

Computing through Simplicity: Towards a Theory of Dynamics

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SIMONS
INSTITUTE
for the Theory of Computing



Berkeley
UNIVERSITY OF CALIFORNIA

Academic Path

- 2017 - PhD in CS, [Sapienza University](#)
- 2014/15 (3 months)- Visiting [IRIF](#)
- 2016 & 2018-now (1 year) - [Fellow](#) of [Simons Institute for the Theory of Computing](#) (Brain Program)
- 2017-now - PostDoc, [Max-Planck Institute for Informatics](#)



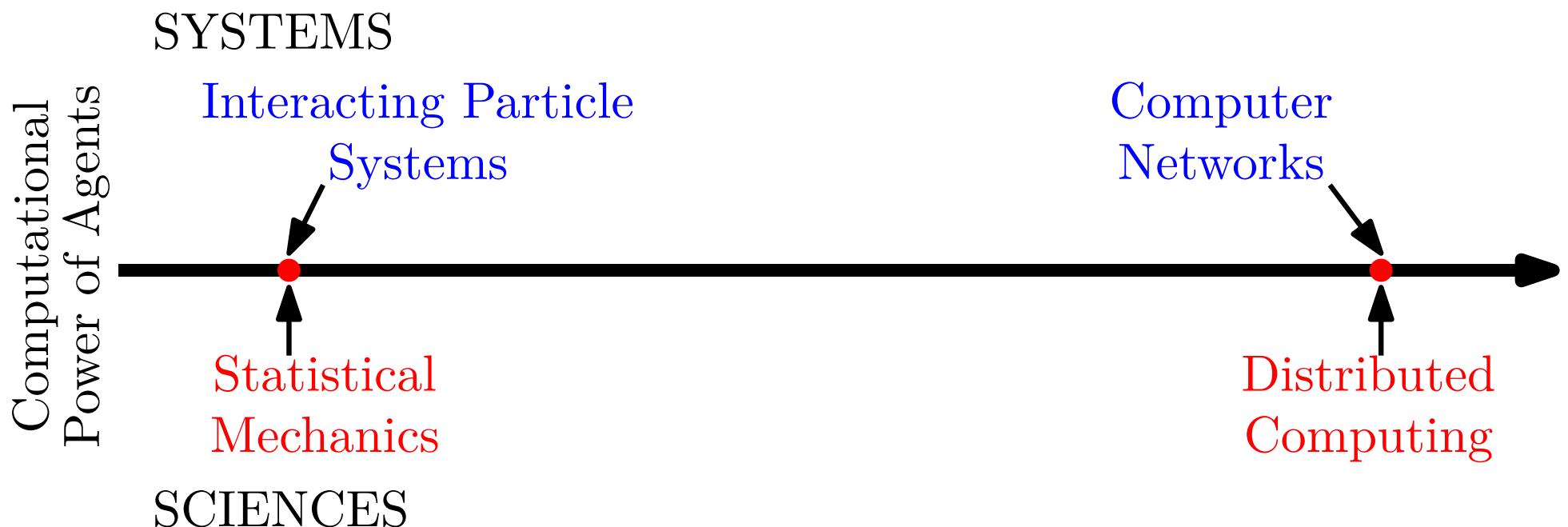
Awards

- ESA'16 **Best Student Paper**
- EATCS **Best Italian PhD Thesis** (Springer monograph in preparation)
- Sapienza 2016 **Outstanding PhD**
- Sapienza 2015 **Best CS Paper**

Invited speaker

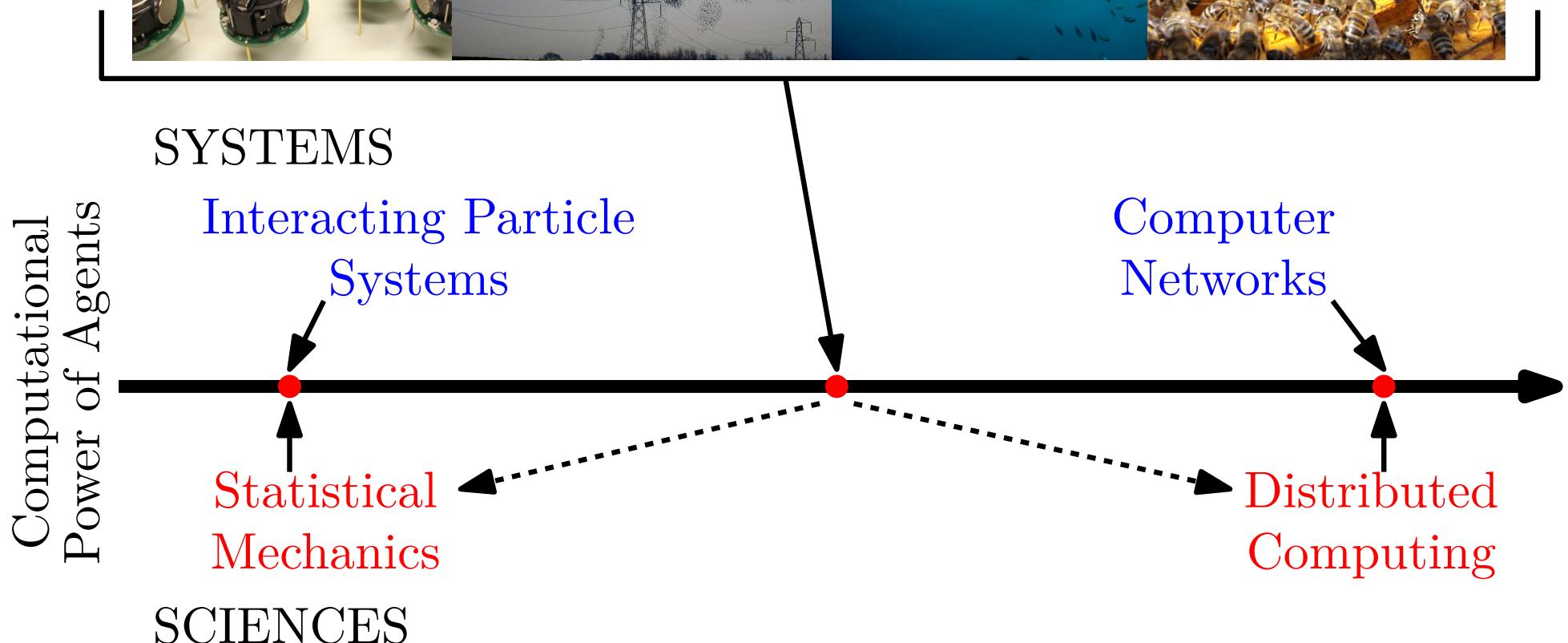
- ICTCS 2017
- Workshop on Random Processes in Discrete Structures, University of Warwick 2016

What can *Locally-Simple* Systems *Compute*?



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A **computational lens** on how
global behavior emerges from
simple local interactions among individuals



The Vision: A Theory of Dynamics

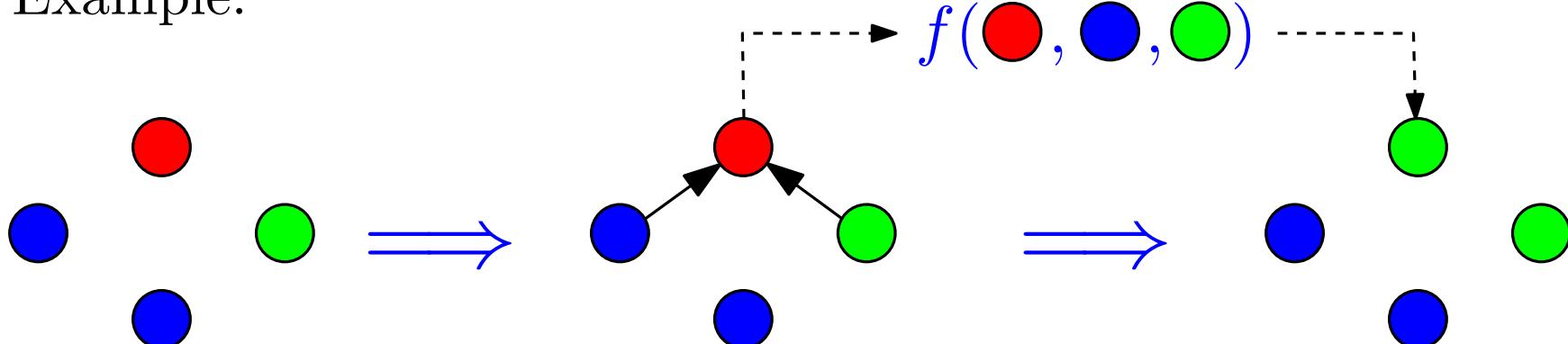
Dynamics [PhD Thesis]

Small set S and function f , agents have state $s \in S$ and

$$s^{new} = f(s^{old}, s^{\text{neighbor } u_1}, s^{\text{neighbor } u_2}, \dots)$$

$\{u_1, u_2, \dots\}$ typically random.

Example:



The Vision: A Theory of Dynamics

Dynamics [PhD Thesis]

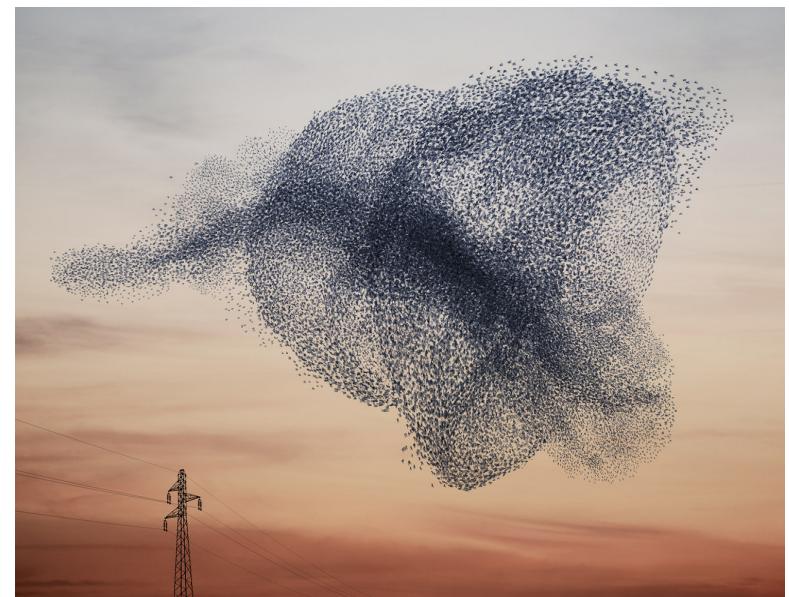
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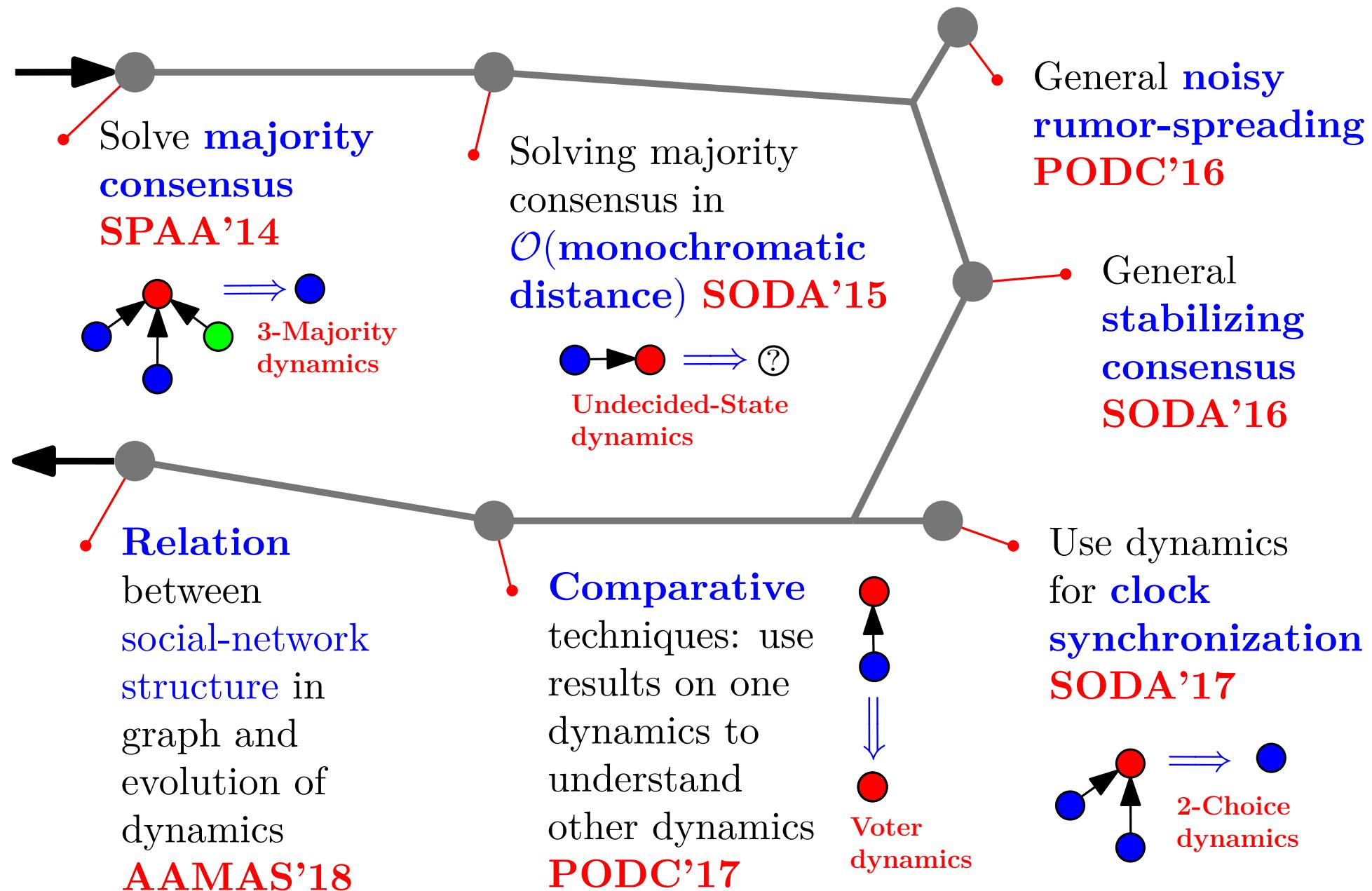
$\{u_1, u_2, \dots\}$ typically random.

Wide applications

- Biological *and* technological settings (dynamic networks)
- Biological experiment *from* TCS predictions
- Neural networks (*Simons Institute, UC Berkeley*)



Towards the Project: Previous Work on Dynamics



A Representative Result

Dynamics are shown
to solve difficult problems
in *distributed* settings

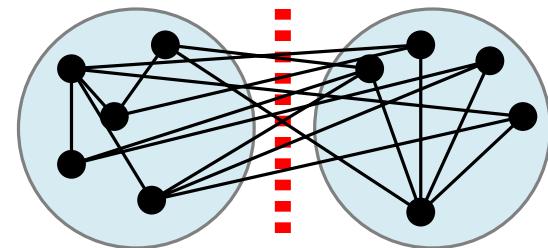
Can we use dynamics
to solve difficult problems
even in *classical* settings?

Start of Technical Part: Clustering

Minimum Bisection Problem

Find bipartition that minimizes cut

...NP-Complete!

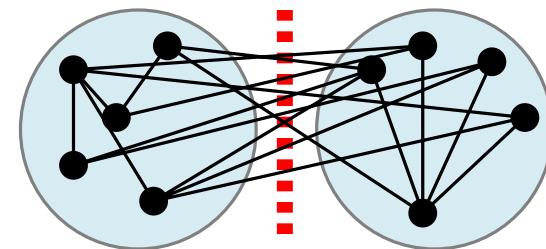


Start of Technical Part: Clustering

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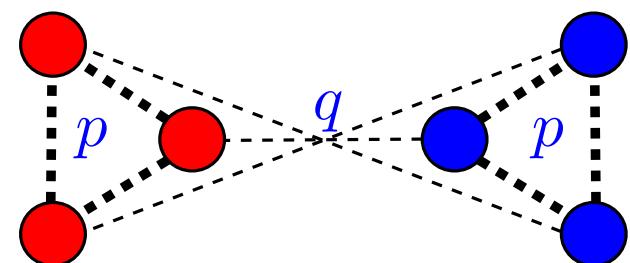
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Stochastic Block Model

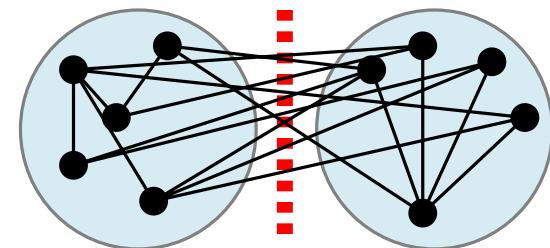
- “Communities” V_1 , V_2 , with $|V_1| = |V_2|$
- include each edge with probability
 - p if edge is inside V_1 , V_2
 - q if edge is between V_1 and V_2



Start of Technical Part: Clustering

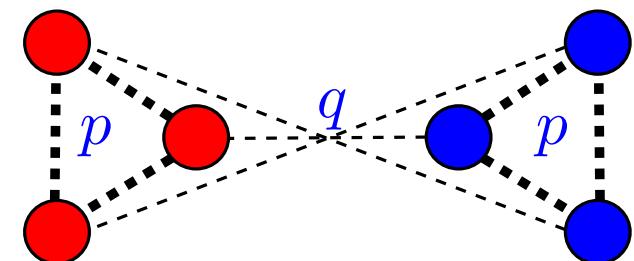
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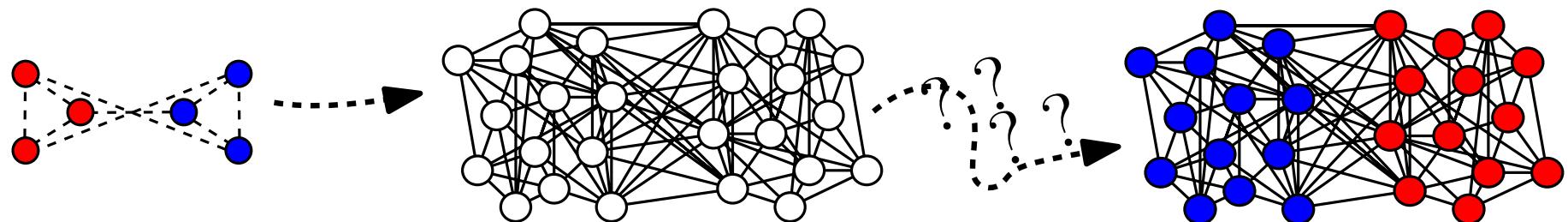
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Clustering problem

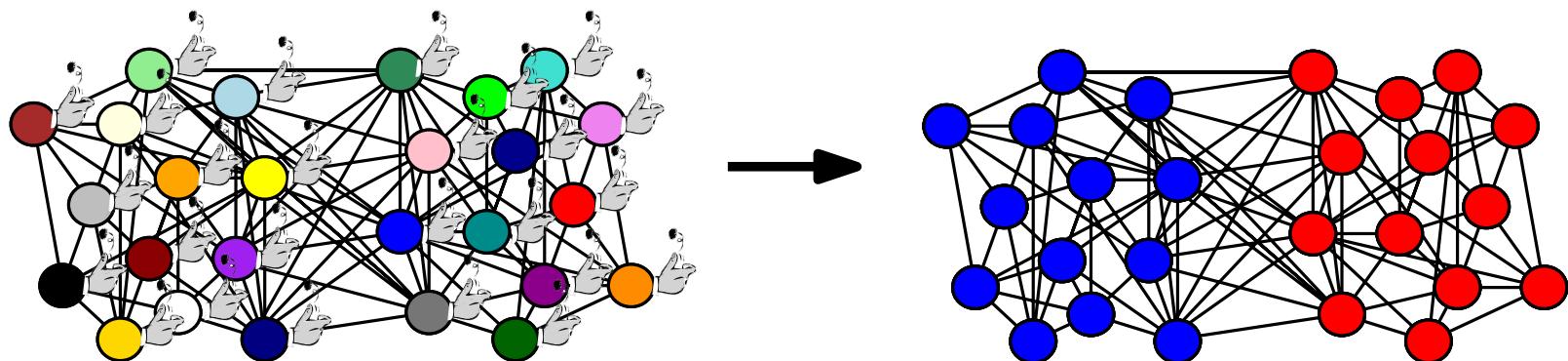
Given graph generated by SBM, find original clusters



Known: clustering possible **if and only if** p and q in a precise regime

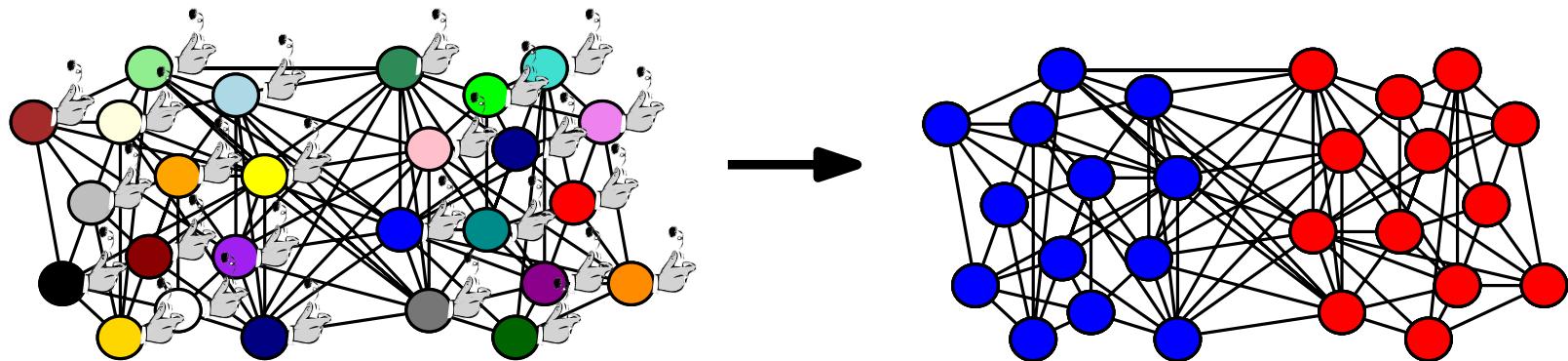
Clustering via Averaging [SODA'17]

Label Propagation Algorithms. Widely used heuristics in Data Mining: Each node initially gets random label, then updates label with simple rule of neighbors' states



Clustering via Averaging [SODA'17]

Label Propagation Algorithms. Widely used heuristics in Data Mining: Each node initially gets random label, then updates label with simple rule of neighbors' states



Theorem. There exists a dynamics that, in Stochastic Block Model with

$$p - q > \sqrt{const(p + q)/n} + \mathcal{O}(\log n/n),$$

finds clusters with high probability

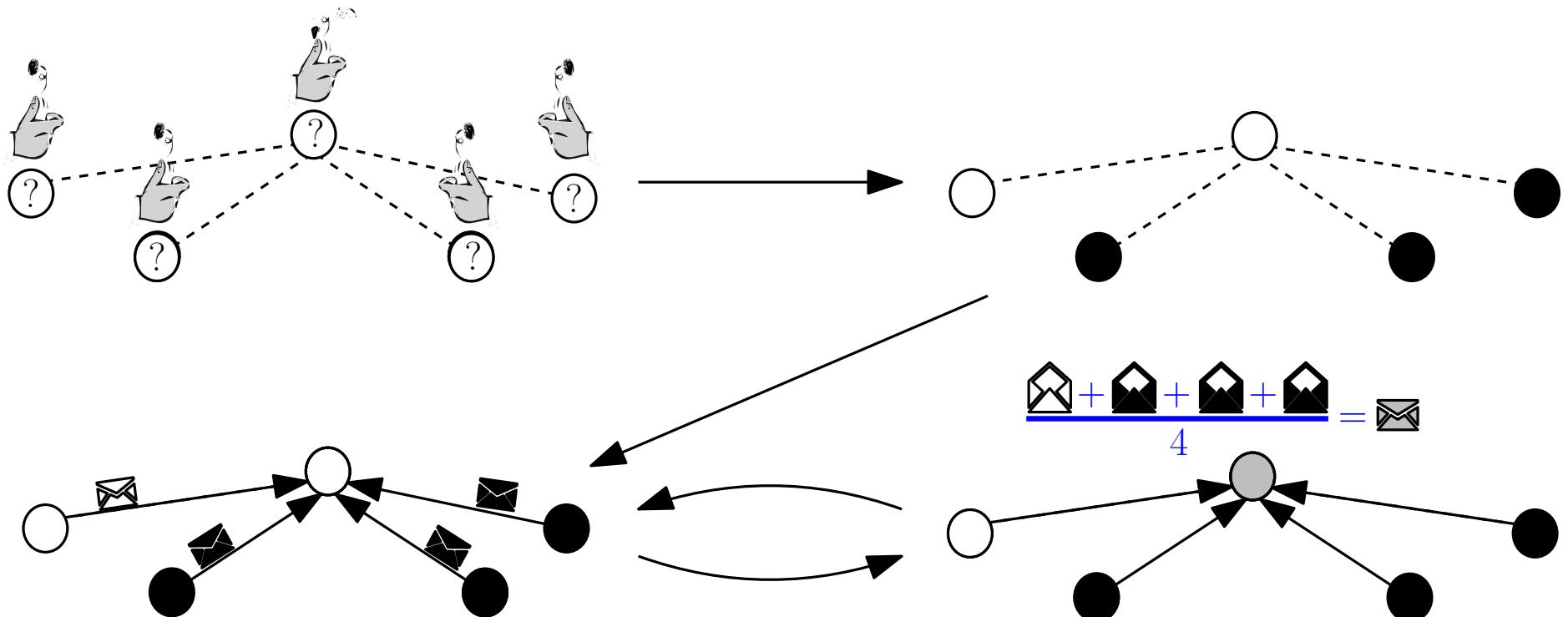
after $\mathcal{O}(\frac{\log n}{\log \lambda_2/\lambda_3})$ steps, with $\mathcal{O}(\frac{p+q}{p-q})$ errors

- Improve state of the art in efficient distributed clustering
- Simulations show good performance in practice

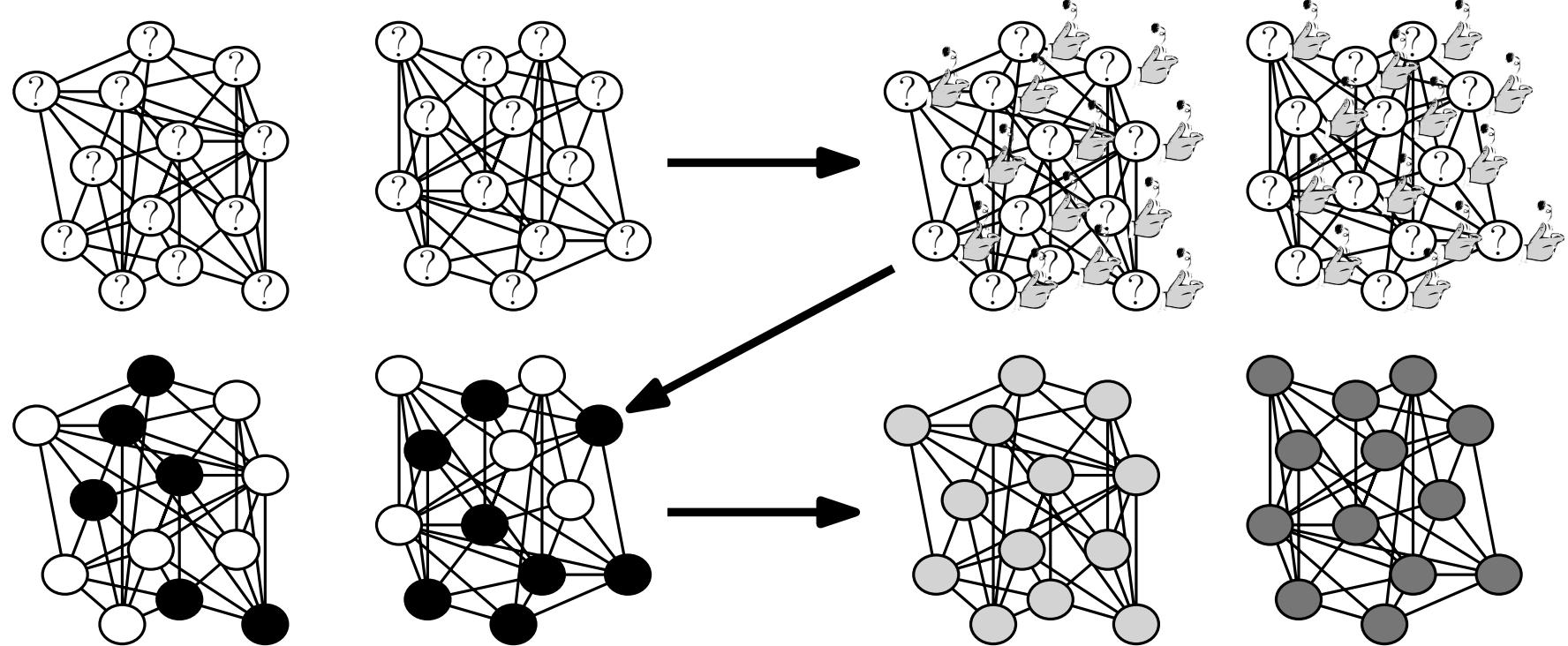
Averaging Dynamics [SODA'17]

All nodes at the same time:

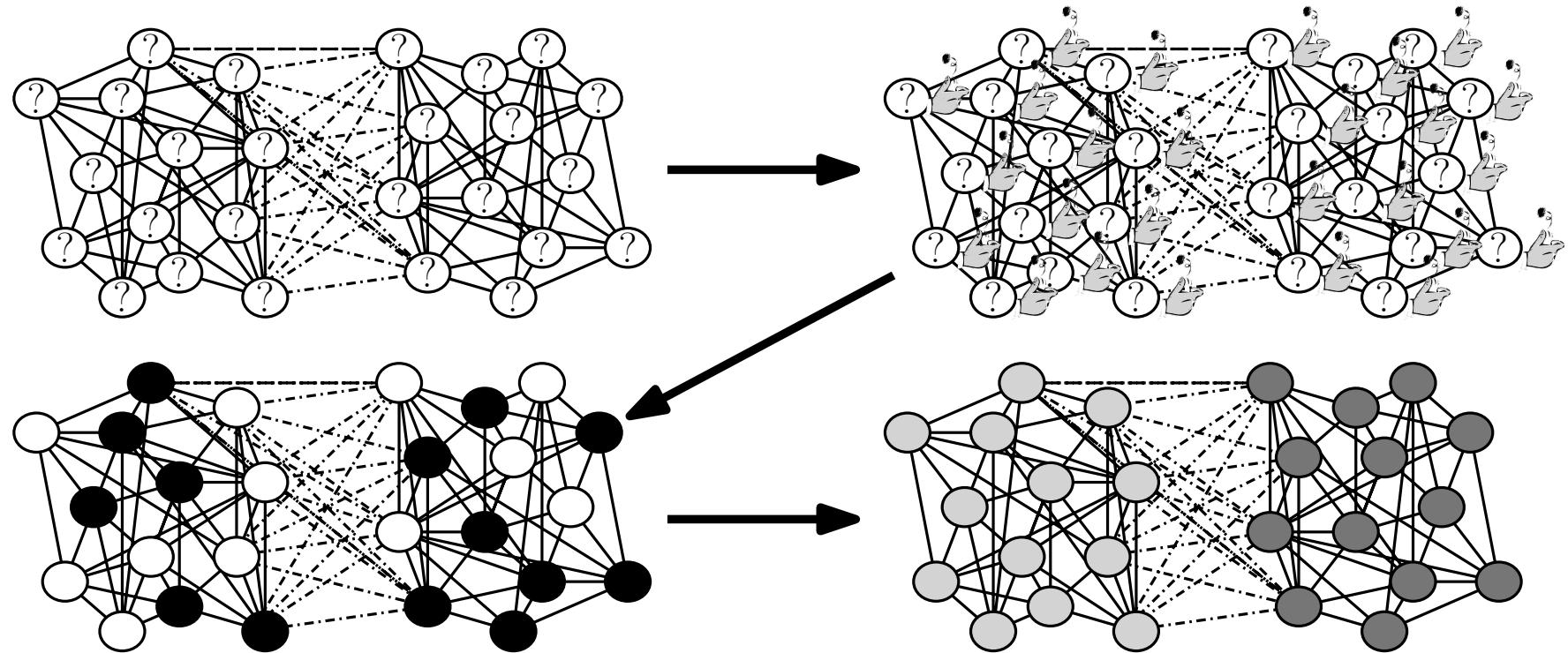
- At $t = 0$, randomly pick value $x^{(t)} \in \{+1, -1\}$
- Then, at each round
set value $x^{(t)}$ to average of neighbors



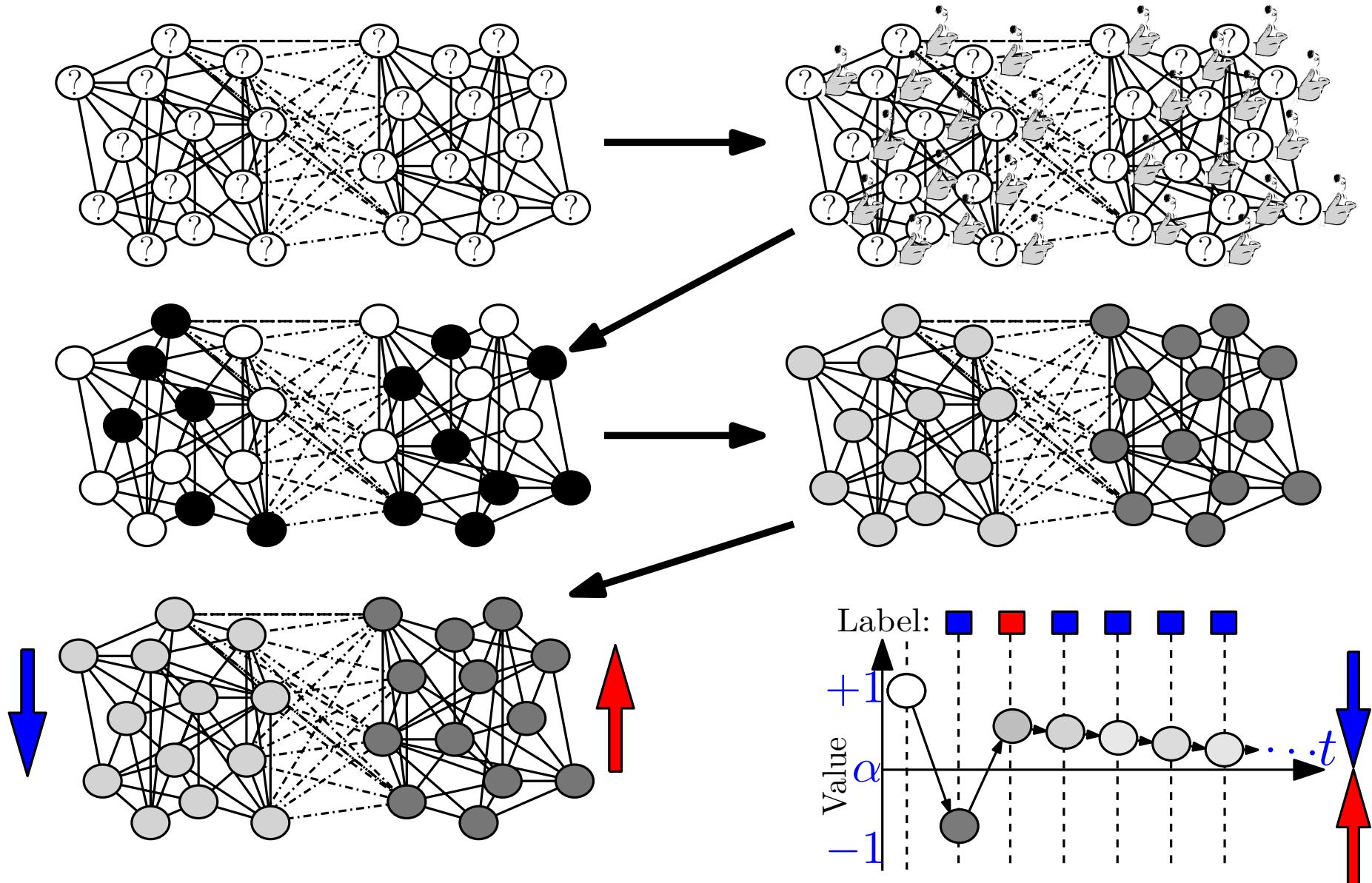
Why it Works: Intuition



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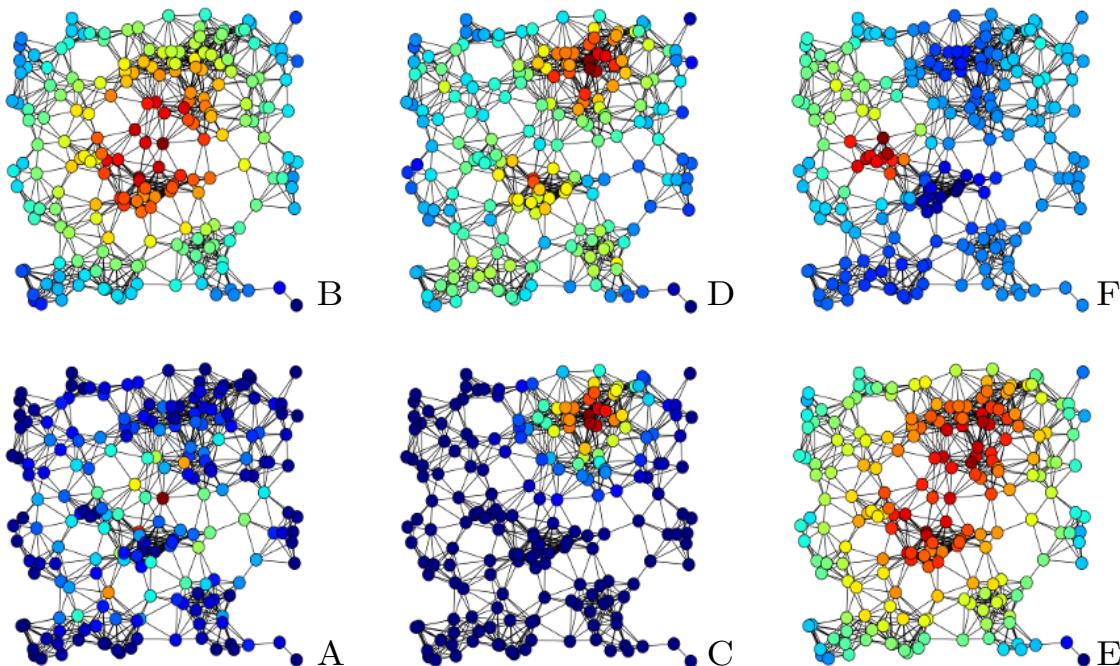


Why it Works: Intuition



- Set label to **blue** if $x^{(t)} < x^{(t-1)}$, **red** otherwise

Theory-Driven Algorithm Engineering



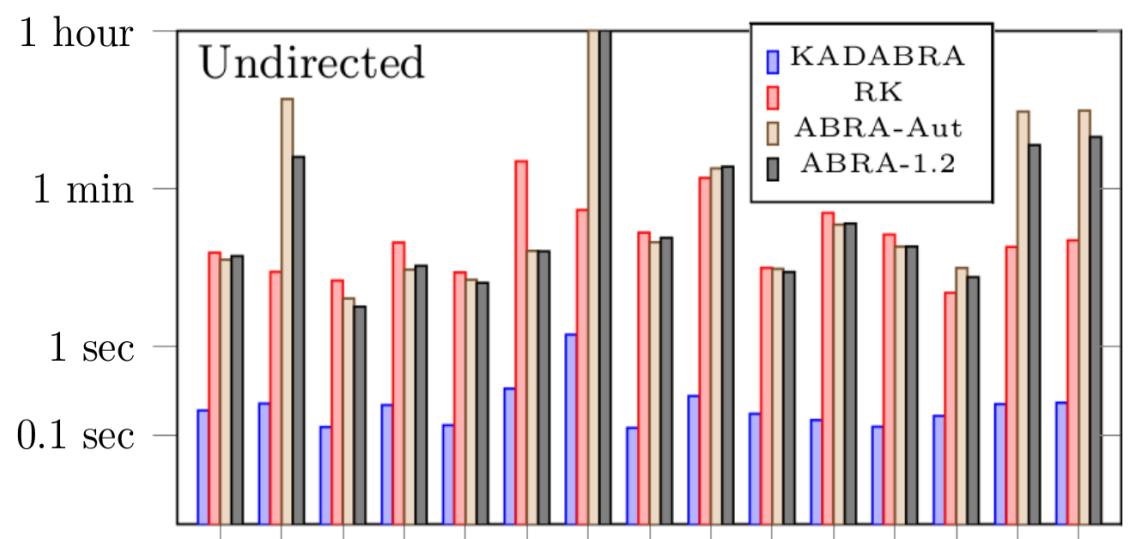
Examples of A) Betweenness centrality, B) Closeness centrality,
C) Eigenvector centrality, D) Degree centrality, E) Harmonic
Centrality and F) Katz centrality of the same graph.

Previous state-of-art:
ABRA [KDD'16].

We *proved* new results on
- Bidirectional Balanced BFS and
- Adaptive Sampling,
and developed **KADABRA**:

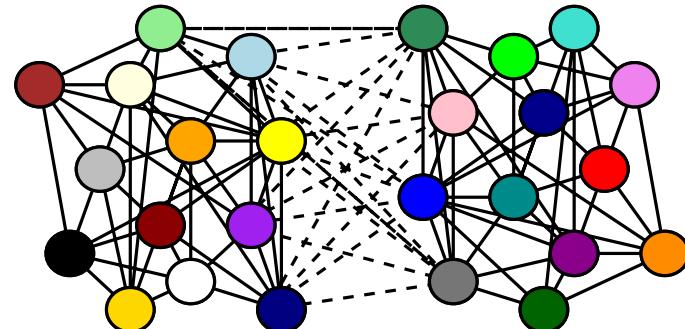
Betweenness centrality of u :
Probability to transit
through u when
- sample nodes s, t and
- sample $s-t$ -shortest path.

!!! Betweenness is fundamental
but (assuming SETH), hard
to compute: must use
randomized algorithms



The Future with COATI

- Computing in **Dynamic Networks**
 - **Label-Propagation-Algorithm**
heuristics made rigorous
 - Evolution of dynamic network properties
 - Extraction of metric properties of social networks using simple statistics
(D. Coudert, S. Pérennes, F. Giroire, N. Nisse, K. Avrachenkov (NEO))



- From **theoretical neuroscience** to neuromorphic machine learning
 - **Simons Institute, Brain Program:**
Reverse-engineering neural code
(R. Deriche (ATHENA), A. Richard (I3S))
 - New *neuromorphic* algorithms



Merci pour votre attention

Conference (16)

- *16 Cruciani[†], E.; N., E.; Nusser, A.; Scornavacca[†], G. **AAMAS'18**
- *15 Becchetti L., Bonifaci V., N. E. **AAMAS'18** [†] = supervised interns
- *14 Boczkowski, L.; Korman, A.; N. E. **ITCS'18**
- *13 Becchetti, L.; Clementi, A.; N., E.; Pasquale, F.; Trevisan, L. **SODA'17**
- *12 Boczkowski, L.; Korman, A.; N., E. **SODA'17**
- *11 Berenbrink, P.; Clementi, A.; Elsässer, R.; Kling, P.; Mallmann-Trenn, F.; N., E. **PODC'17**.
- *10 Becchetti, L.; Clementi, A.; N., E.; Pasquale, F.; Trevisan, L.. **SODA'16**
- 9 Gualà, L.; Leucci, S.; N. E.; Tauraso, R. **FUN'16**
- 8 Borassi, M.; N. E. **ESA'16 (Best Student Paper Award)**
- *7 Kaaser, D.; Mallmann-Trenn, F.; N., E. **MFCS'16**
- *6 Fraigniaud, P.; N., E. **PODC'16**
- *5 Becchetti, L.; Clementi, A.; N., E.; Pasquale, F.; Silvestri, R. **SODA'15 (Best 2015 PhD Paper in CS at Sapienza Award)**
- 4 Becchetti, L.; Clementi, A.; N. E.; Pasquale, F.; Posta, G. **SPAA'15**
- 3 Gualà, L.; Leucci, S.; N. E. Bejeweled, **CIG'14**
- *2 Becchetti, L.; Clementi, A.; N., E.; Pasquale, F.; Silvestri, R.; Trevisan, L. **SPAA'14**
- *1 Clementi, A.; Di Ianni, M.; Gambosi, G.; N. E.; Silvestri, R. **SIROCCO'13**

Journal (6)

- *6 Boczkowski L., Feinerman O., Korman A., N. E. Accepted to **PLOS Computational Biology**
 - *5 Fraigniaud P., N. E. **Distributed Computing**
 - *4 Boczkowski L., Korman A., N. E. **Distributed Computing 2018**
 - 3 Becchetti, L.; Clementi, A.; N. E.; Pasquale, F.; Posta, G. **Distributed Computing 2017**
 - *2 Becchetti, L.; Clementi, A.; N. E.; Pasquale, F.; Silvestri, R.; Trevisan, L. **Distributed Computing 2017**
 - 1 Clementi, A.; Di Ianni, M.; Gambosi, G.; N. E.; Silvestri, R. **Theor. Comp. Scie. 2015 (Special Issue)**
- Submitted (2 conference, 1 journal)**
- *3 Becchetti, L.; Clementi, A.; Manurangsi, P.; N. E.; Pasquale, F.; Raghavendra, P.; Trevisan, L. **Sub. ESA**
 - *2 Clementi, A.; Gualà, L.; Pasquale, F.; Scornavacca, G.; N. E.; Ghaffari, M. **Submitted to MFCS**
 - *1 Borassi, M.; N. E.. **Submitted to J. of Experimental Algorithms (Special Issue)**

Red text= Important/A* conference
* item = Related to Dynamics
Blue box = New

authors in alphabetical order