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The Web as an Adaptive Network: Coevolution of Web Behaviour and Web Structure

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Adaptive Networks on the Web

- Adaptive Web Networks is a growing multi-disciplinary research area at the intersection of Web & Network Science & Complex Systems.
- Combines the study of dynamics ‘on’ (**behavior**) and ‘of’ (**structure**) complex networks
- Structure (**topology**) e.g. (small world, scale free, community structure, dyads, triads)
- Behaviour (**state**) e.g. (communicating, blogging, sharing links, pictures, changing opinion)

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Web as a Complex Adaptive System

The Web is not just another complex network, it is a self-organising complex adaptive system (CAS). It co-evolves with Web user behaviour and exhibits emergent complexity.

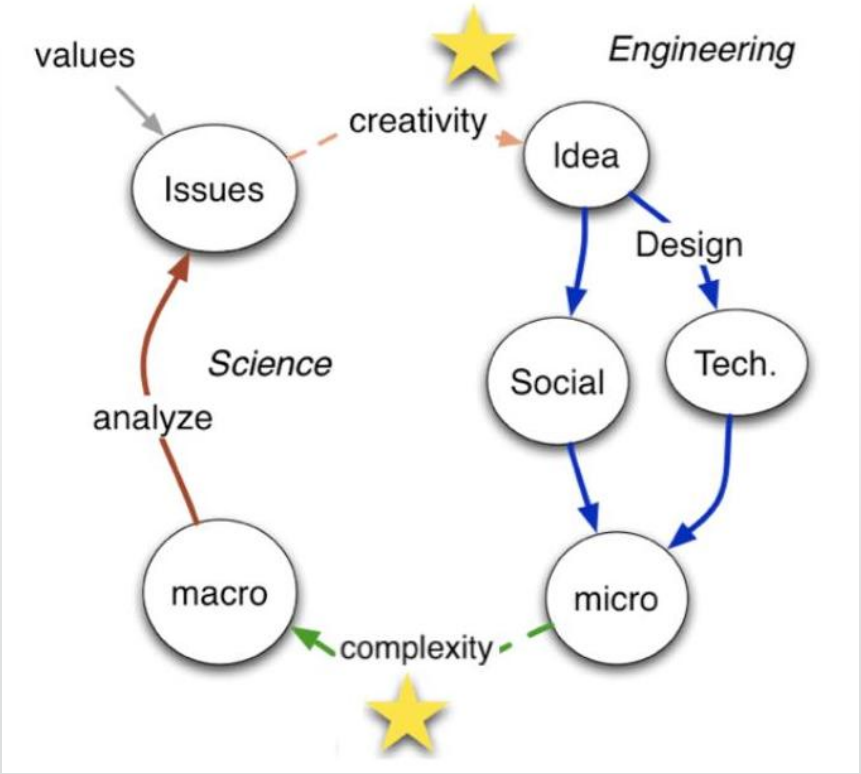

Fig. “2 Magics of Web Science.” Berners-Lee’s diagram of how some complexity on the Web can emerge.

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Research Questions

- Question 1: How does topology affect behaviour and how does behaviour affect topology, in different Web networks?

- Question 2: What are the implications of adaptive mechanisms for Web networks?

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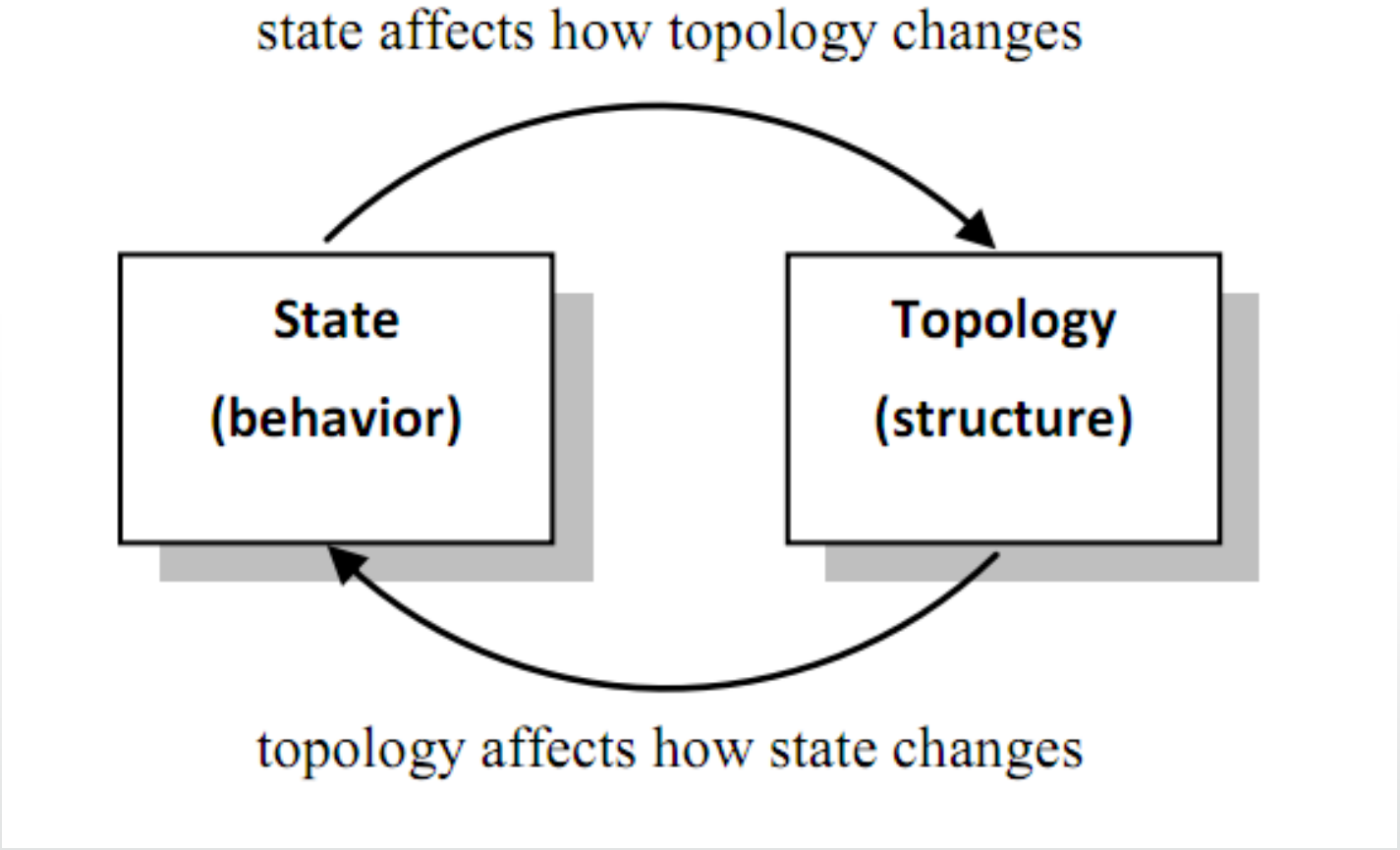
State-topology Coevolution Cycle



Adapted from Gross & Sayama, 2009

Gross, T. and Sayama, H. 2009. Adaptive Networks. Springer-Verlag: Berlin

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Behaviour Affecting Structure

Dynamical linking (DL), or active linking, describes how actors re-wire links to suit their own individual preferences.

- DL is a key feature of adaptive networks
- Unlike static networks, adaptive networks with DL have been shown to support emergent phenomena at the macro-level (network level).
- Several theories exist for DL in different contexts, and how it can be applied e.g. (Hebbian Learning, Homophily and social segregation).

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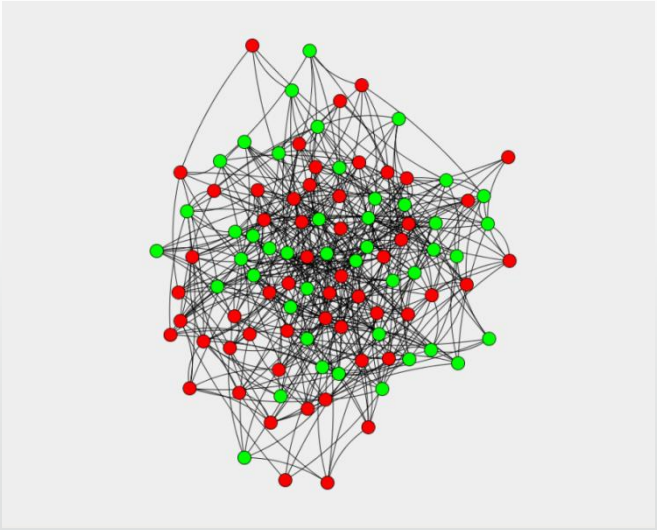
Dynamical Linking at Different Timescales

A separation of timescales between DL & structural process effects nodes state, can result in very different state-topology co-evolution. e.g. Opinion Dynamics Model (ZuErbach-Shoenberg & McCabe et. al 2011).

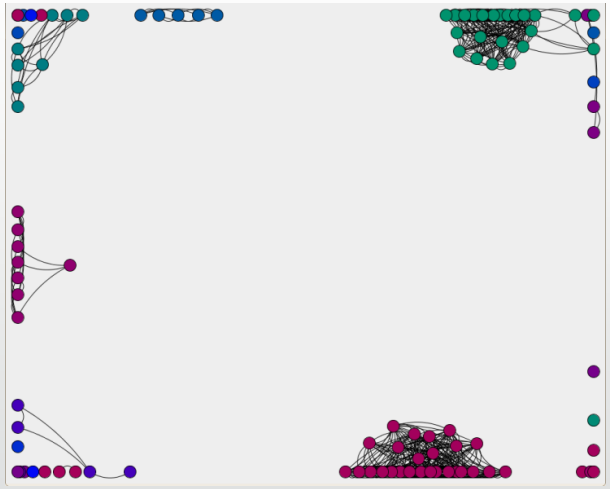
Initial Network



Moderate DL

Moderate topological effects

Community structure



zu Erbach-Schoenberg, E., C. McCabe, et al. (2011) On the interaction of adaptive timescales on networks. Proc. European Conference on Artificial Life, Paris, France.

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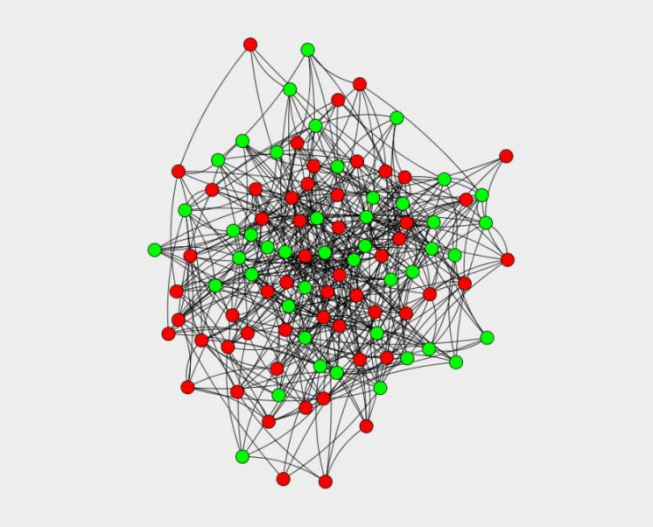
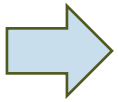
Dynamical Linking

Initial Network

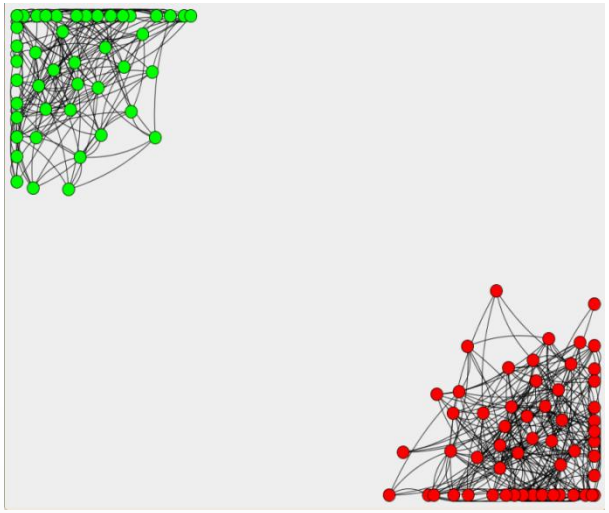


Fast DL



Slow topological effects

Assortative Mixing



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Dynamical Linking

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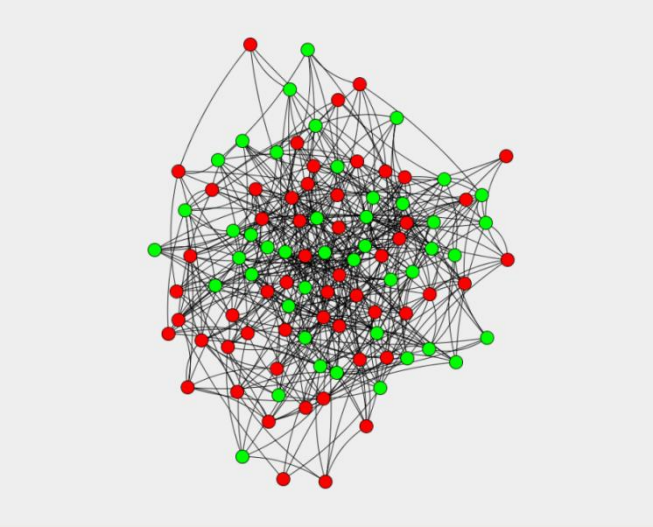

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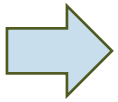

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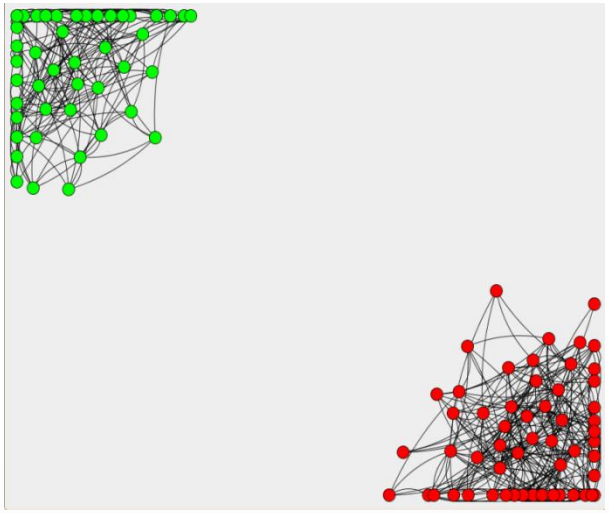

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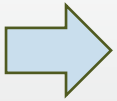
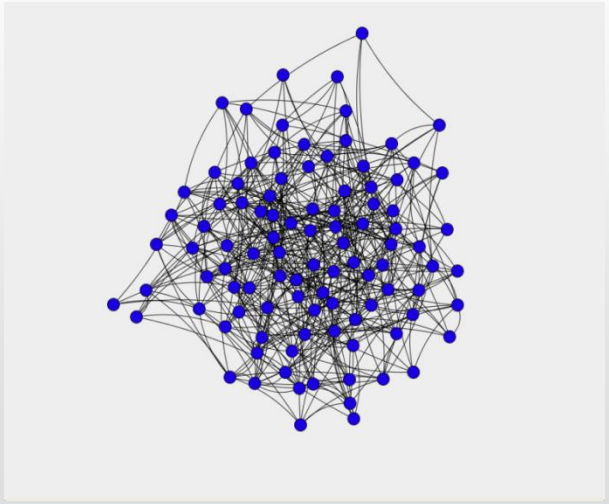


Fast topological effects

Consensus Formation



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Structure Affecting Behaviour

How does structure affect behaviour?

- For Web networks, structure can relate to how documents, objects and web users are linked together. (explicit hyperlinks, or implicit social links based on interactions)
  - Structure affects information dynamics: how easily items can be browsed; search engine results, and who connects directly to whom.
- Different topologies of Web networks (small world and random lattice), can impact collective user behaviour (e.g. Centola, 2010).

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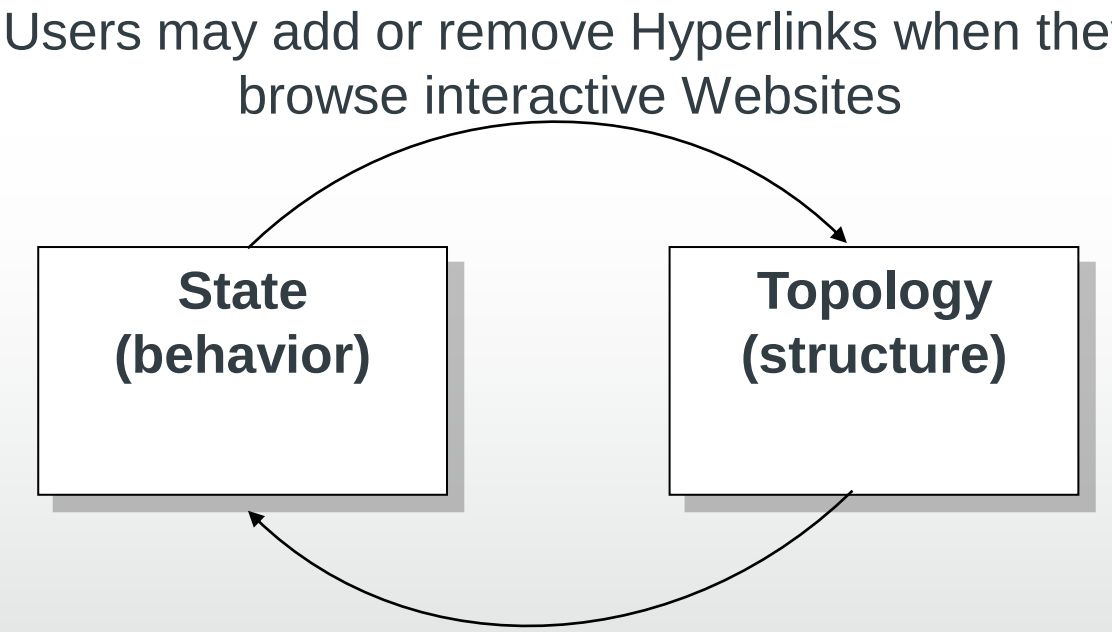
State-topology Coevolution of the Web

1. Information Networks, (e.g. **the Web Graph)**



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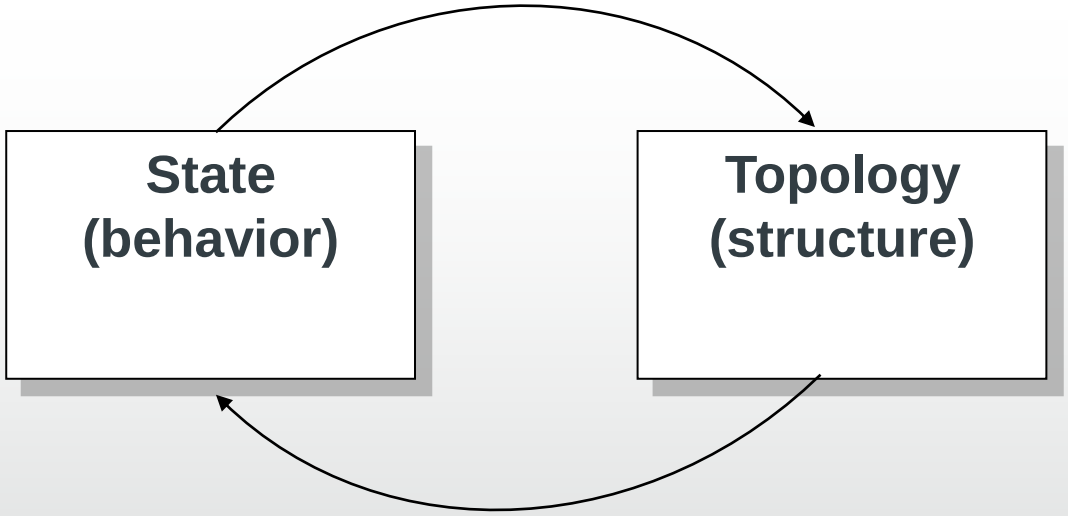
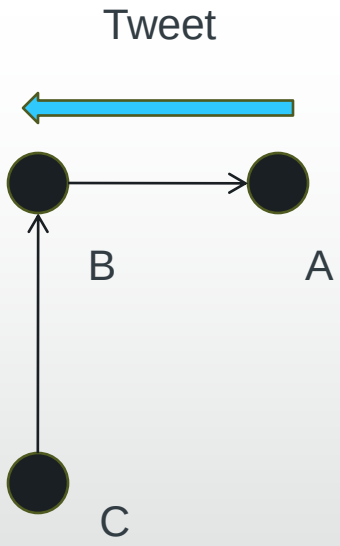
State-topology Coevolution of the Web

2. Micro-blogging Social Network (e.g.**Twitter**)

Users who receive retweeted messages may form direct links to source.



Twitter social network structure determines what messages are propagated directly



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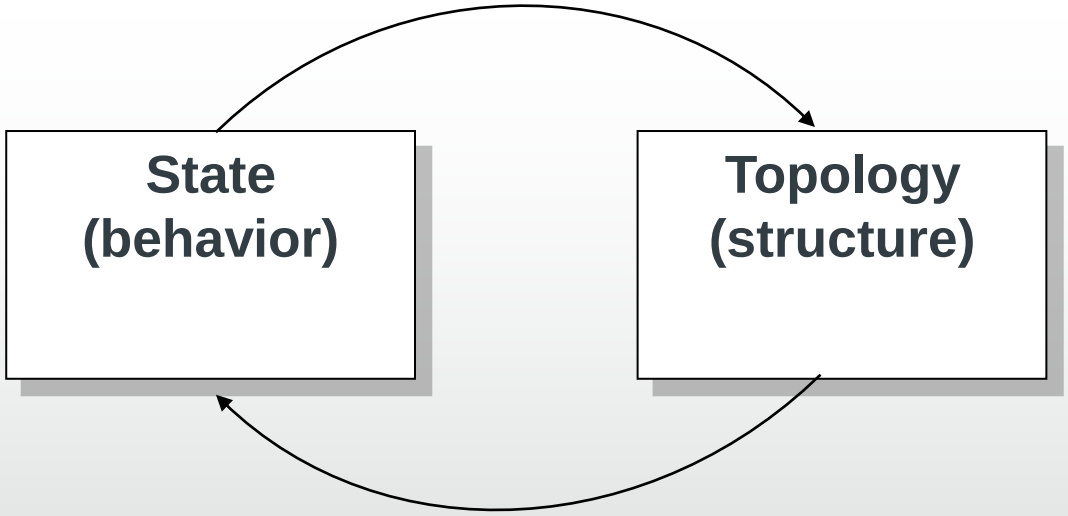

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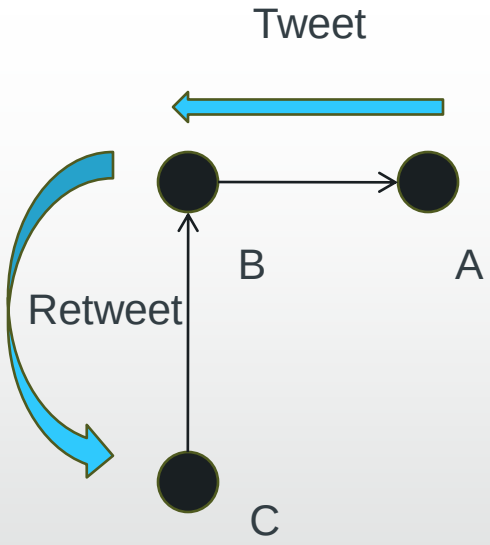

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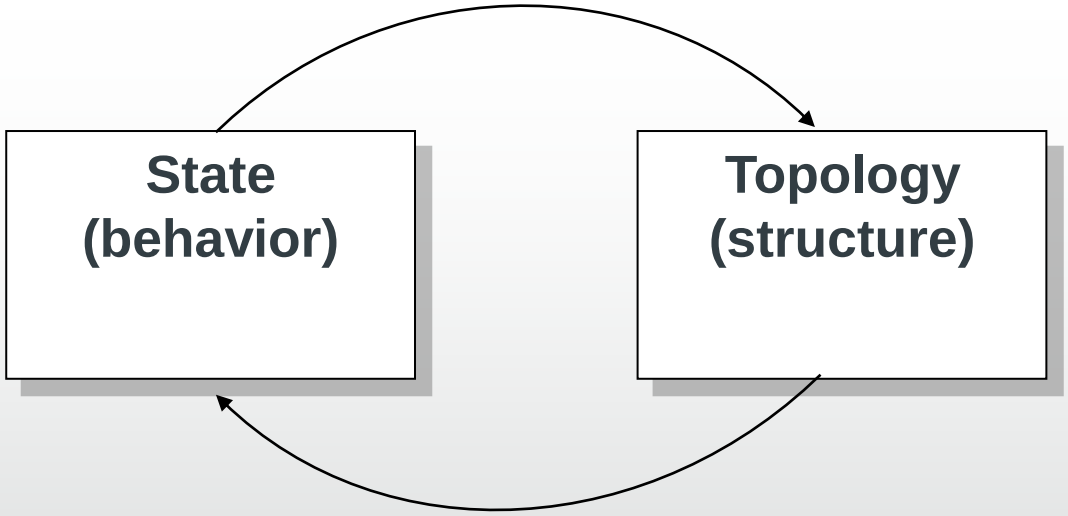

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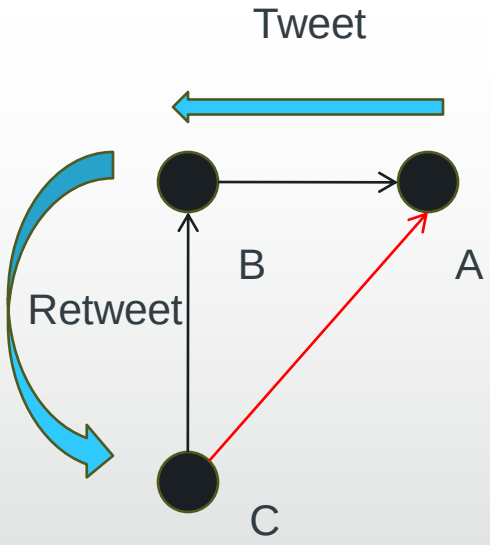

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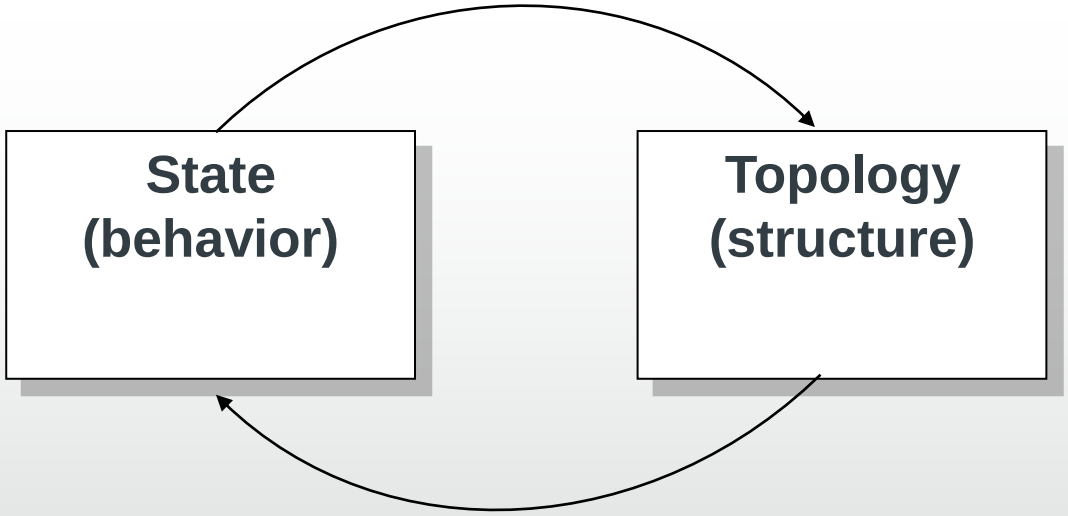

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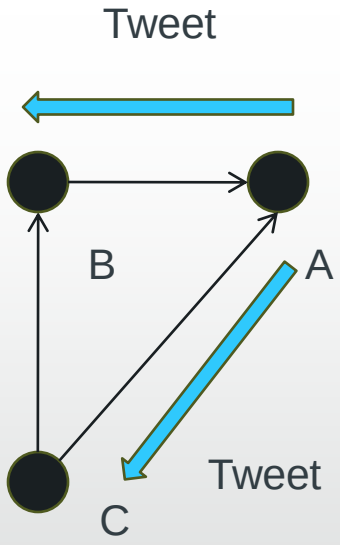

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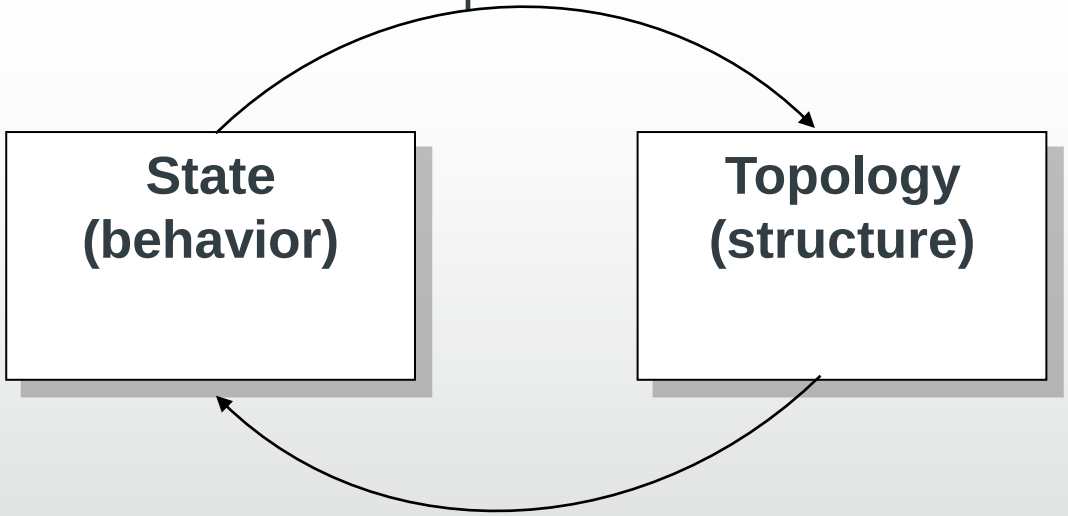
State-topology Coevolution of the Web

3. Collaborative filtering, **embedded user-user collaborative recommendations** e.g. Netflix, Amazon.

When a user buys an item, then it creates a link between a product and user.



Topology of links influences behavior by enabling recommendations to users to buy or sample other products

e.g. Amazon's 'Frequently Bought Together' collaborative recommendations

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Implications of Adaptive Web Networks

The hallmarks of adaptive networks (Blasius and Gross, 2009) have implications for adaptive networks in Web Science.

- Robust topological self-organization
- Spontaneous emergence of hierarchies and division of labour, e.g. (distributed optimization behaviour)
- Complex system-level dynamics, e.g.(self re-inforcing loops).

Blasius, B. and Gross, T. 2009 Dynamic and Topological Interplay in Adaptive Networks . Wiley-VCH Weinheim.

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Summary and Conclusions

- Adaptive network theory and methods offer a formal framework to study Web complexity (“magics of web science”)
- State affects the structure of Web networks, and reflexively the structure affects state on adaptive Web Networks.
- Coupled state-topology generates positive feedback loops
- Dynamic linking produces adaptive Web networks
- Process can happen at different timescales, and lead to different co-evolved state-topology.

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