Modelling Wireless Sensor Networks

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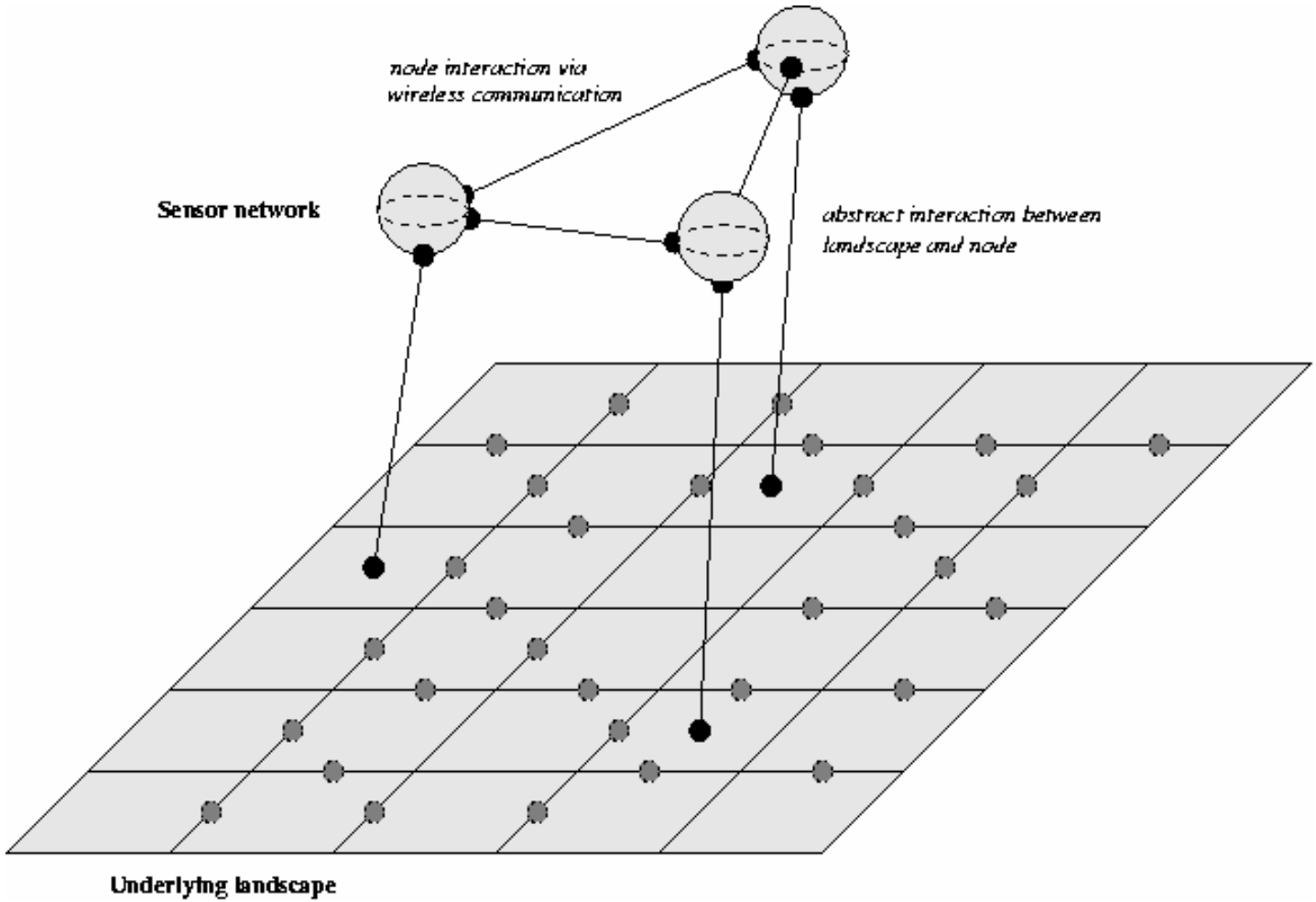
Wireless Connected Ad-Hoc Sensor Networks

- wireless connectivity
- low power
- locality significant
- location significant
- possible mobility

Future Sensor Networks

- low cost and “disposable”
- can be “sown” onto the landscape
- how to utilise, exploit, understand, design and analyse such systems
- need to model – but how?
- model sensor nodes on a CA-like landscape model



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Two Interacting Systems: Ad-Hoc Network and Dynamic Landscape

- sensor network resides in landscape
- nodes sense change to landscape

  e. g. water movement
  salinity changes
  spread of bushfire
- communication between network nodes
- interaction between landscape and network
- conceptually, they “talk” to each other

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Modelling Ad-Hoc Networks

- *design* communication strategies
- *analyse* system behaviour
- *understand* trade-offs
  e. g. density on landscape vs performance
- *compare* and *contrast* different protocols
- *understand* effects of landscape on sensor network

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Characteristics of Ad-Hoc Networks

- broadcast-type communication
- location / locality with broadcast footprint
- possible mobility
  - system can change connective topology through time
  - nodes die, sleep, awaken, are added, move

Model These Concepts

- construct accurate and tractable models
- use as testbed for exploring concepts such as locality, location, mobility, dynamic structure -- concepts *not found* in traditional computer systems
- what underpinning modelling theory?

Process Algebra

- model “engineered” systems
  - static, fixed structure
- Circal used for modelling and analysis of:

  digital hardware, asynchronous logic, communication protocols
- process algebra for dynamic structures
  - dsCircal

Process Algebra Philosophy:

- represent *structure* of interacting components in terms of where communication occurs
- represent *behaviour* of components in terms of state transition actions occurring between them ….interacting FSM behaviour known as a process
- synthesise behaviour of composite system from processes via *composition operator*
- this supports hierarchical and modular design methodology, helps manage design complexity found in large systems

Previously

- created a process algebra called CIRCAL with features which permit novel description and verification techniques such as for timing and property verification.
- developed a mechanisation of the CIRCAL formalism which permits automatic proof of system properties - relies on manipulating a labelled transition semantics of the CIRCAL syntax.
- discovered powerful specification and verification techniques by applying CIRCAL system to commercial applications such as communication protocols and asynchronous digital logic.

What Are The Core Concepts?

FSM:

- actions aP
- action choice $aP + bQ$
- terminating process $\triangle$

System of interacting FSMs:

- composition $P * Q$
- abstraction $P - a$
- instantiation $P \stackrel{def}{=} Q\,[b / a]$

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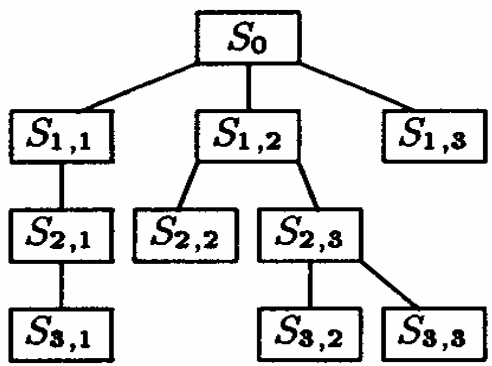
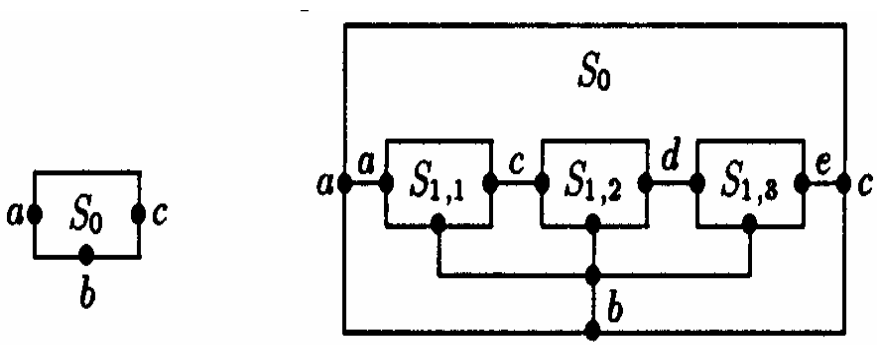


Hierarchy of system components



System structure at 2 levels of abstraction

CIRCAL language constructs capture this system structure and allow behaviour of total system to be generated from behaviour of component parts

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Process Behaviour

Parallel composition of behavioural processes expanded into global behaviour.

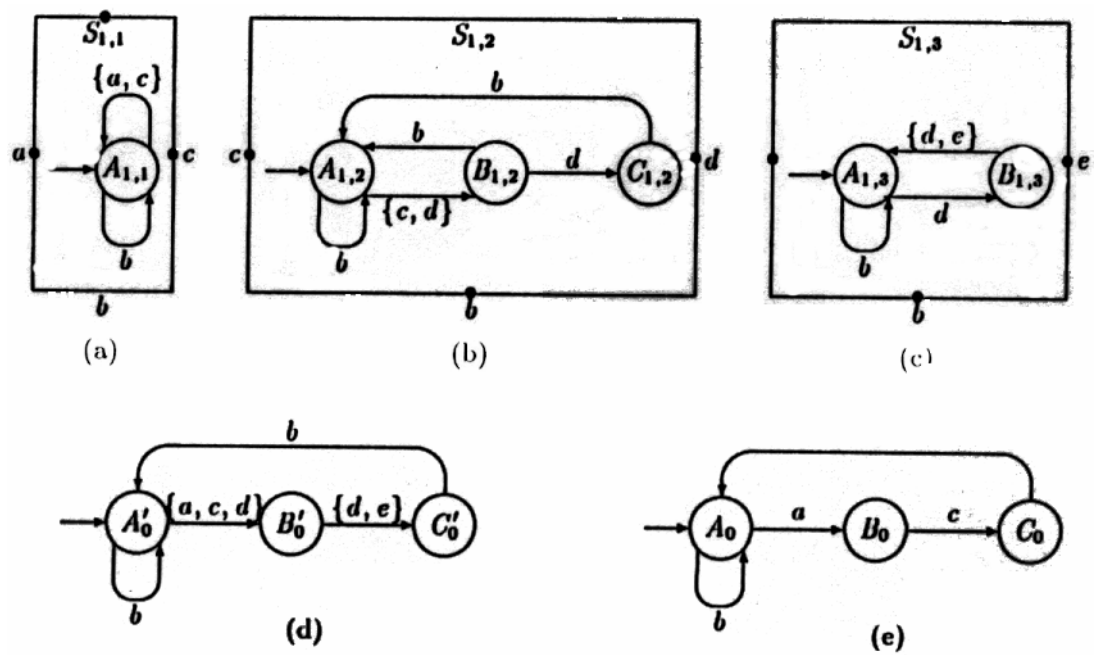

Figure 2

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Figures 2 illustrates:

- interface structure and behaviour of processes $S_{1,1}$, $S_{1,2}$ and $S_{1,3}$
- behaviour of constructed system resulting from application of parallel composition operator

Is this implementation behaviour correct with respect to the abstract specification S_o?

Requires abstraction and relabelling operators to show

$$S_o \equiv ([S_{1,1} * S_{1,2} * S_{1,3}] - c - d) [c/e]$$

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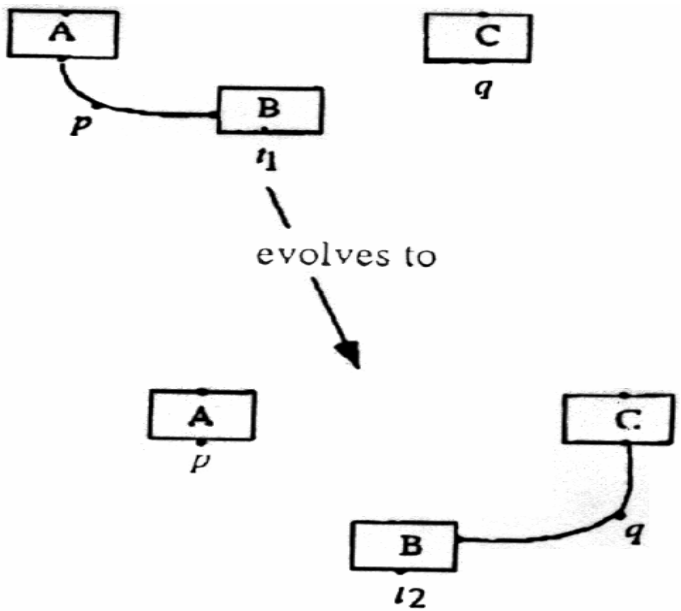
Dynamic Structure CIRCAL

Traditionally many systems are constructed from components with a fixed connective topology.

Today, dynamic links are common with components becoming active and links forming:

- Internet
- Wireless Networks
- Mobile Telephony
- Reconfigurable computing



Investigating new formalisms which permit such dynamically changing structures.

Here we have a system described in Dynamic Structure CIRCAL by:

Sys{a,p,c,q,t} = A{a,p} * B{p,t1} * C {c,q}

Where:

$A\{a, p\} = aA + pA$

$B\{p, t_1\} = pB + t_1 B_1\{q, t_2\}$

$B_1\{q, t_2\} = qB_1 + t_2 B\{p, t_1\}$

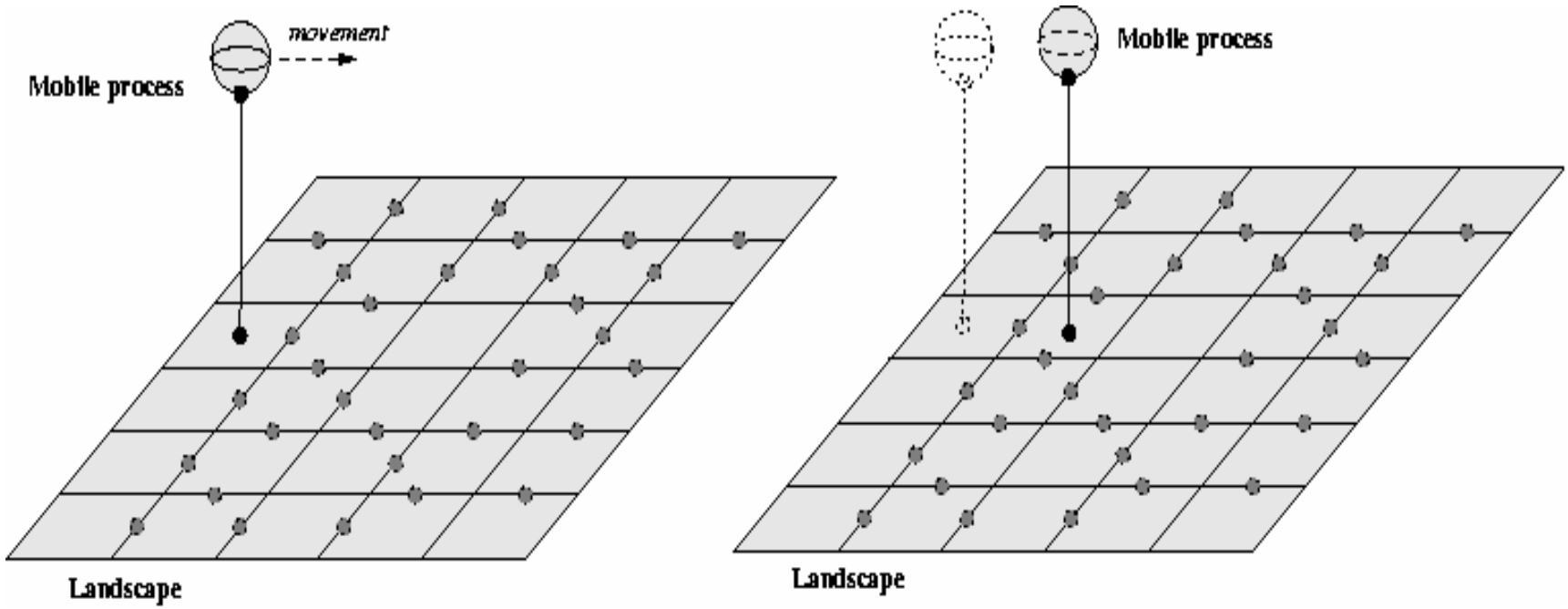
$C\{c, q\} = cC + qC$

As a result of action t_1 process B changes structure.

Link with process A breaks.

Simultaneously, link with C forms.

Abstract description of mobile moving between base stations.



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Spatial Systems

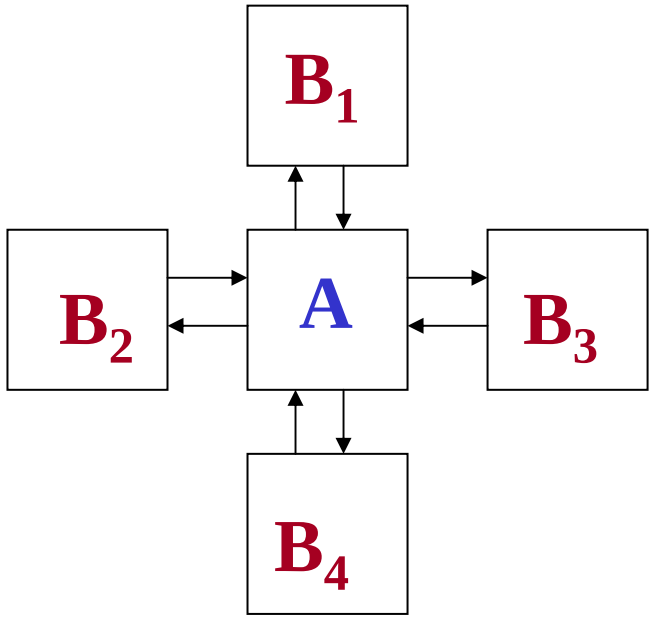
- behaviour over a “landscape”
- discretise space and time
- discrete models give access to discrete theories (process algebra, timed automata, etc.)
- models can be exercised via discrete event simulation
- cellular automata approach embedded into process algebra

Cellular Automata

- discretise space and time
- dynamic change over a landscape
- decentralised decision making
- behaviour captured by locality dependent update rules
- Ulam and von Neumann in 40's

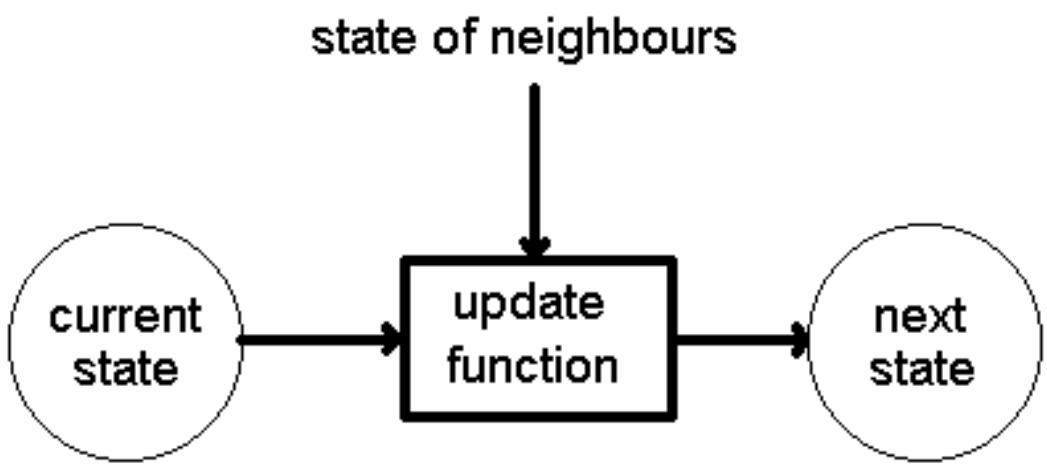
Modelling Using Cellular Automata

- cellular automata are self-organising systems
- fine-grained concurrency
- model behaviour of each primitive object
- global behaviour emerges from local cell behaviour via simulation
- macroscopic from microscopic
- appropriate modelling approach for dynamics of spatial systems
- cells change state according to state of cells in neighbourhood

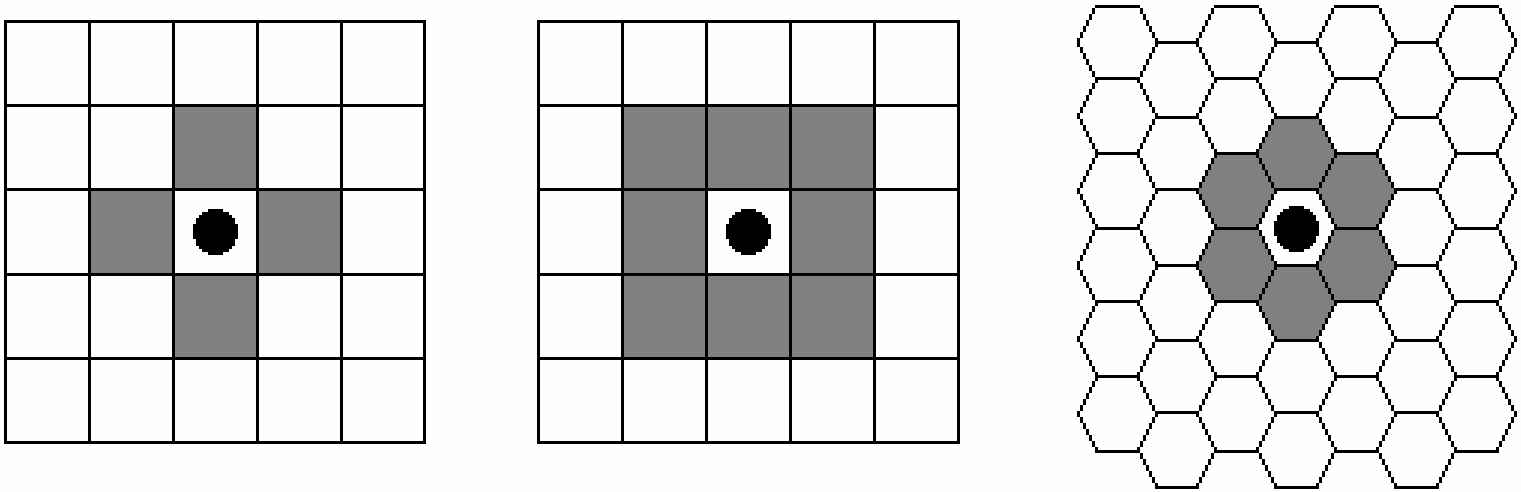


- each cell interacts with *local* environment
- cell A samples states of adjacent cells
- using appropriate update rules, cell A changes state

- basic update rule for each cell
- update function (transition function) may be probabilistic



Different Grids and Neighbourhoods



Modelling Dynamics of Non-Linear Spatial Systems using Interacting Automata

Highly concurrent systems:

- Traffic Systems

  results tested against sampled data; real-time control
- Crowd Dynamics

  stadium design
- Bush Fire Simulation

  real-time control
- Epidemic Spread

  containment measures; foot and mouth (UK)

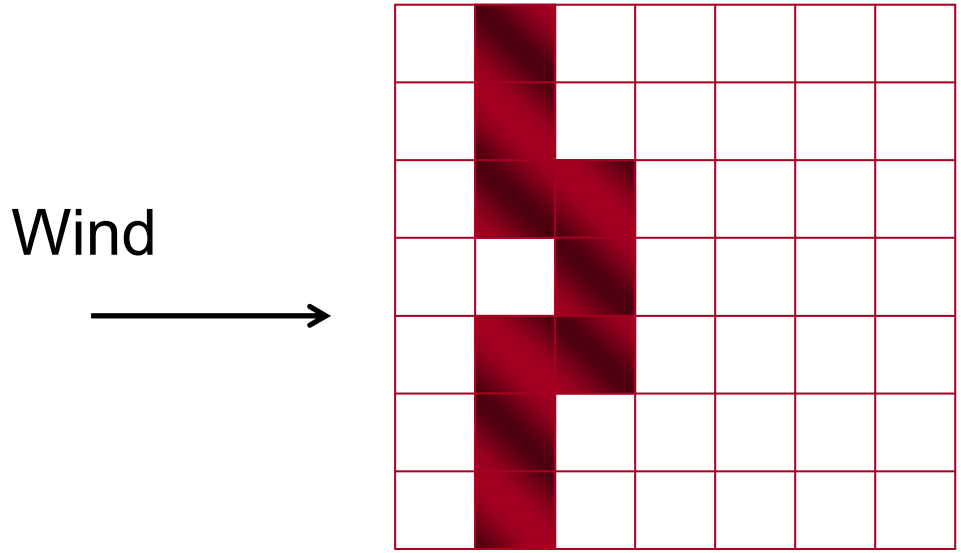
Why Not Pure CAs?

Need a theory based on communication and concurrency: these exist

Theory should support:

- non-homogenous “building block” components
- hence distinct update rules
- global events modelled
- hierarchical / modular description
- combine distinct subsystems
- use of abstraction to manage descriptive complexity

Modelling Bushfires: with Clive Gout



- each cell captures vegetation and slope orientation
- this affects rate of transmission
- wind speed and direction applied globally
- cells change state synchronously

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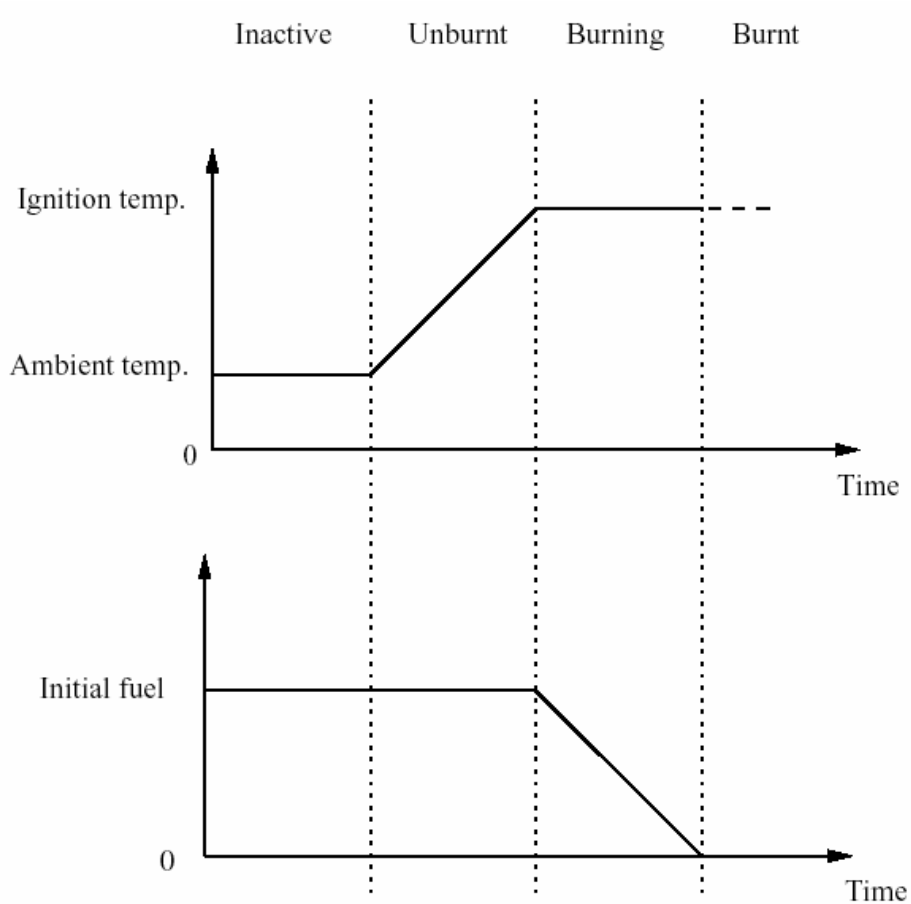
Areas of land take four states



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Crowd Dynamics: with Tim Lightfoot

- Model people movement in stadia
- Can a simple model of dynamics of a cell lead to realistic macroscopic behaviour?
- Predictive modelling for planners and designers
- Rapid and repeated simulations allow us to explore "what if" scenarios……scale of simulations require high performance platforms?

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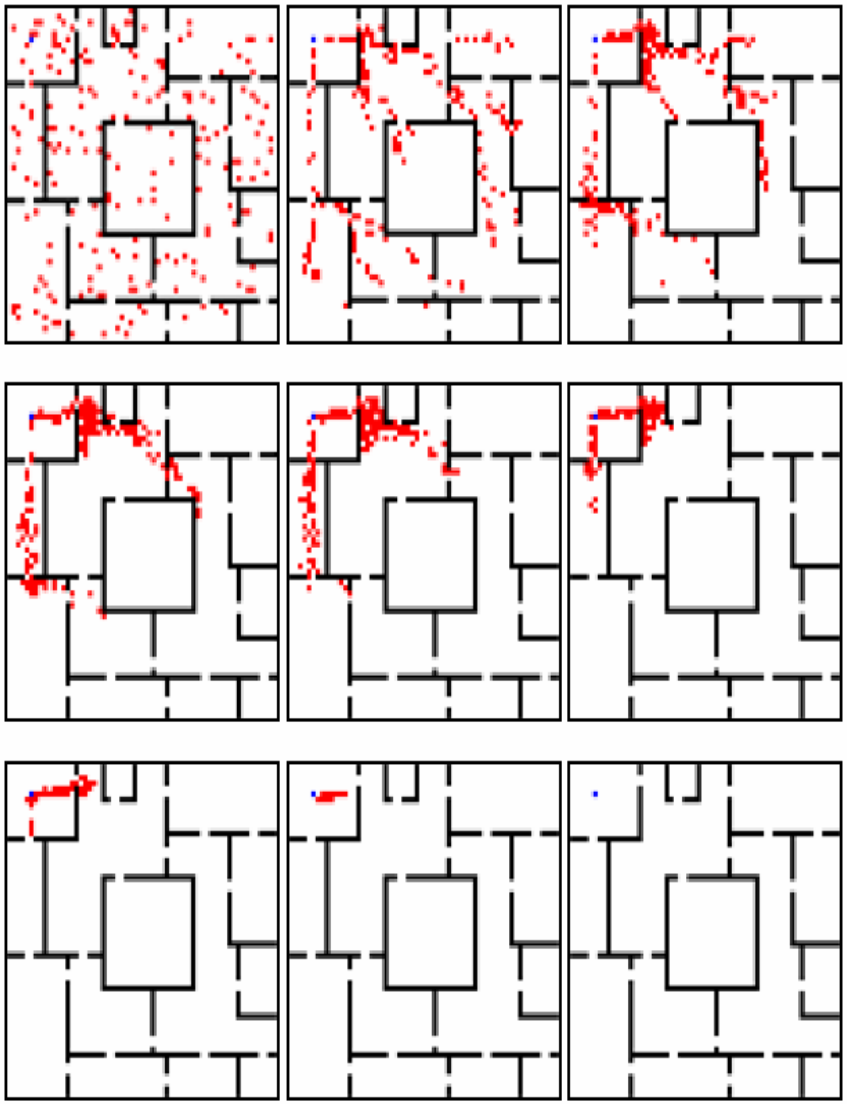
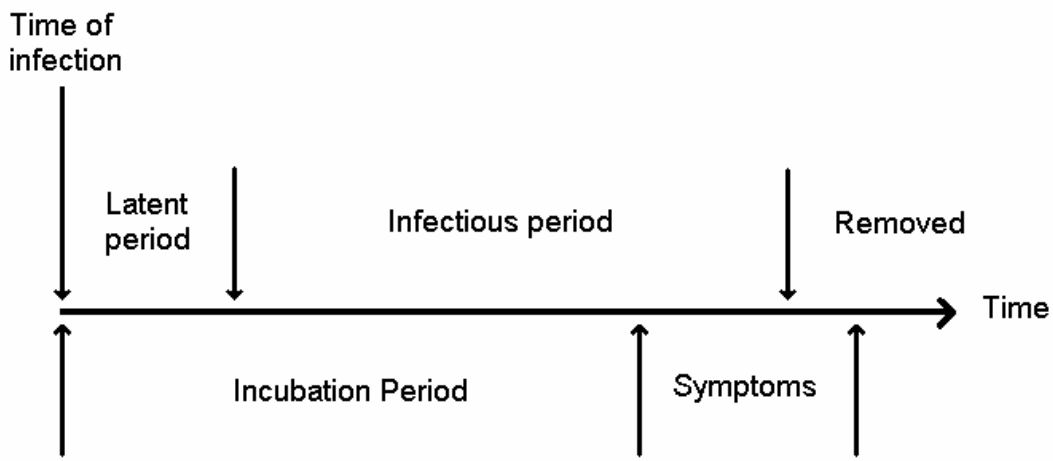


- Movement through rooms with exit top left
- Notice congestion that forms

Epidemic Modelling: with Shih Ching Fu

- Use SIR epidemic framework
- Susceptible, infective, recovered
- Individuals change state through time



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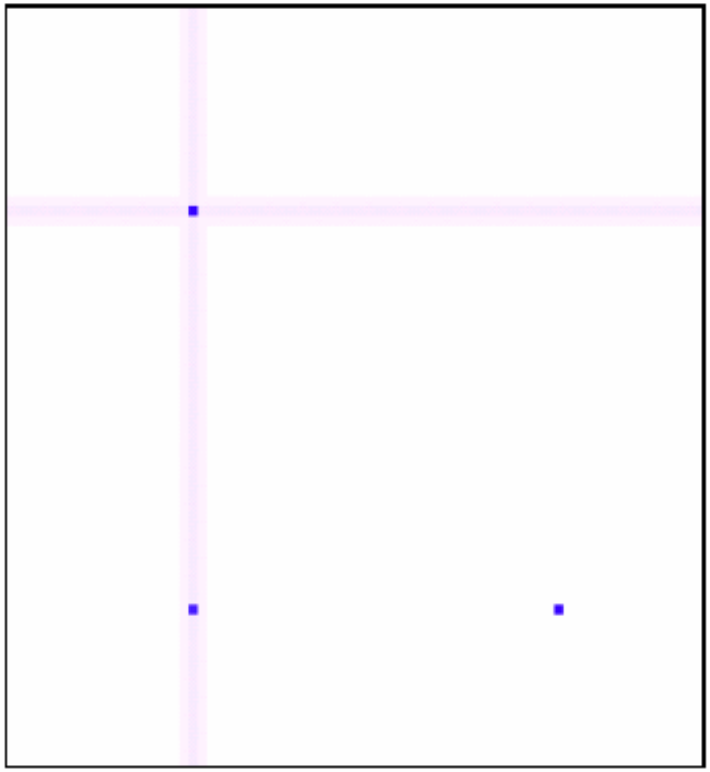
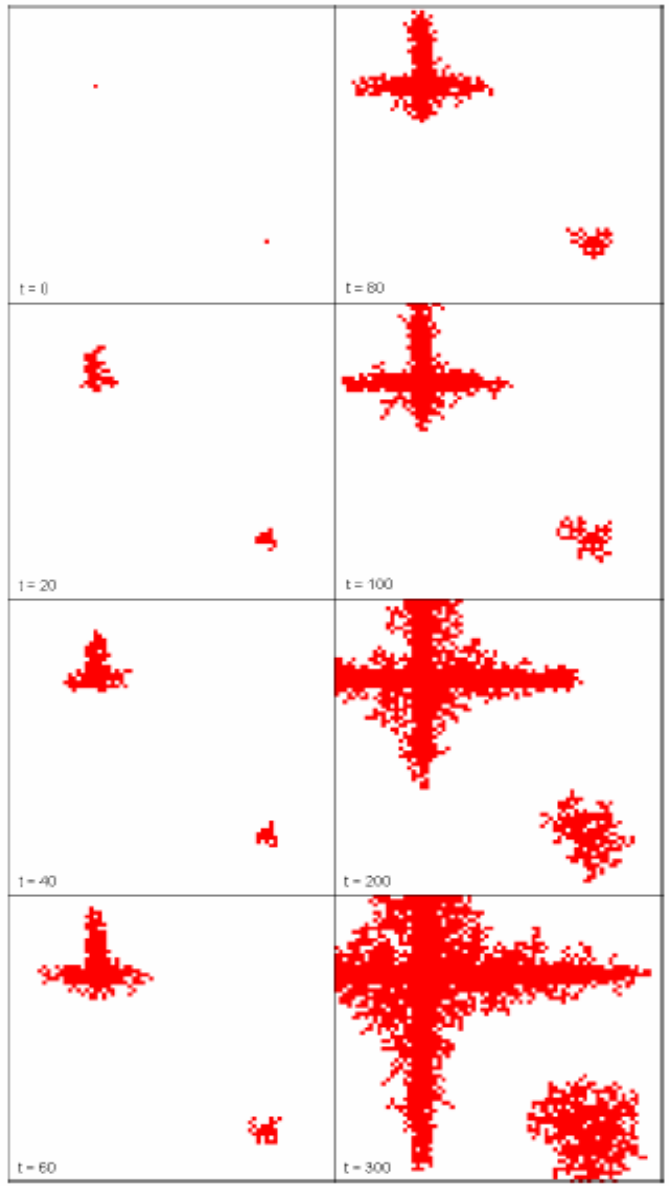


- World is a 2-D lattice of cells
- Update rule is stochastic based on various probabilities
  - Contact infection
  - Recovery
  - Susceptibility
  - Spontaneous infection
  - Movement
  - Morbidity
- Movement along corridors of high population density, as in this figure
- Foot and mouth disease

- Time sequence of steps
- NW outbreak spreads along population corridors
- Infects more, faster than SE outbreak



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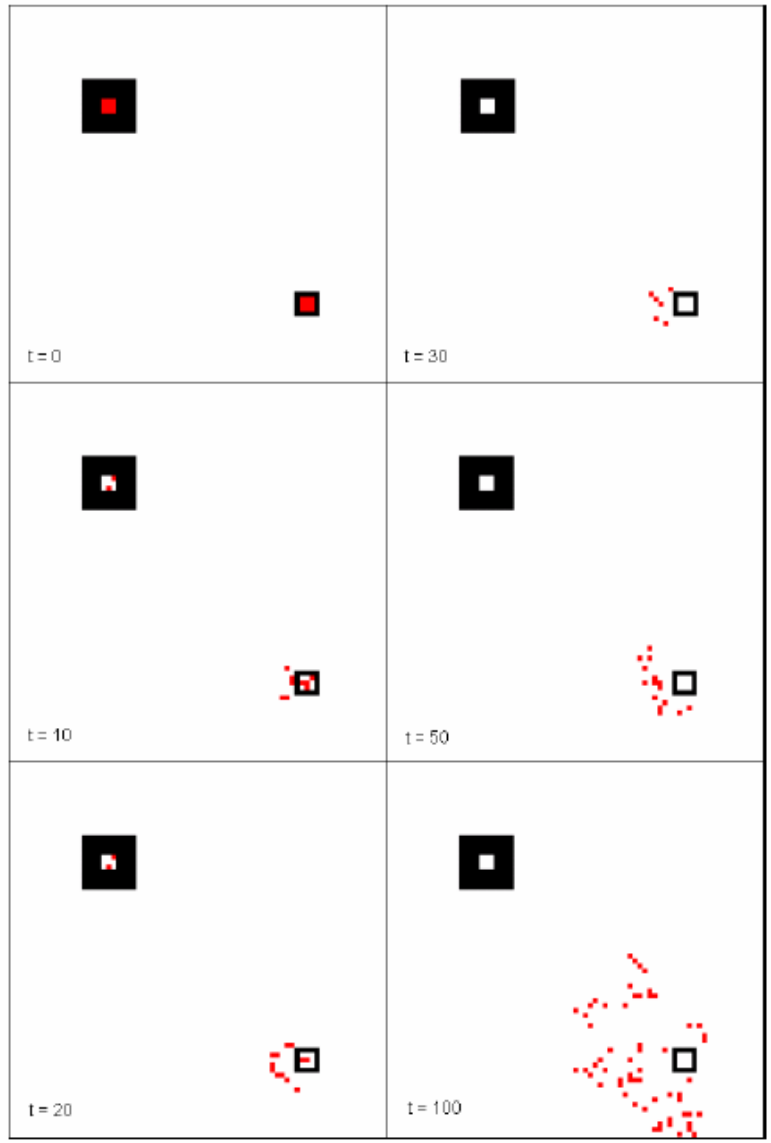
- Containment measures depend on “depth” of barrier
- Barrier restricts infective host movement
- Can see that weak barriers do not prevent virus spread



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Research Challenges for Modelling Ad-Hoc Networks

- appropriate modelling theory?

Given an appropriate theory / formalism:

- how to build models?
- how to describe models?
- how to validate models?
- how to build appropriate simulation environments?

Modelling Environment

Tools for the description, design, verification and simulation of ad-hoc wireless networks

- Validation early in design cycle
- Exploration of design alternatives
- Benefits of rigorous specification
- Helps speed up design cycle
- Simulation is crucial – why?

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