### **Network Dynamics: Introduction**

### Introduction to Network Science

Instructor: Michele Starnini — <u>https://github.com/chatox/networks-science-course</u>



Universitat **Pompeu Fabra** *Barcelona* 





- Introduction to network dynamics
- Spreading phenomena

### Content

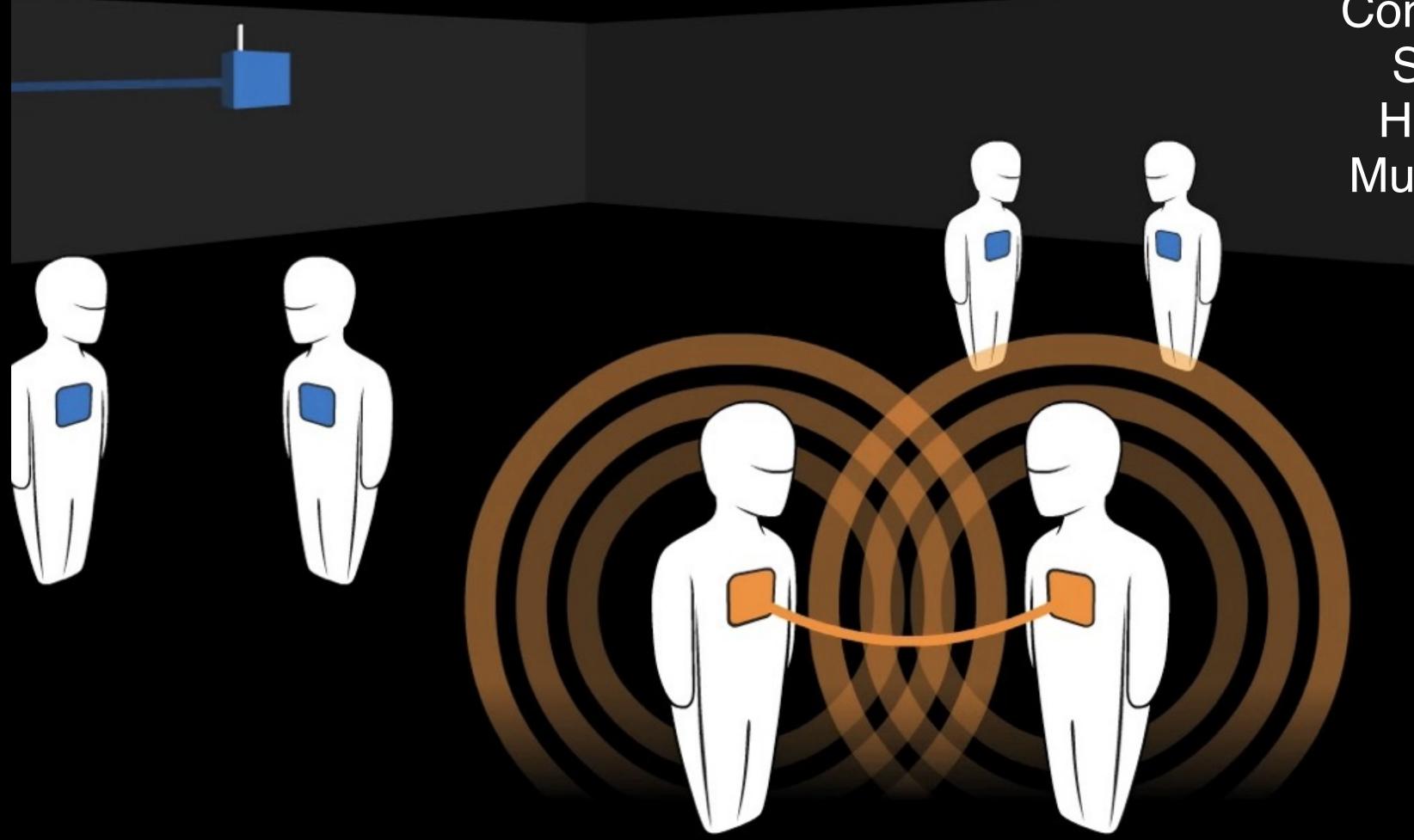
## Network dynamics

- Dynamics OF networks: time-evolving (temporal) networks
- Dynamics ON networks: stochastic processes on static networks
- Dynamics ON & OF networks: stochastic processes on temporal networks

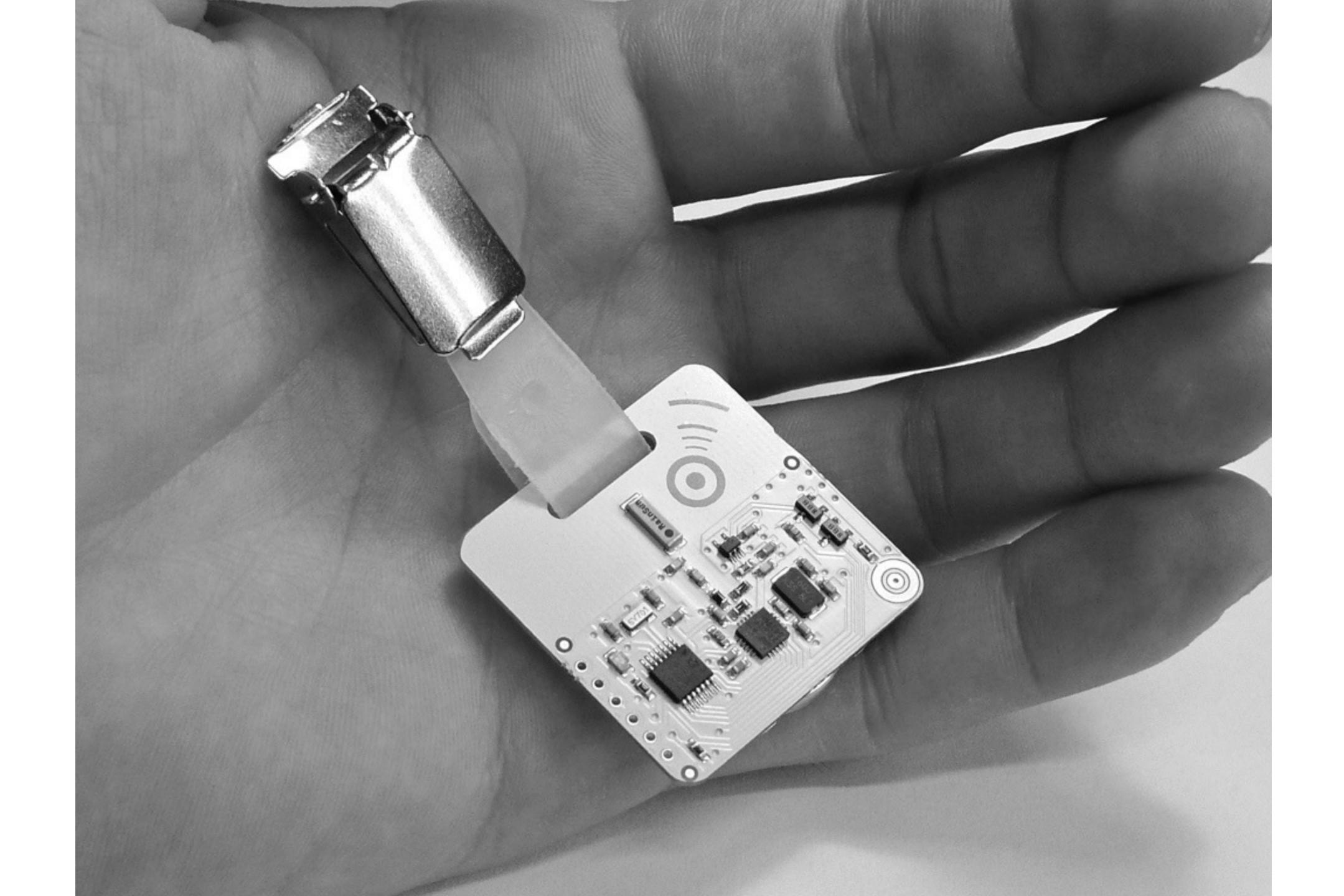
# Temporal networks

- Temporal networks: links (and nodes) appear/disappear in time
- Online social networks: friendship created/removed, new users join/leave
- Contact networks: two persons interact for a while, then separate
- Communication network: each link (email) has instantaneous duration
- Transportation network: bus/train at a certain time
- Financial networks: financial transactions at a certain time

### Face-to-face interaction networks



Conferences Schools Hospitals Museums...

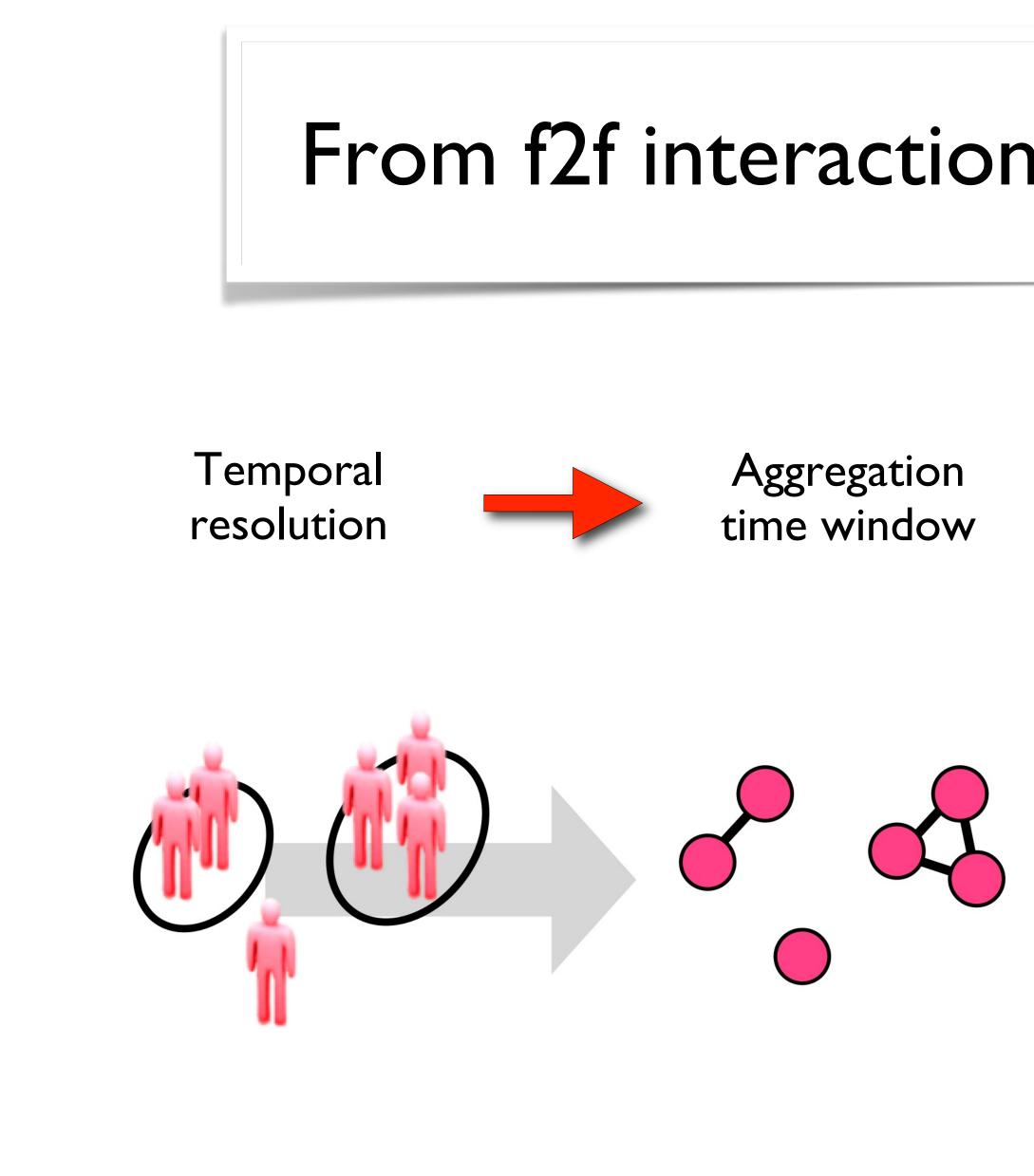


### Temporal networks

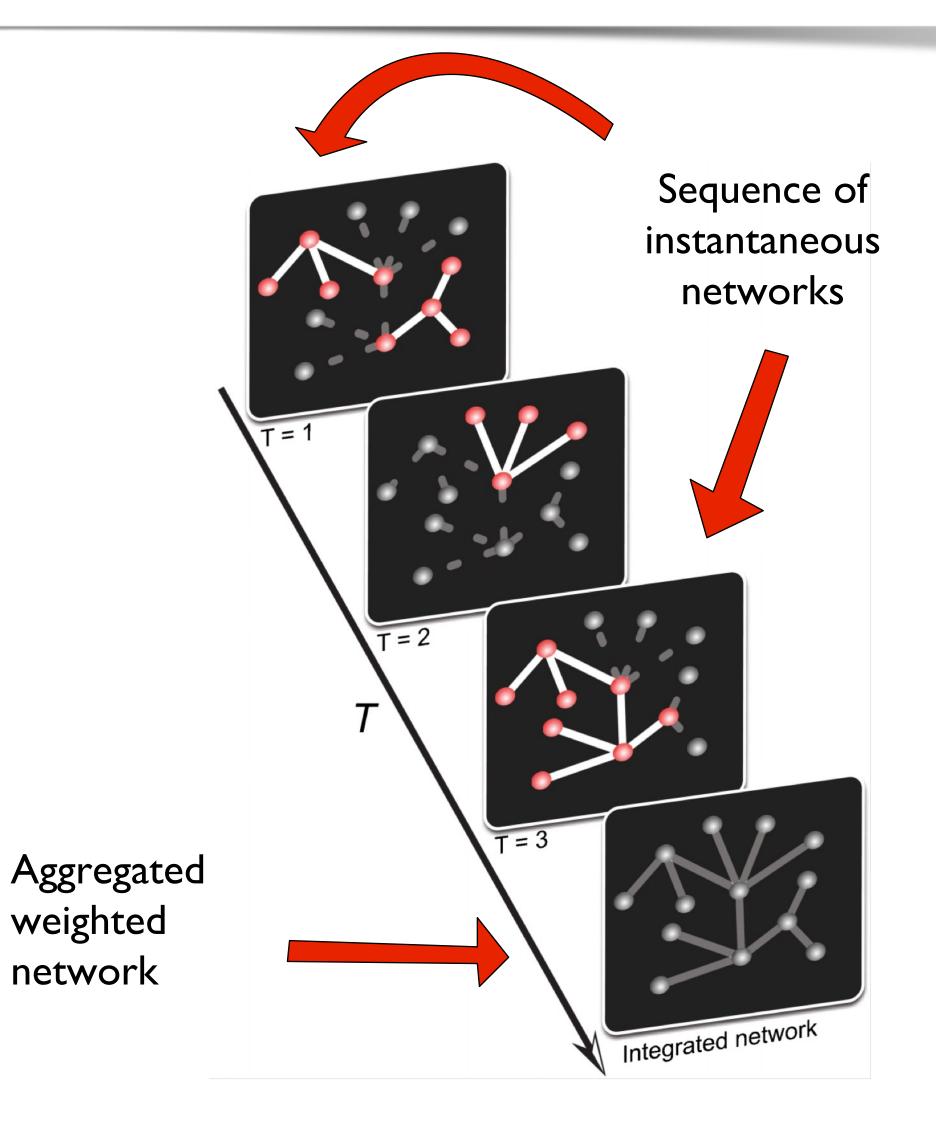
### 1:00 - 2:30 PM lunch, coffee and start of 3<sup>rd</sup> session

#### SocioPatterns

https://www.youtube.com/watch?v=ObtVS547lu4



#### From f2f interactions to temporal networks



### Dynamics on networks: Stochastic processes

- Information diffusion
- Epidemic spreading
- Opinion dynamics
- Sychronization

### Stochastic processes on networks

- Each node i has a certain state xi
- Such a state changes in time according to some rules,  $x_i(t)$
- Random walk: x<sub>i</sub>=1 if random walker is on node i, 0 otherwise
- Epidemics: x<sub>i</sub>=1 if node i is infected, 0 otherwise
- Info diffusion:  $x_i=1$  if node i knows a certain piece of info, 0 otherwise
- Opinion dynamics:  $x_i=1$  if node holds opinion A (left), 0 otherwise (right)

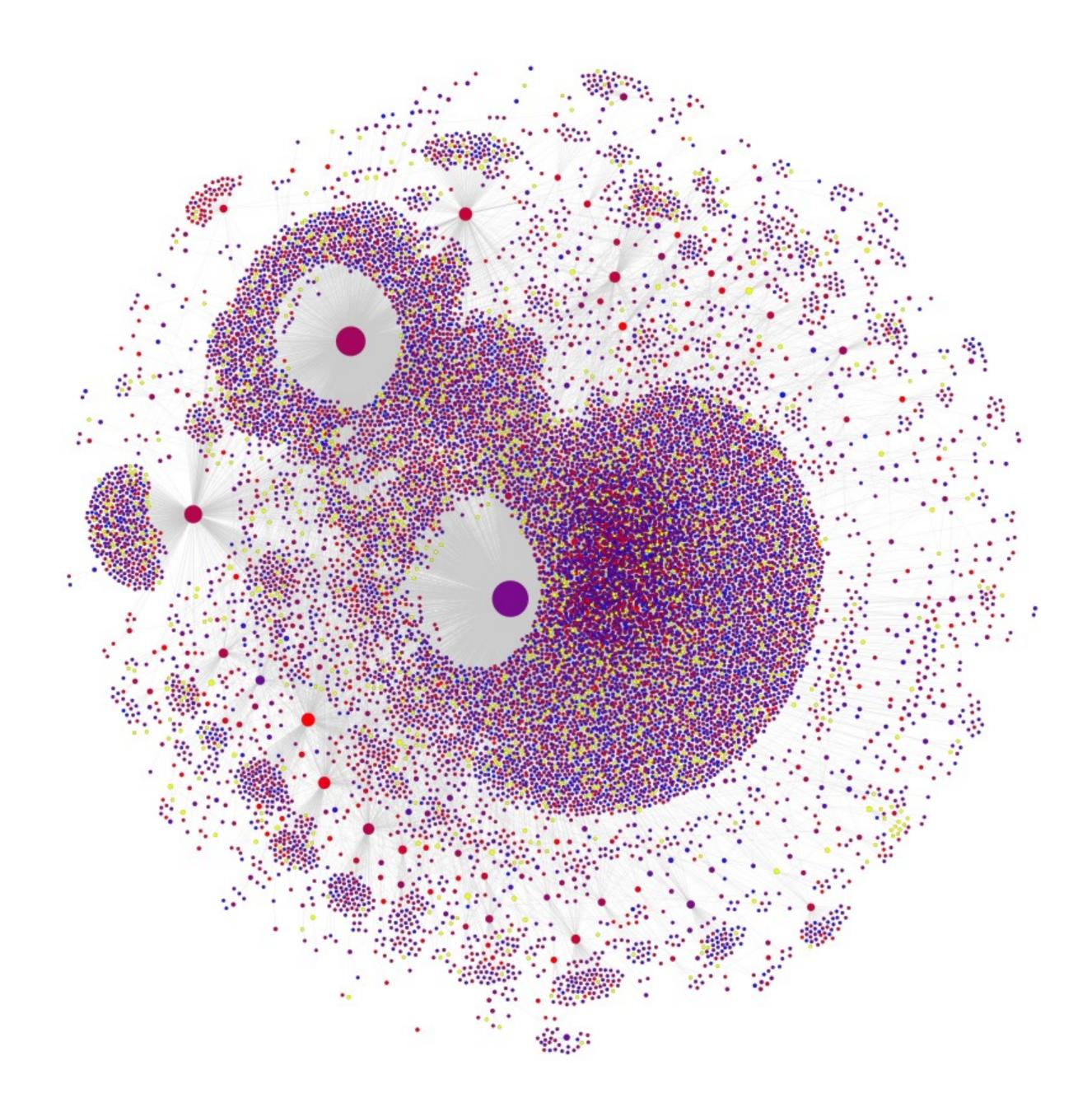
### Stochastic processes on networks

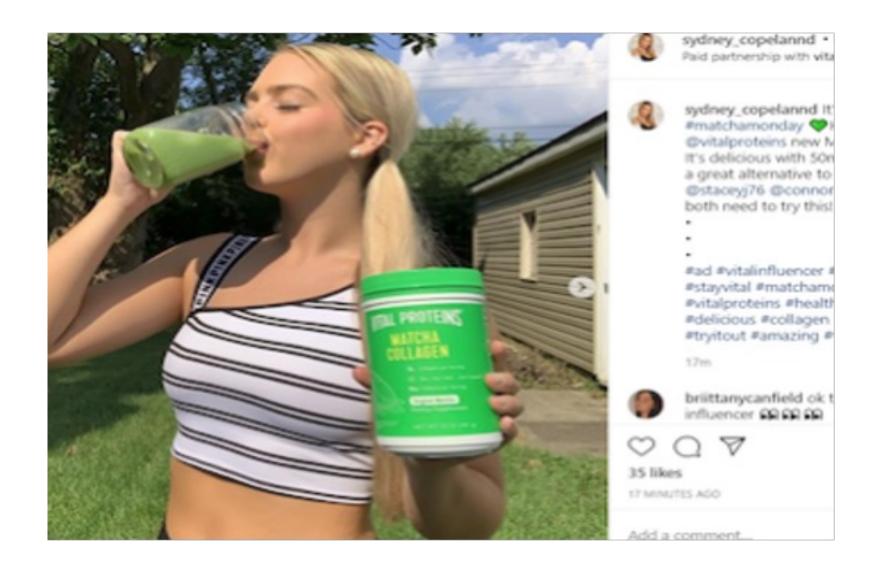
- Each stochastic process is defined by the update rules
- How does state of node i changes in time,  $x_i(t+1) = F(x_i(t), x_j(t), x_k(t), ...)$ ?
- On networks, the state of node i only depends on the previous state of its neighbors:  $x_i(t+1) = F(x_i(t), x_{j1}(t), \dots, x_{jk}(t), | j1, \dots, jk$  neighbors of node i)
- Random walk:  $x_i(t+1) = 1$  if the RW was at some neighbour at time t
- Epidemics:  $x_i(t+1) = 1$  (infected) if some neighbor was infected at time t
- Opinions:  $x_i(t+1) = 1$  (opinion A) if the majority of neighbors hold opinion A

## Spreading phenomena: fake news

A fake news article spreading via Twitter during 2016 US presidential campaign

Red nodes are likely bots







gossmakeupartist 📀 • Follow

gossmakeupartist Who has tried the @sundayriley luna night oil? I try a LOT of skincare but this is one that I keep coming back to. It's a retinol in an oil form so is nourishing for the skin while doing renewal like a retinol - absolutely love this product!! Join the Waitlist – link in bio! @cultbeauty

#### #WayneGossXCultBeauty #ad

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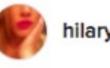
kelsey\_chronicbeauty @sundayriley Luna oil has been my holy grail night serum for 3 years now! 🙁

kal\_ho\_naa\_ho76 Also use this often. :) callmefifiii It's so good. It removes my small wrinkles after one night's sleep

clareflintmakeupyork Just starting using this, is is so lovely 💧

VQ⊥	
6,217 likes	
Log in to like or comment.	





#### 120k likes

hilaryduff Summertime sippin' with some delicious @sparklingice. Show me how you #FlavorUp #ad bit.ly/1VkhEfC

view all 596 comments

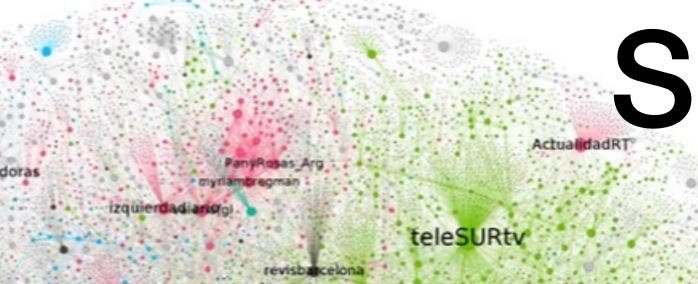
daniel\_\_ferreira\_\_ @kealeyjo exploringwithaj isssabae Omg I love those 😎 ehabseirafi erikrichison "Hey Jesse, babe." @chambreezey abbeyruby Lime is the best mike\_nelly Pretty cool natalie\_evenson333 @michellefafard @katb63 hippiielovee @ratchetnasty\_ tombender191 @hilaryduff Hilary, it is my dream to be shrunk like in honey I shrunk the kids and fall into your cereal how!

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Winston Dunhill

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# Spreading phenomena: Viral propagation

Spread of the #NiUnaMenos hashtag: a movement against gender-based violence and femicide started in Argentina in 2015

Colors based on communities detected through modularization optimization



# Spreading phenomena: Non-trivial examples

- Back pain: spread from West to East in Germany after fall of Berlin Wall
- Suicide: well known to spread throughout communities on occasion
- Sexual "scripts": expected sequences of behaviors during intimate situations
- Politics: the denser your connections, the more intense your convictions
- A wide array of phenomena spread through networks, not only viruses and information



# Stochastic processes on temporal networks

- Both state of the nodes & presence/absence of links change in time
- The evolution of the process depends on the network dynamics

	Network	Process
Epidemic	Face-to-face contacts	Disease transmission
Information	Online social networks	News diffusion
Mobility	Transportation networks	Passengers flows

# Stochastic processes on temporal networks

- mobility (days)

• The time scales of the network & process can be similar or very different

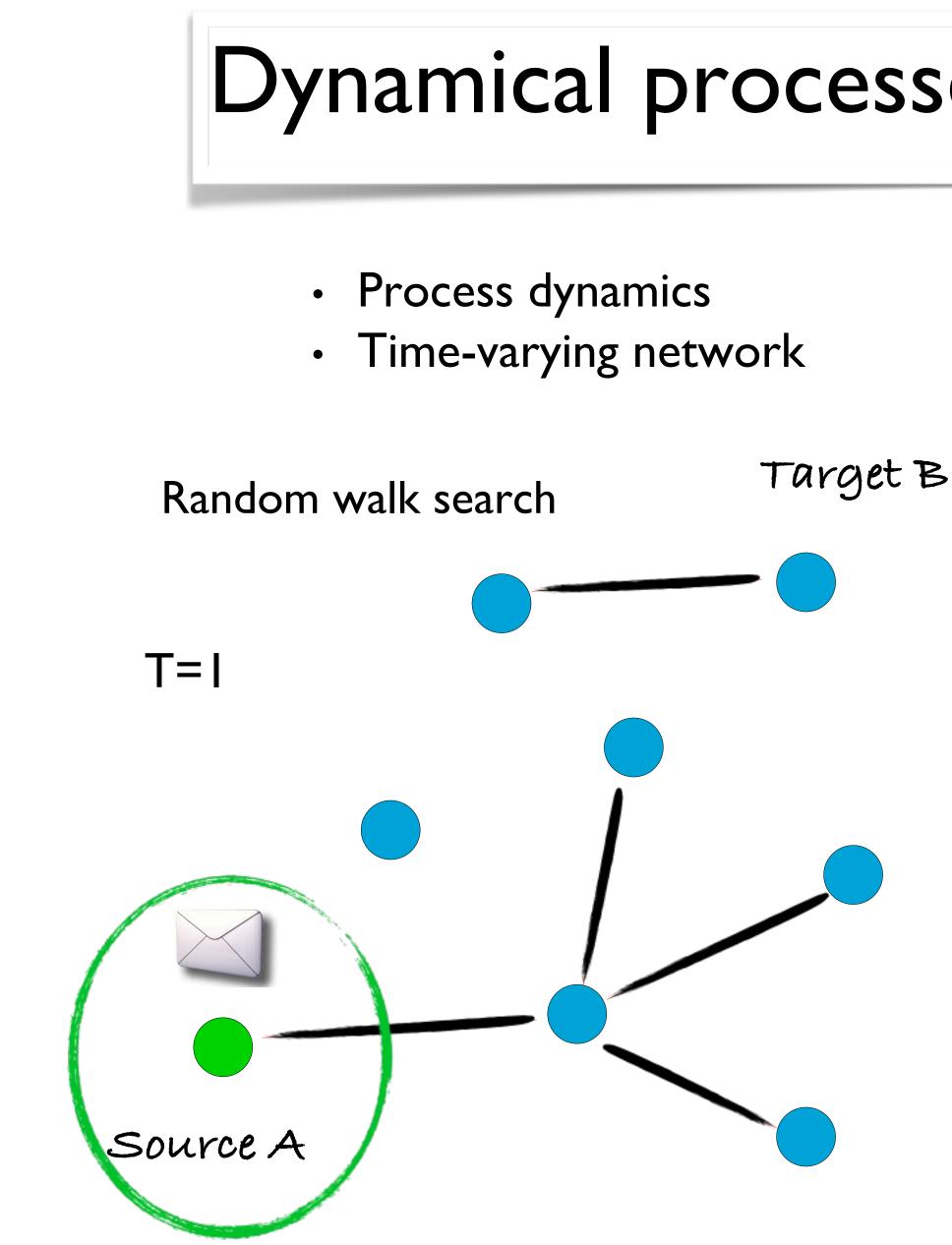
 Viral propagation on social media: viral propagation much faster (hours) than new connections on online social networks (weeks/months)

Epidemic spreading: epidemic transmission (days) comparable with

#### Stochastic processes on temporal networks

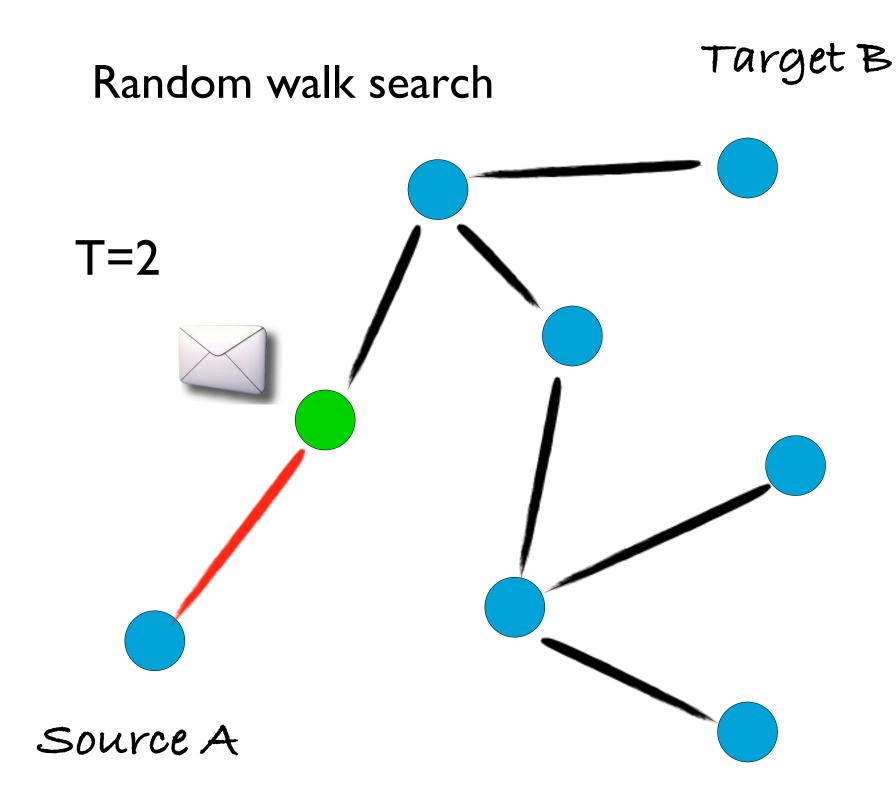
- Process dynamics
- Time-varying network

Time scales coupling



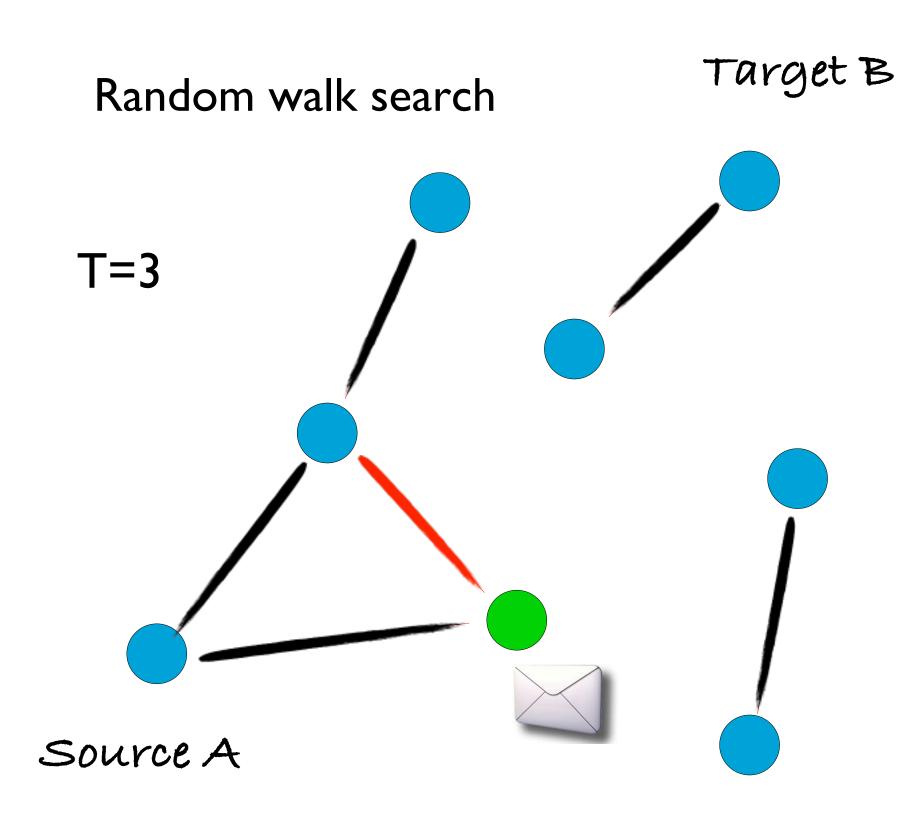
Time scales coupling

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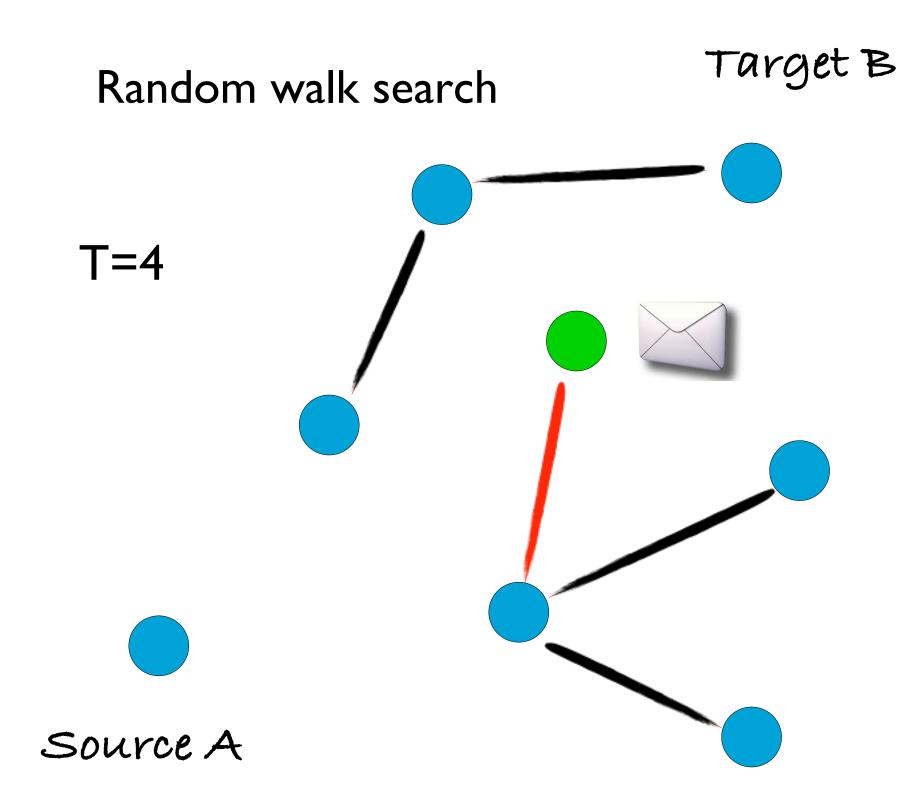
Time scales coupling

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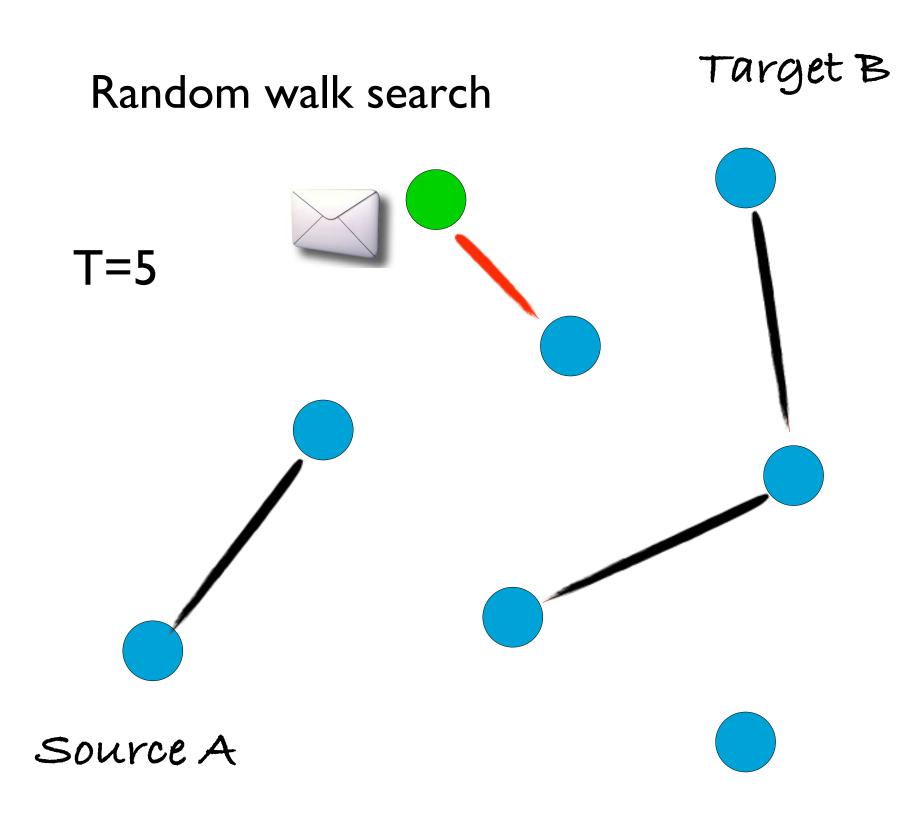
Time scales coupling

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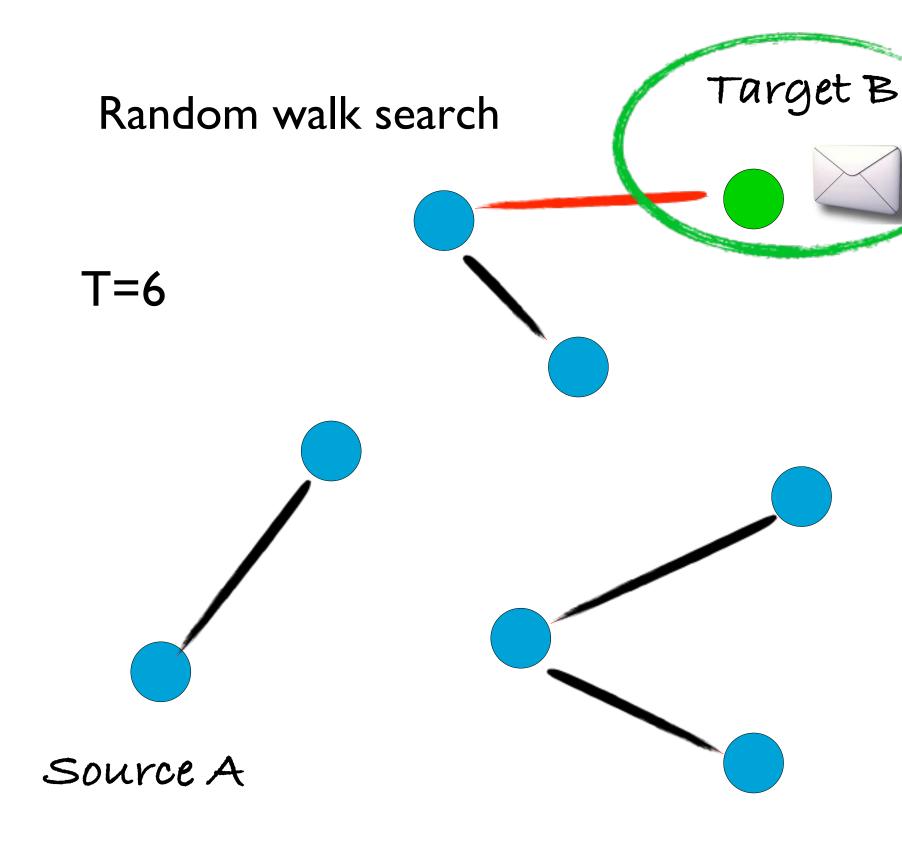
Time scales coupling

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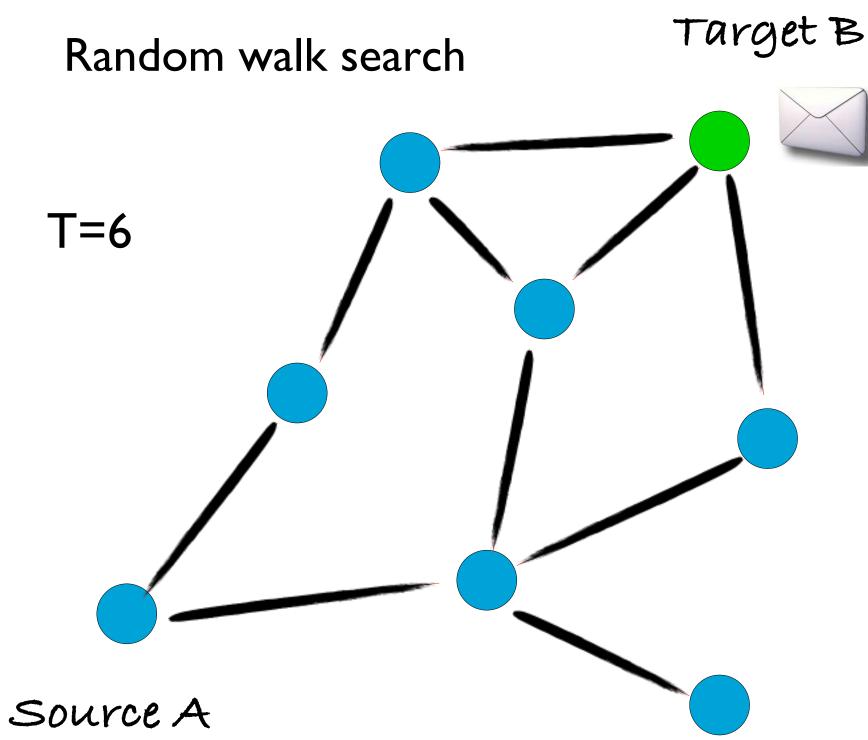
Time scales coupling

- Process dynamics
- Time-varying network



Time scales coupling

- Process dynamics
- Time-varying network



Time scales coupling



On a static network, more links are available: Very different process

- Difference between dynamics ON and OF networks
- Definition of stochastic process on networks
- Examples of spreading phenomena, temporal networks
- How a stochastic process unfolds on temporal networks

### Things to remember: