towards congestion control based on emergent behaviour

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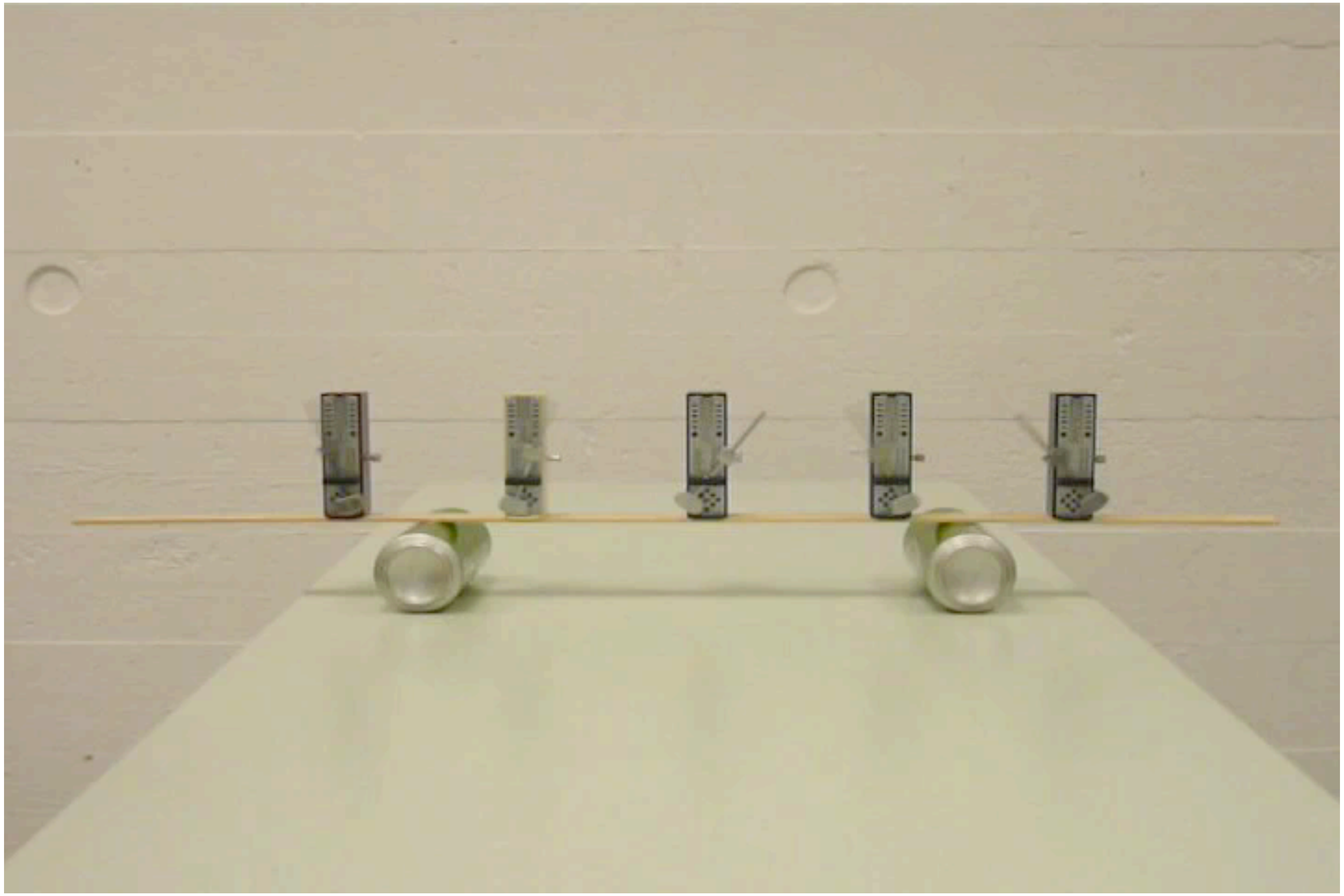
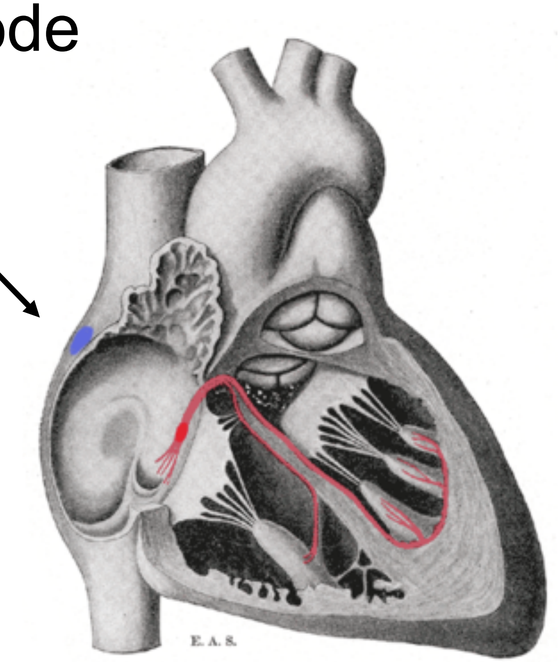
sync



the sinoatrial node (SA node)

- cells in the SA node spontaneously depolarise resulting in contraction
  - approx. 100 “bpm” (native rate)
  - native rate regulated towards 70 bpm for average adult in rest
  - cells in SA node **synchronise** in order to produce “steady” beat
- SA also called

  “primary pacemaker”



human heart

Peskin's model

- model:
  - cells of the SA node are identical oscillators
  - interaction between oscillators is pulse like
- study:
  - emergence of synchrony in populations of pulse-coupled oscillators
- conjecture (1):
  - "for arbitrary initial conditions, the system approaches a state in which all oscillators fire synchronously"

growth; state (voltage)

$$\frac{dx_i}{dt} = S_0 - \lambda x_i, \quad 0 \le x_i \le 1, \ i = 1, \ldots, N$$

dissipation

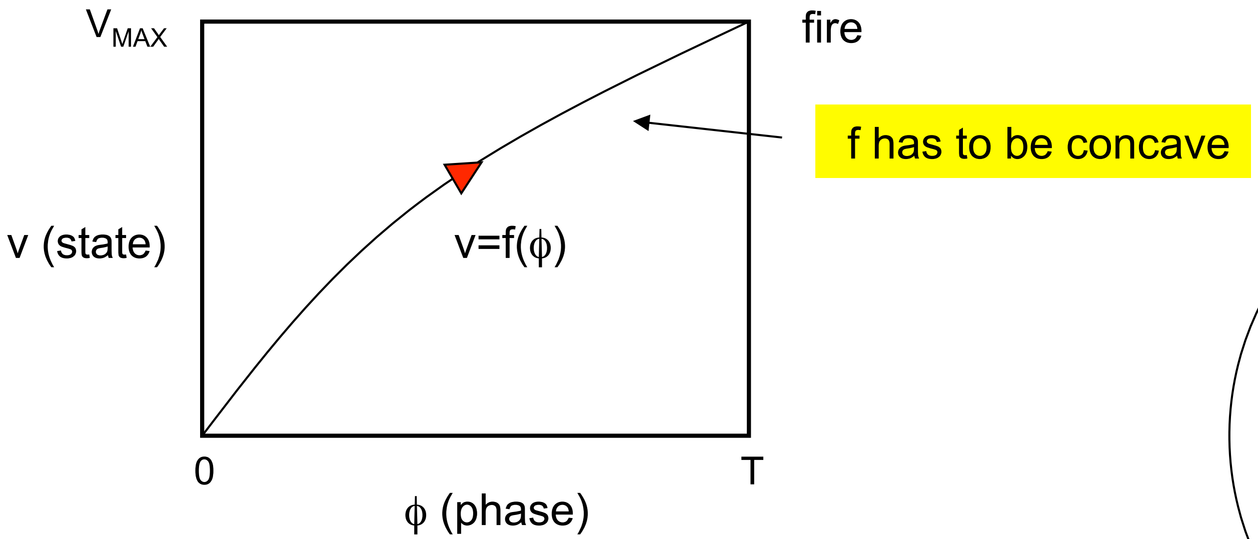
when an oscillator fires, it pulls all the others by ε i.e.

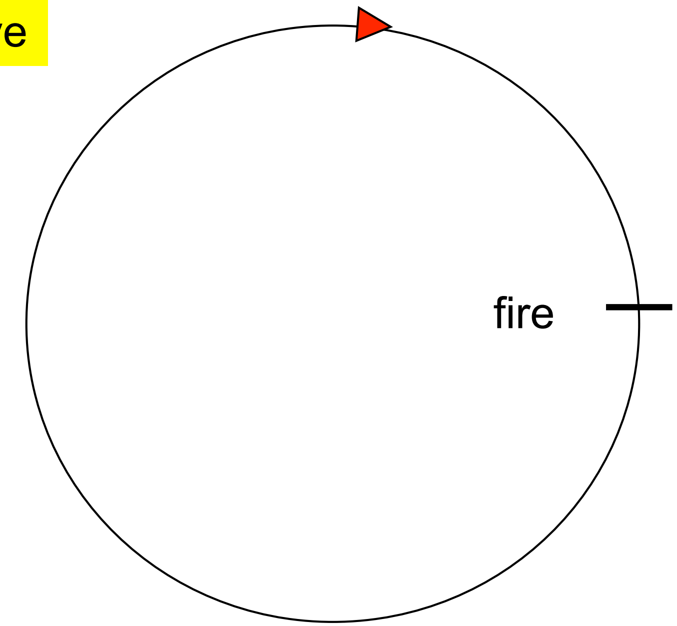
$$x_i(t) = 1 \Rightarrow x_j(t^+) = \min(1, x_j(t) + \varepsilon), \forall j \ne i$$

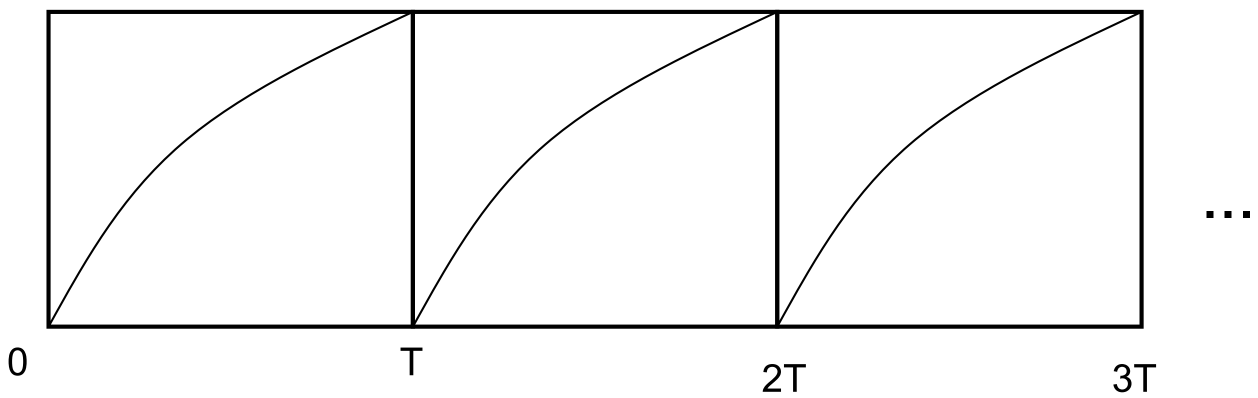
Peskin proved (1) for N=2 and selected $\varepsilon, \lambda > 0$

C. S. Peskin, *Mathematical Aspects of Heart Physiology*
Courant Institute of Mathematical Sciences, New York University, New York (1975): pp. 268-278.

a model by Mirollo and Strogatz

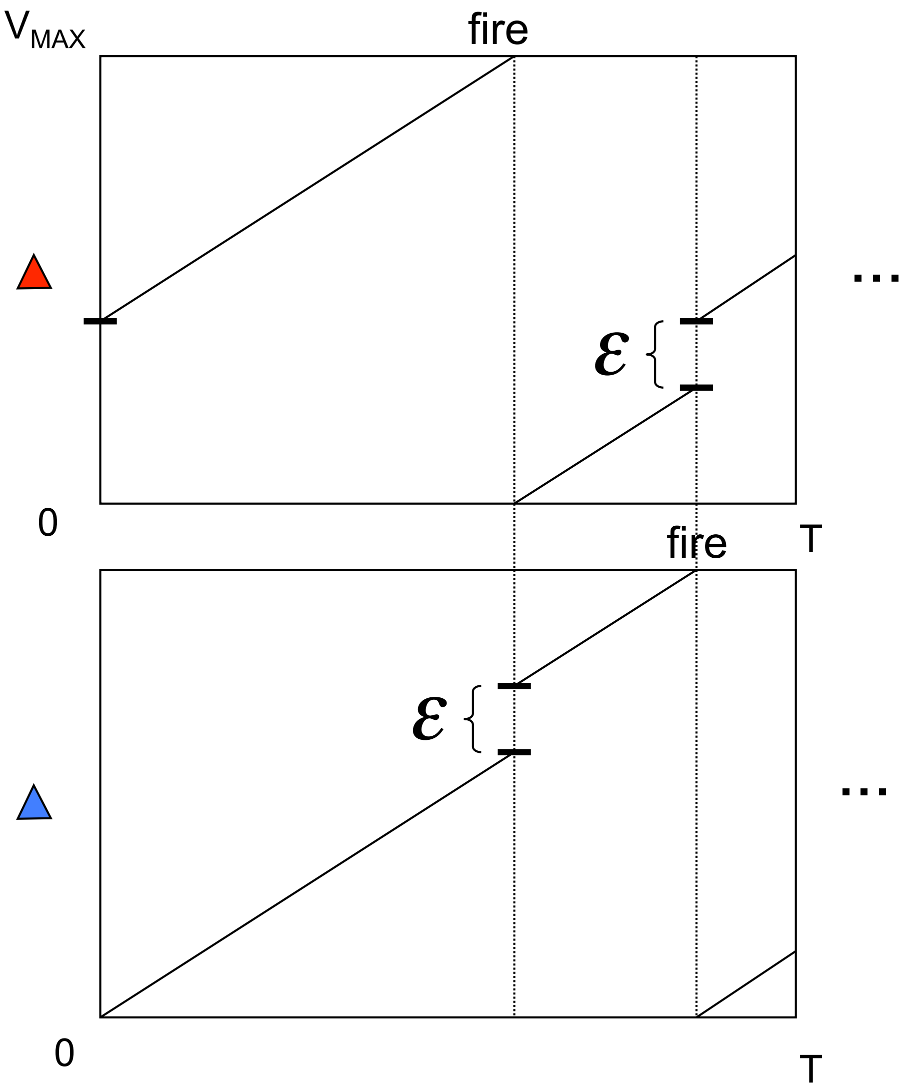


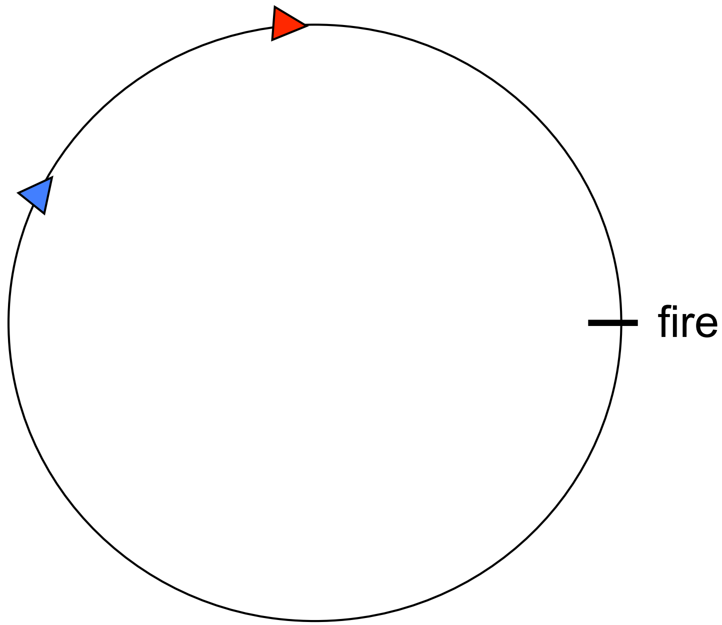




R. E. Mirollo and S. H. Strogatz. *Synchronization of pulse-coupled biological oscillators*.
SIAM Journal on Applied Mathematics, 50(6):16451662, December 1990.

pulse coupled oscillators





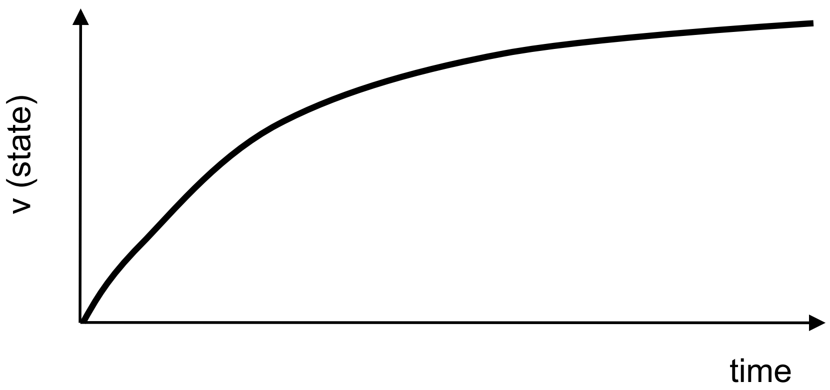
Mirollo and Strogatz

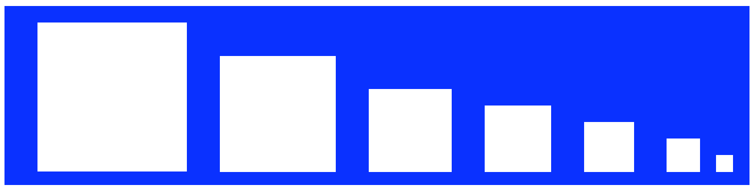
- used described model to prove conjecture (1) for
  - oscillators with identical dynamics
  - each oscillator is coupled with each other
  - all N, and for $\varepsilon > 0$
- extension by Watts,Strogatz (using simulation)
  - conjecture (1) is still true if oscillators are coupled through a "small world" network (e.g. with logarithmic *characteristic path length*)
- remark: is working still in case of lattice graph coupling

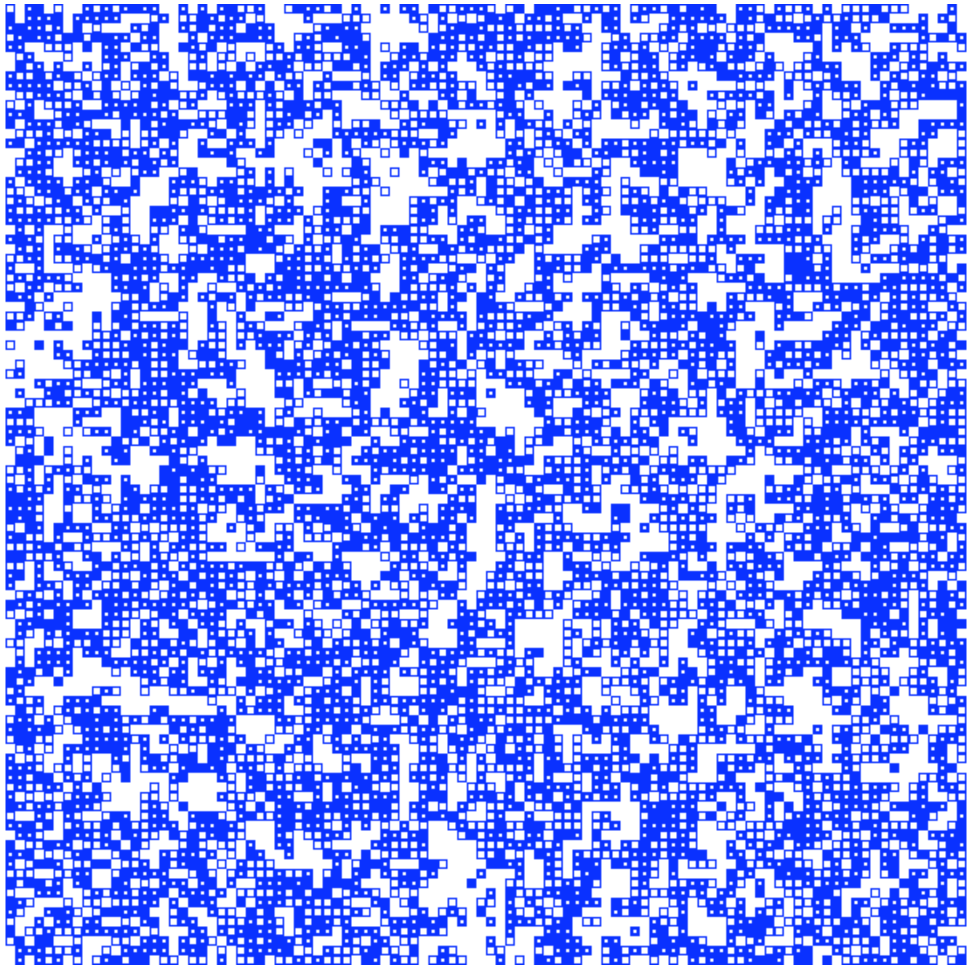
R. E. Mirollo and S. H. Strogatz. *Synchronization of pulse-coupled biological oscillators*.
SIAM Journal on Applied Mathematics, 50(6):16451662, December 1990.

example 1

- sync effect
- 10000 oscillators
  - Mirollo/Strogatz
- network: 2D lattice

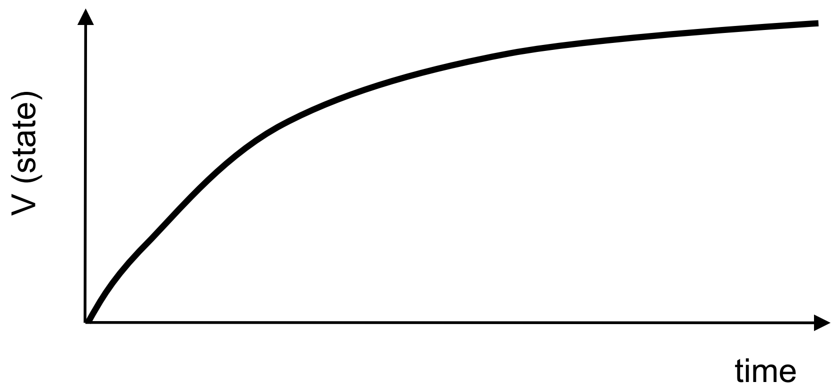


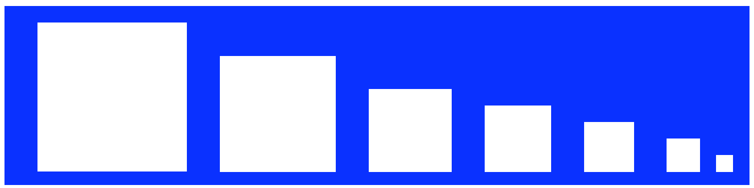


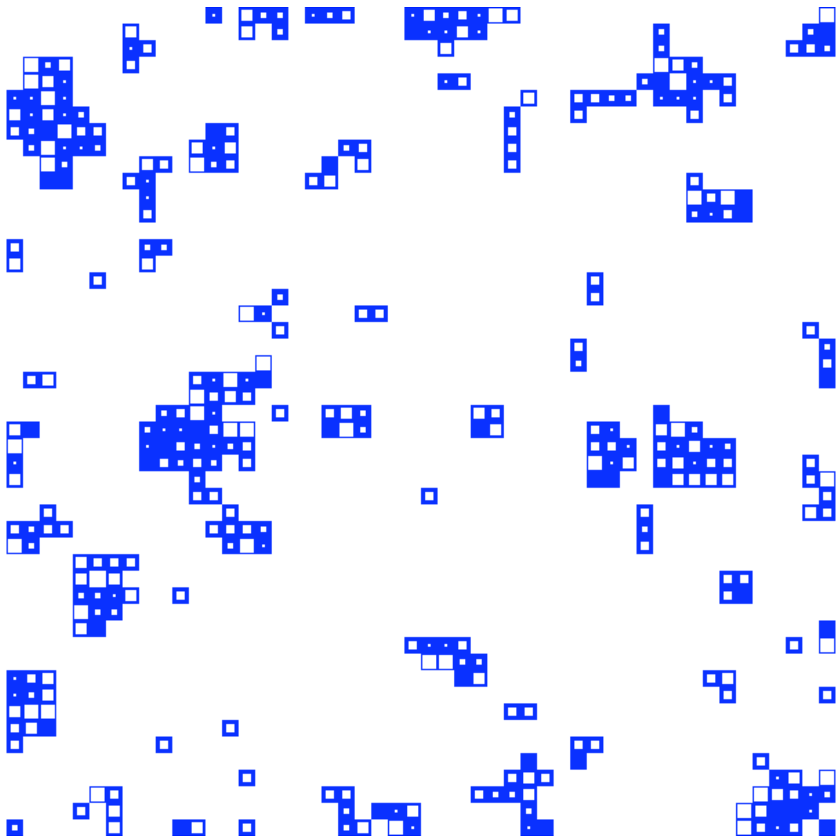


example 2

- frequency change
- 2500 oscillators
  - Mirollo/Strogatz
- network: 2D lattice







sync

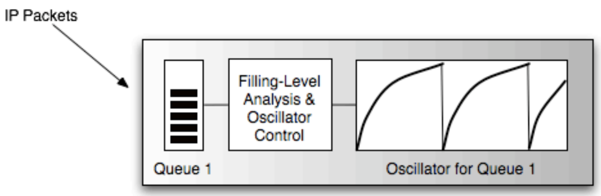
- sync is example for
  - self-organisation
    - i.e. organisation without any need for an external or central control entity
  - emergent behaviour
    - i.e. each entity in the system applies “simple” rules (microscopic behaviour) which results in “sophisticated” behaviour of the overall system (macroscopic behaviour)
- sync **requires** cooperation & communication

it can be applied to networking problems !

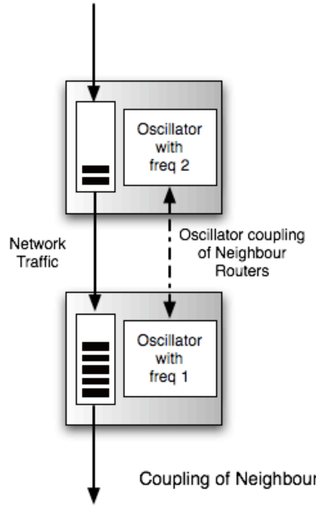
- examples:
  - Tyrrell, Auer, Bettstetter:
    - "Firefly Synchronization in Ad Hoc Networks", *MINEMA workshop*, 2006
  - Hong, Scaglione:
    - "A scalable synchronization protocol for large scale sensor networks and its applications," IEEE Journal on Selected Areas in Communications, pp. 1085–1099, May 2005.
- main topics addressed:
  - effects of transmission delays
  - nodes can't send and receive at same time
- our focus:
  - effects of frequency changes in oscillator groups
  - distributed maximum calculation (as in example 2)
  - can sync be applied to congestion control?

sync for congestion control/avoidance

- Idea: Identify queue filling level with frequency of oscillator
- interconnect oscillators of neighbour routers
- interact with routing
- experiment with oscillator "frequency" changes
- apply to multipath routing scenario in 4WARD project

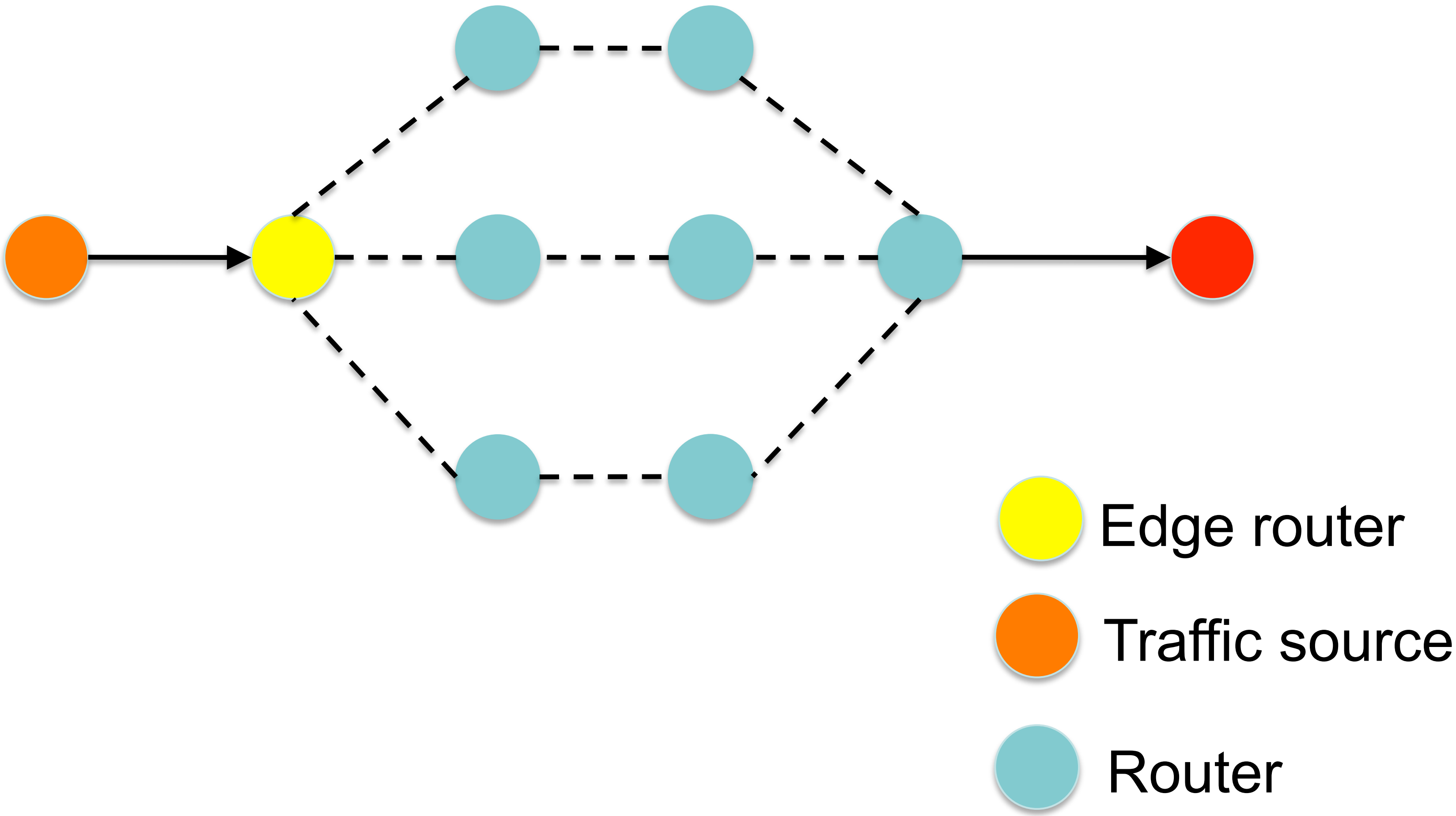


Router with Oscillator



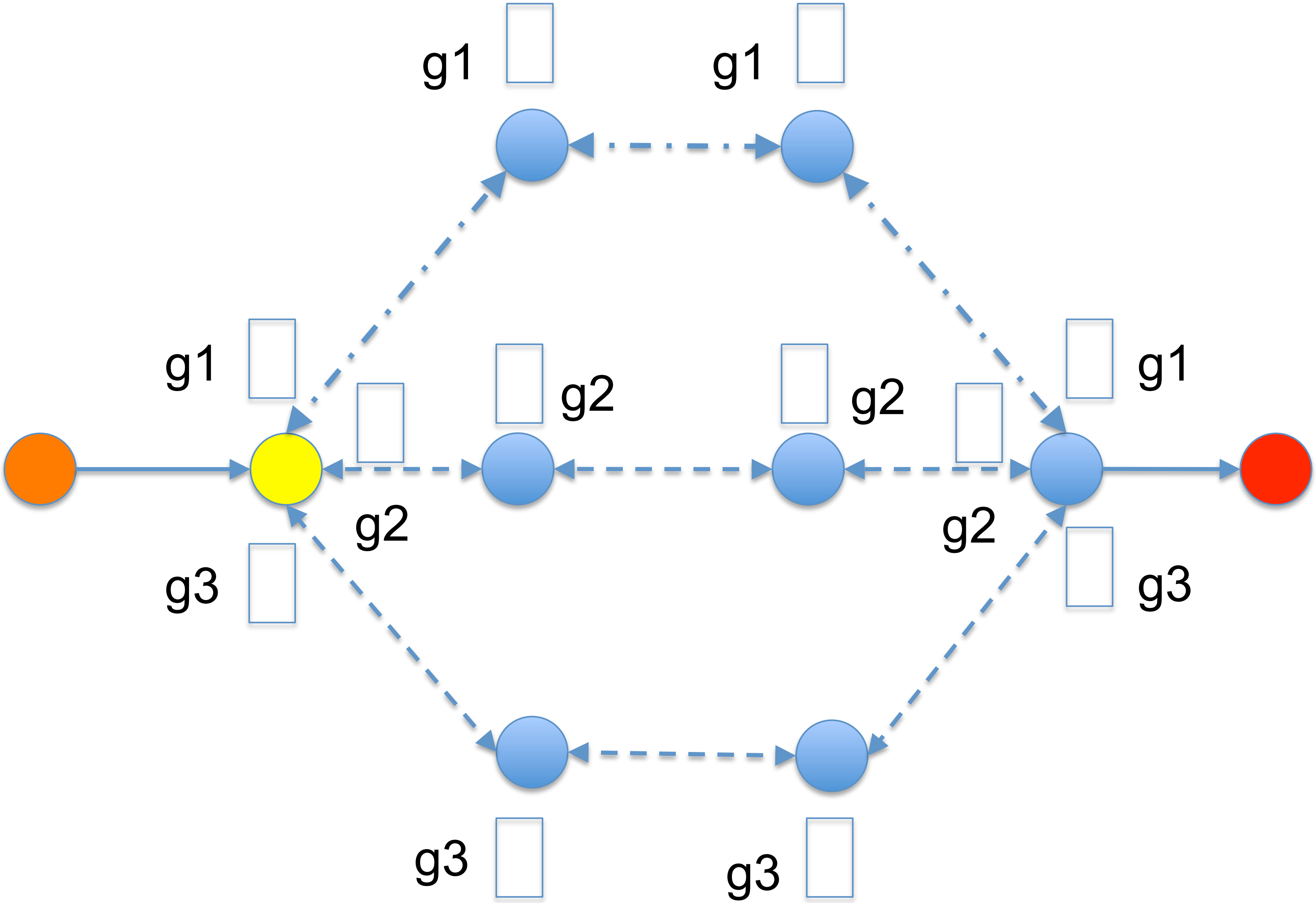
Coupling of Neighbour Routers

multipath routing



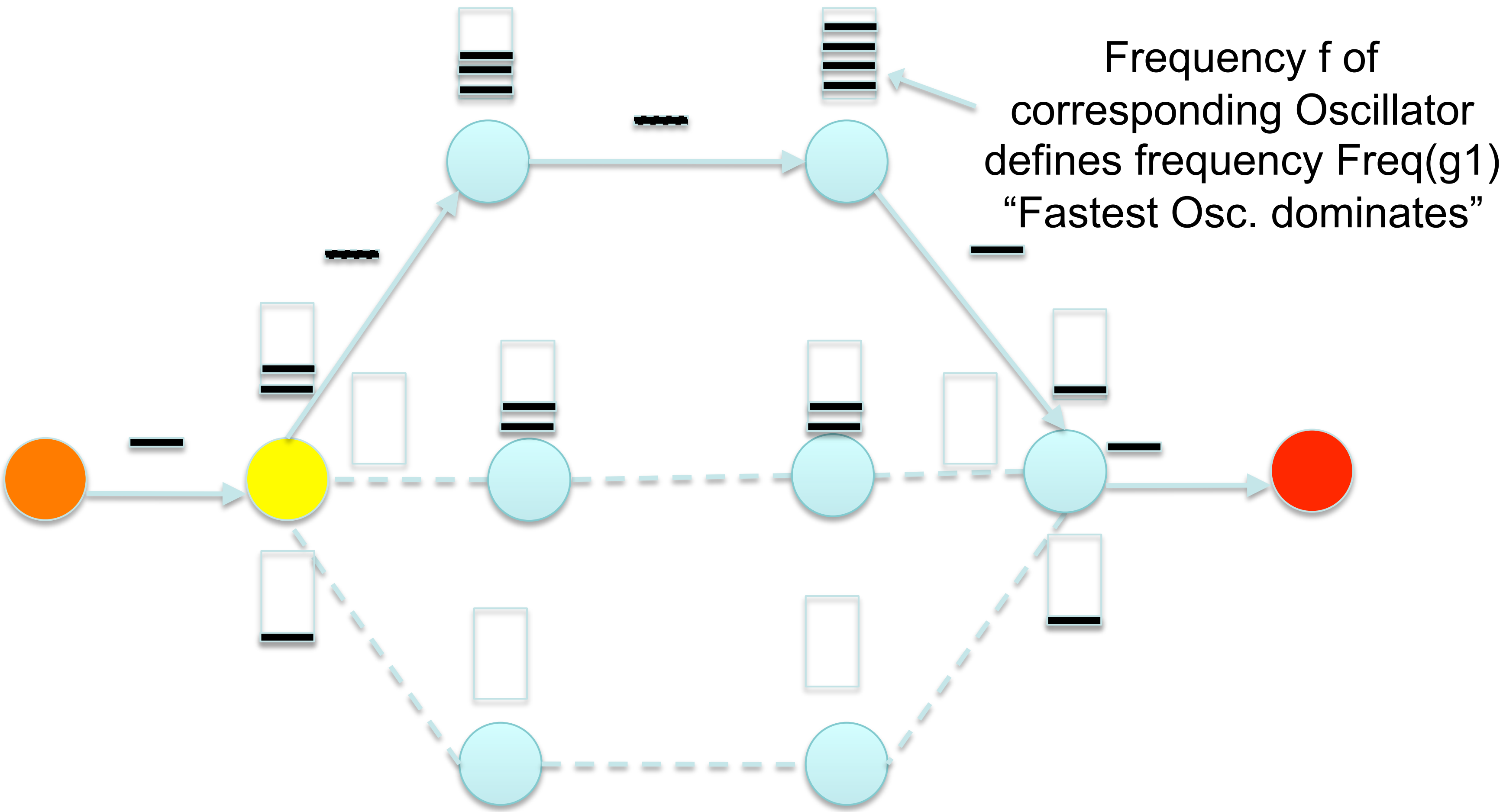
approach

- oscillators are associated with corresponding router queues
- each path defines a group of oscillators
- we aim to exploit property:
  - “fastest Oscillator Dominates” as shown in example 2

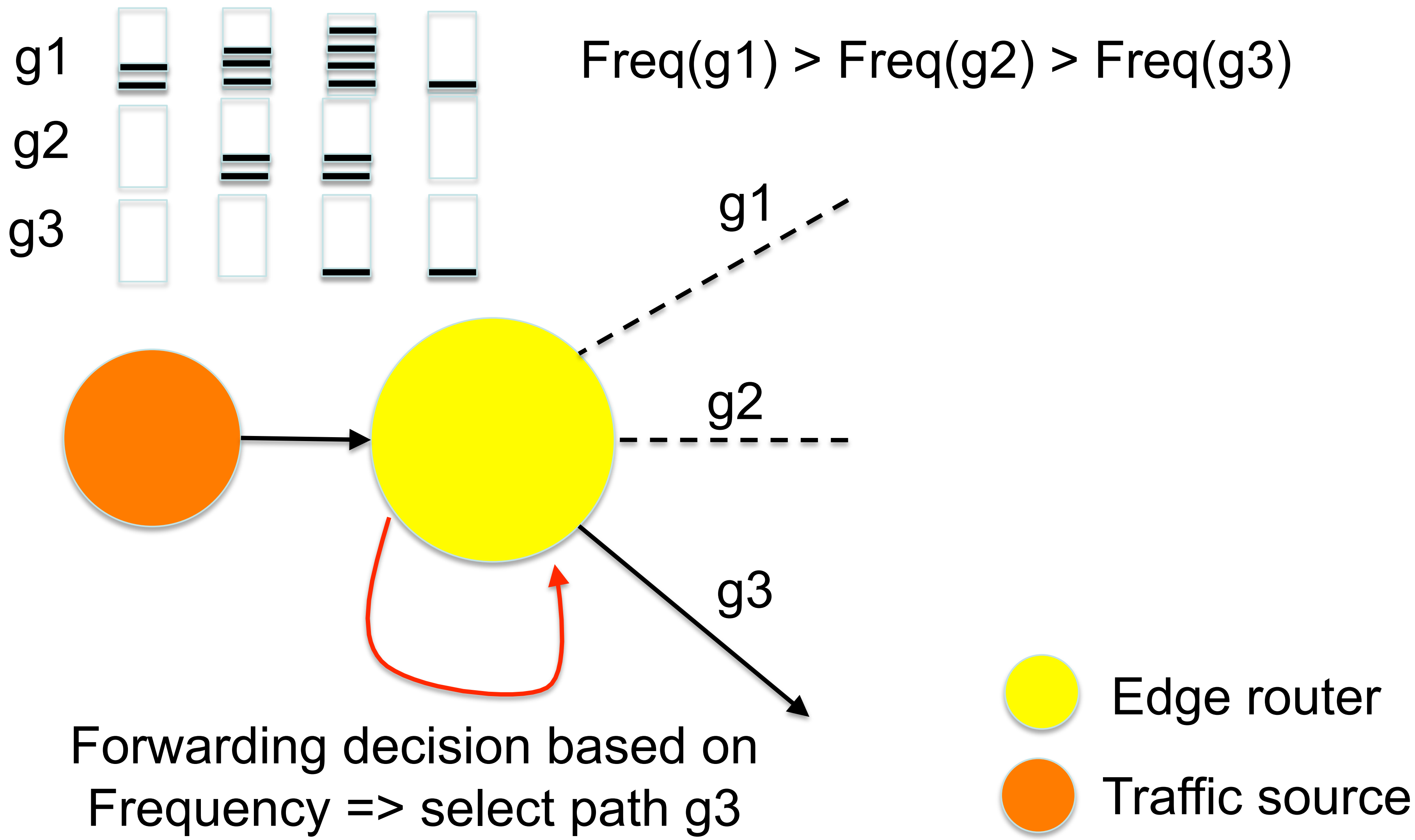


g1
g1
g1
g2
g2
g1
g2
g2
g3
g3
g3
g3

Multipath routing



least congested path first



done so far

- evaluation of different oscillator models
  - Mirello/Strogatz based model selected
  - parameter set defined
- development of simulation environment
  - discrete event simulation
- evaluation in progress
- **claims**:
  - small variations in oscillator characteristics don’t “destroy” sync property
  - sync can be used for distributed maximum calculation

discussion

- evaluation work performed inside 4WARD project
- sync signals can be transmitted on layer 2 or below
- oscillator could even be realised based on hardware on interface card of router

thank you

questions ?