at least $\Omega(\log \Delta)$ and $\Omega(\log^{1/2} n)$ time.

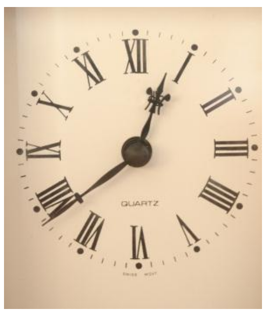


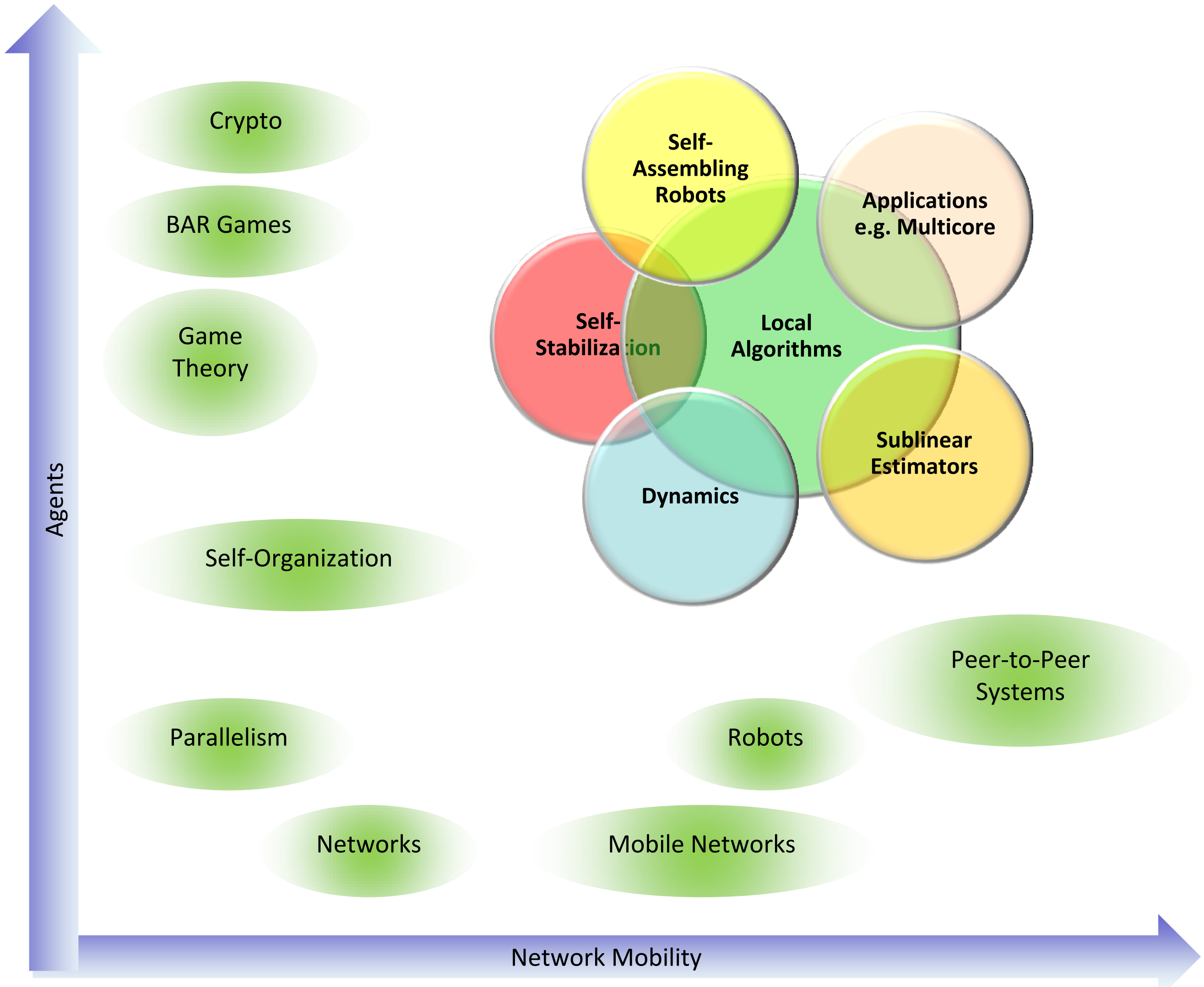
[Kuhn, Moscibroda, W, 2004, 2006, 2010]

Local Algorithms ("Tight" Lower & Upper Bounds)



Summary & Open Problems





Thank You!

Questions & Comments?

Thanks to my co-authors
Fabian Kuhn
Christoph Lenzen
Thomas Moscibroda
Thomas Locher
Johannes Schneider
Philipp Sommer

Let's get
Physical!

Let’s get Physical!

Roger Wattenhofer