

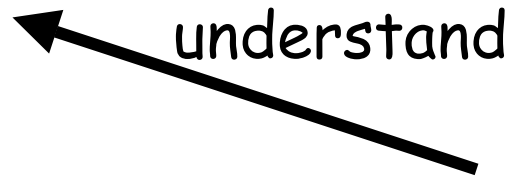
From Objects to Events

Modeling the Dynamic World

Mike Worboys

SISE and NCGIA, University of Maine

Real world



People

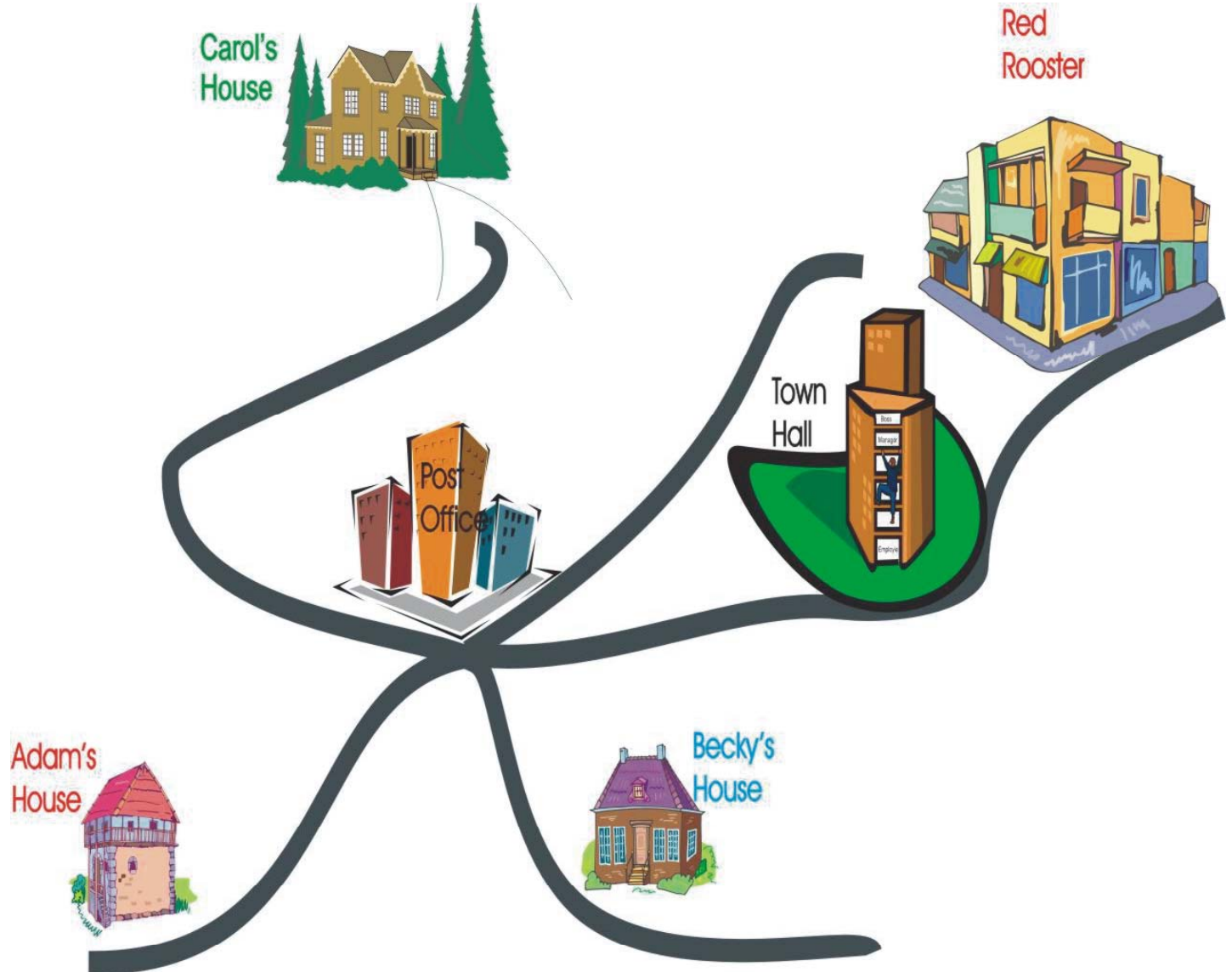
use for
predictive
models

query



Spatio-temporal
information
systems

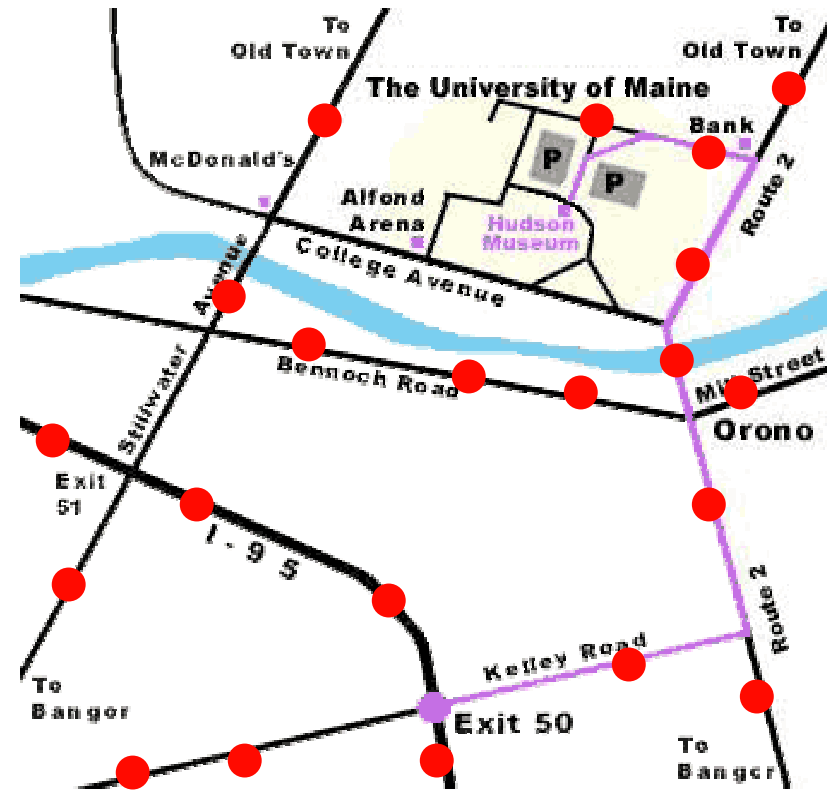
Adam and Becky plan lunch together at the Red Rooster



Spatiotemporal information system

PERSON	LOCATION	TIME
Adam	Adam's house	1200
Becky	Becky's house	1200-1230
Carol	Carol's house	1200-1215
Adam	Between his house and Red Rooster	1200-1250
Carol	Between her house and Post Office	1215-1245
Becky	Between her house and Post Office	1230-1245
Becky	At Post Office	1245-1300
Carol	At Post Office	1245-1300
Becky	Between Post Office and Town Hall	1300-1330
Carol	Between Post Office and Town Hall	1300-1330
...		

Traffic management scenario



Is there a vehicle at Exit 51?

Is the vehicle on Stillwater moving onto Bennoch Road?

Is the traffic slowing down on Bennoch Road?

Will the wide vehicle coming off the I-95 cause problems on Stillwater?

Are there any unusual events currently in the system?

Have there been any unusual events in the system in the last 12 hours?

QUERY?

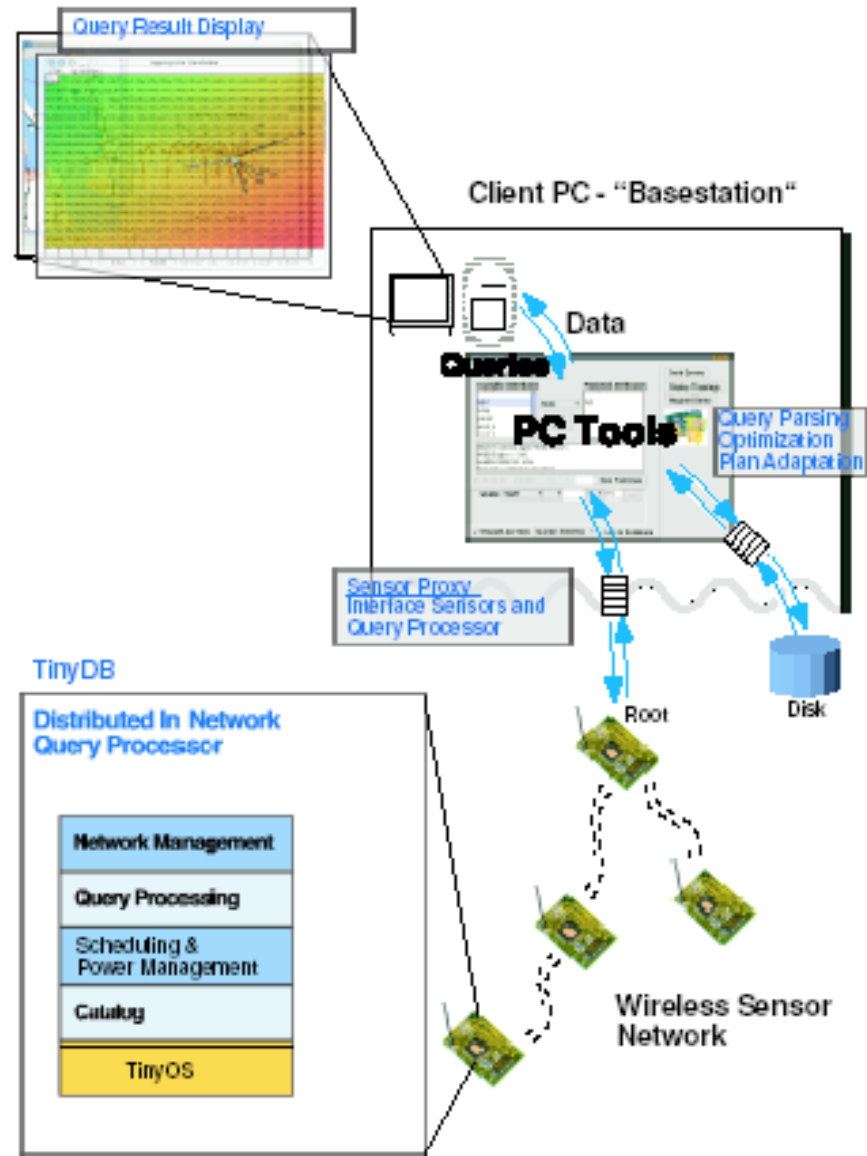


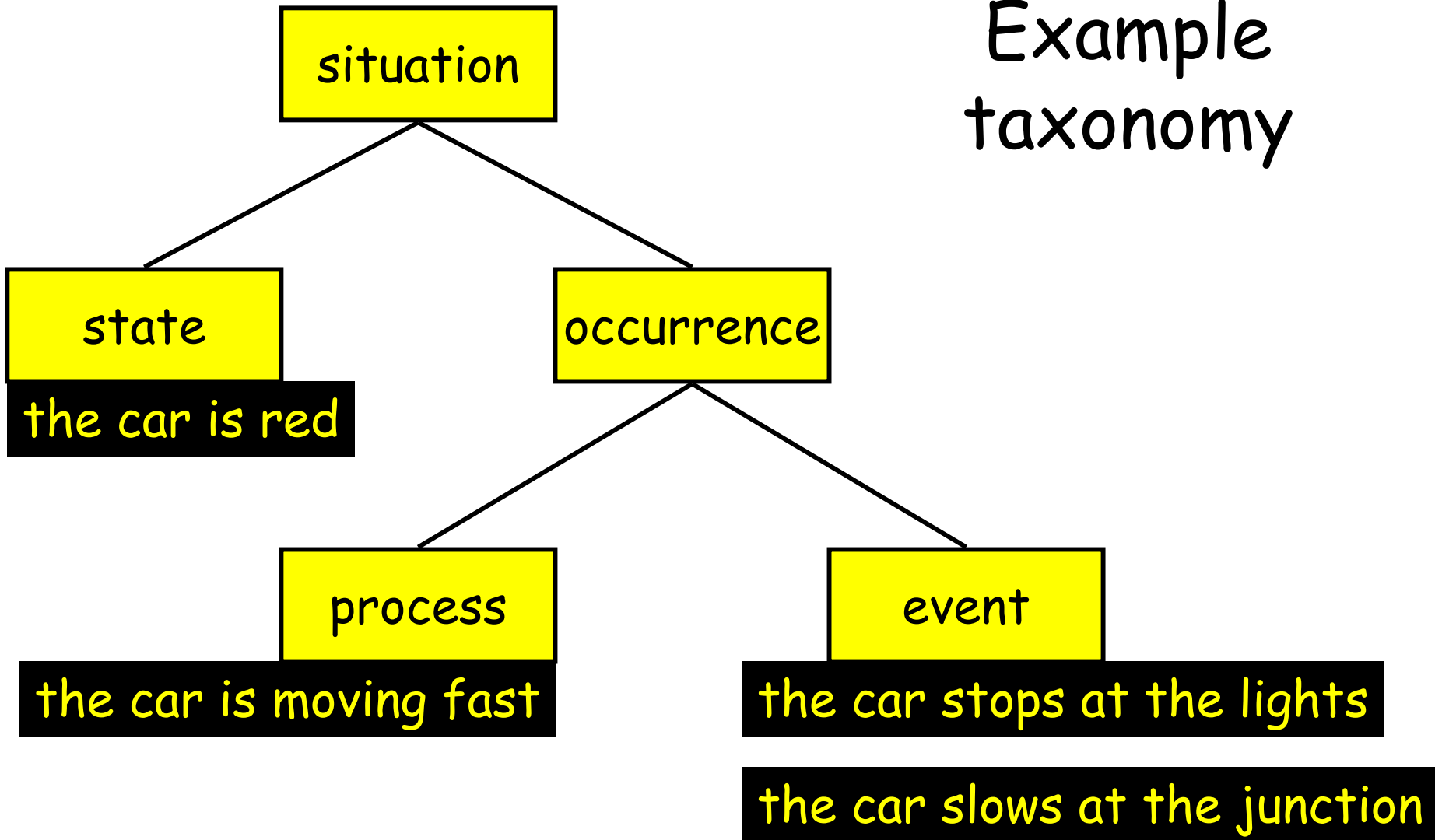
Figure 3.1: Sensor Network Query Processor Architecture

Ontology of the dynamic world

Events, processes, actions, time

Earlier work by philosophers and
linguists

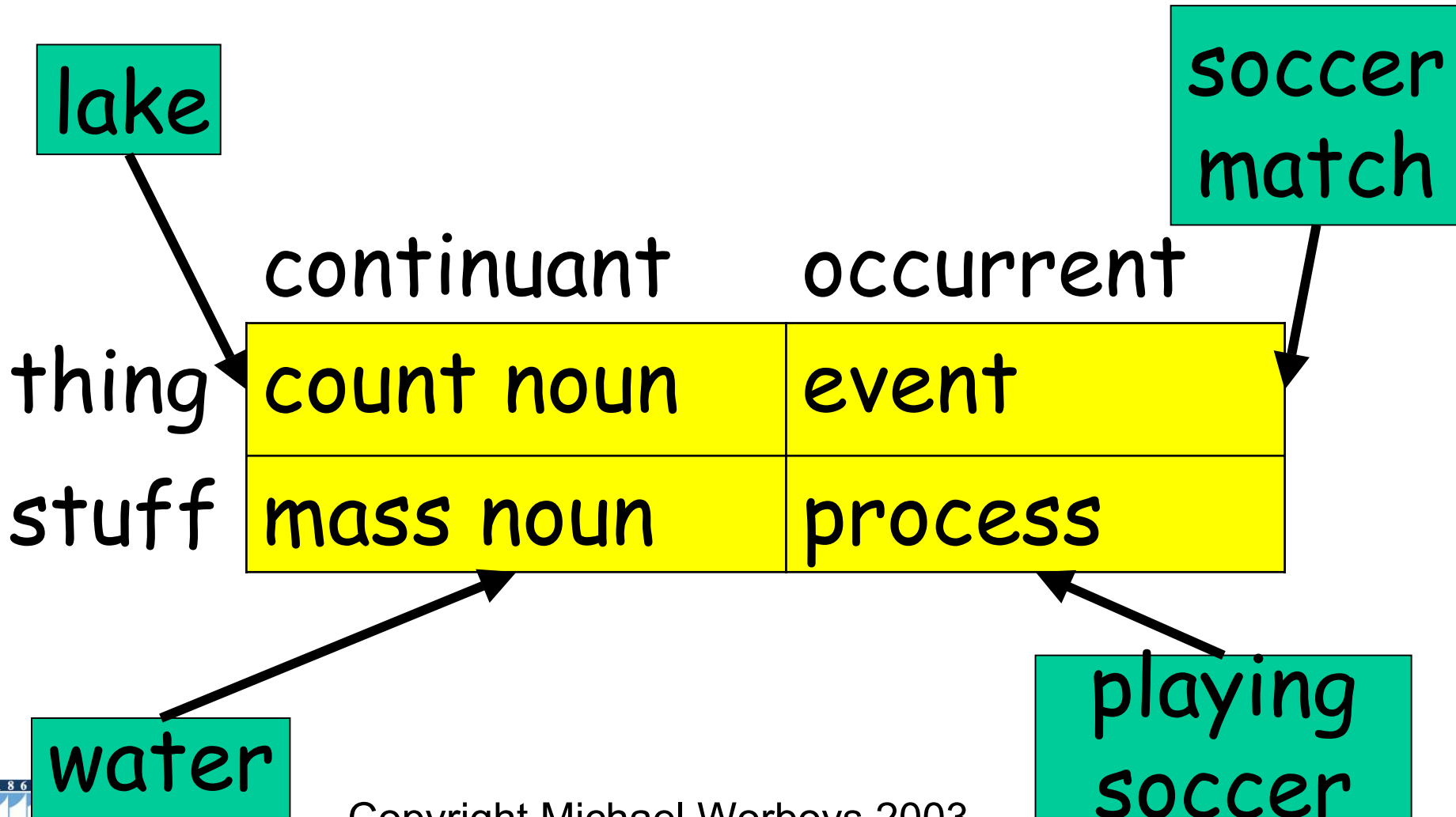
Example taxonomy



(similar to Mourelatos 1978)

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Another way to look at events and processes



Metaphors for events (Lakoff)

Events are locations

"My father was in the war" (event as container)

"The US is going to war" (event as place)

Events are objects

"I have a headache" (event as something to be possessed)

Events are forces

"The war changed the boundary of our country" (event having impact on an object)

Space as a metaphor for time

Christmas is coming
The goose is getting fat
Please put a penny in the old
man's hat
(Christmas song)



Space as a metaphor for time

Love is just around the corner
And standin' out of view
Love is just around the corner
For you
(Popular song)



Space as a metaphor for time

"Tired of third gear? LEAP into the 21st century with a GM overdrive behind your V12 Jaguar motor."

(Advert)



Metaphors for actions

I take an action to reach a goal

↑
path

↑
location

I make an action to get a result

↑
movement

↑
possession

SNAP and SPAN Grenon and Smith

SNAP

Continuant

those entities that endure in the world through time

tables, houses, people, cities, boroughs

SNAP

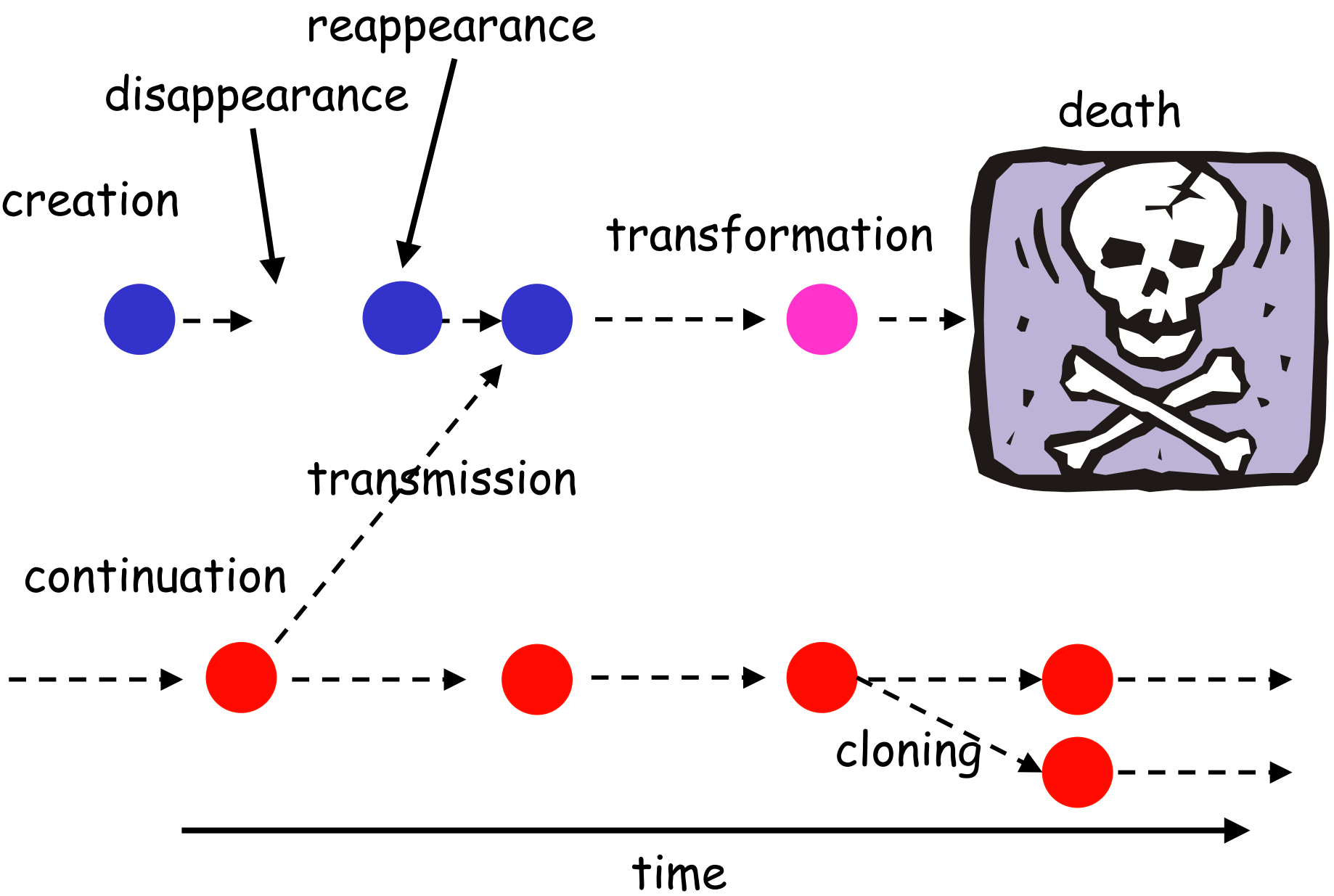
Temporal sequences of continuants

anatomy

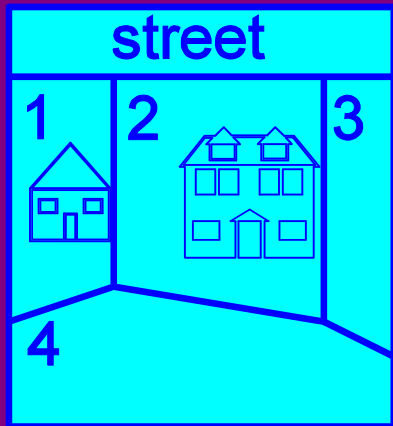
SNAP geo-entities have spatial parts.

Object evolution

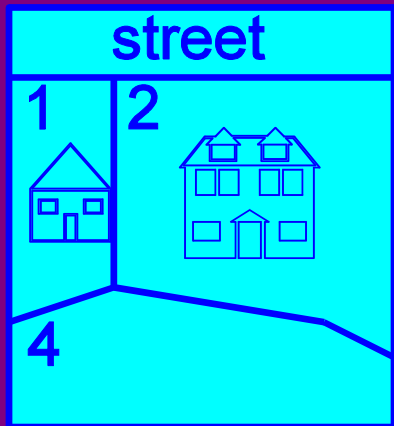
An intermediate stage



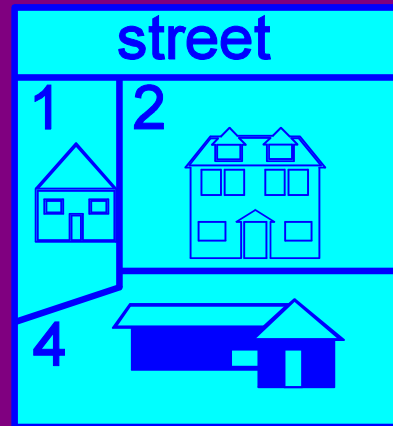
Changing patterns of houses, schools, and streets



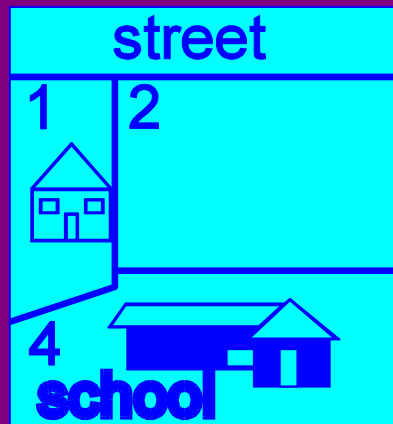
1908



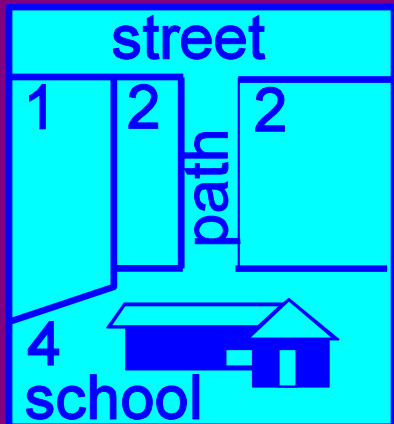
1920



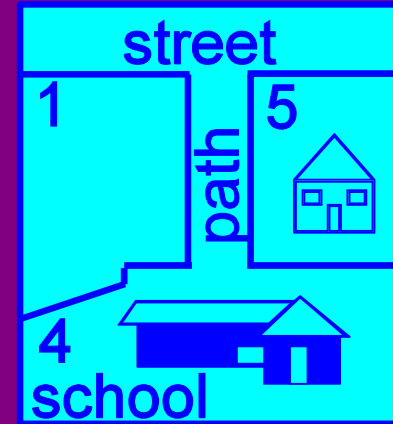
1938



1958



1964



1974

Components of object change

Creation/deletion/(reincarnation)

Appearance/disappearance

Fission/fusion

Attribute change: spatial
(position, shape, size), aspatial

Relationship change: spatial,
aspatial

Partonomic change

Taxonomic change

...

Classification of boundary changes

(Oregon Department of Revenue, 1999)

An **annexation** occurs when one district extends its boundaries outside of its previous service area. . . .

A **merger** occurs when two or more districts formed under the same statutory authority, providing the same services, agree to operate as one district. One of the districts is the "surviving" district. . . .

A **consolidation** occurs when two or more districts agree to dissolve and form a new district providing the same services as the old districts. . . .

A **division** occurs when an existing district is divided into two or more smaller districts. . . . The "existing" district is dissolved. . . .

A **new district** is formed after an election or action of the county governing body. . . .

SPAN

Occurrent, perdurants

entities that happen or occur

lectures, people's lives, boat races

SPAN

collections of occurrents

physiology

SPAN entities have temporal parts.

Structure of SPAN domains

Event properties

Event-event relationships

Object-event
participation relationships



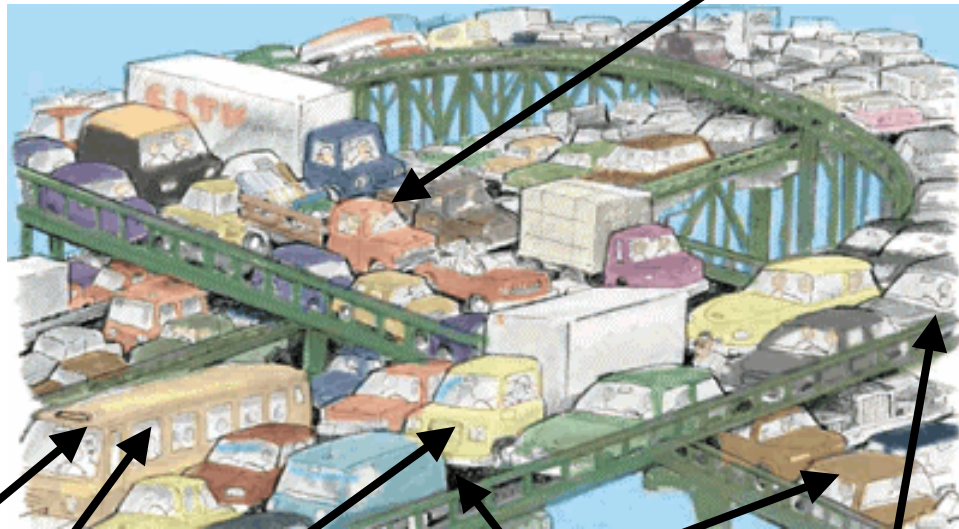
wind

erosion

cliffs

sea

gridlock



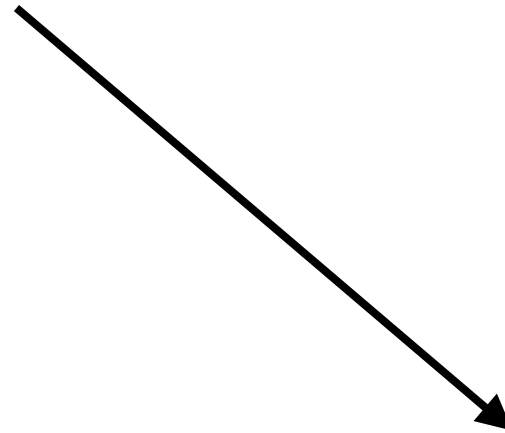
cars

bridges

people

handshake





handshake

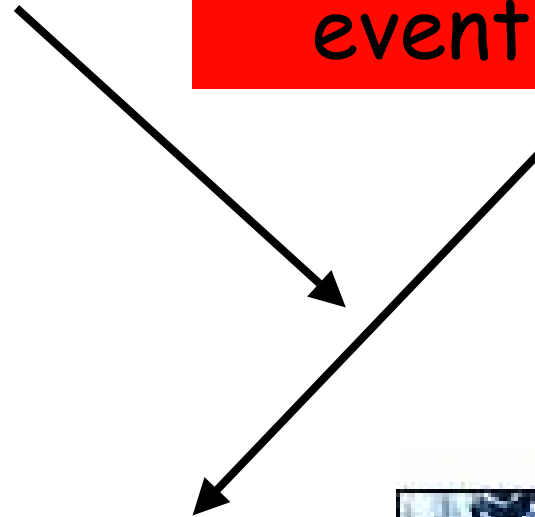


marriage



handshake

legal
event



marriage

Reasoning with events: event calculus (Kowalski and Sergot 1986)

Narrative based

Dependent on an independent time domain

Sorts:

Events

Fluents (time-varying propositions)

Times

Predicates

Occurs (event, time)

HoldsAt (fluent, time)

Initiates (event, fluent, time)

Terminates (event, fluent, time)

Theory examples

A fluent is true once it has been initiated by an event.

A fluent is false once it has been terminated and before it has been initiated.

Event-event relationships (roughly)

Given events e and f , and times t and t' ,
where $t' \geq t$:

$\text{occur}(e,t) \Rightarrow \text{occur}(f,t')$	sufficiency
$\text{occur}(e,t) \Rightarrow \neg \text{occur}(f,t')$	blocking
$\neg \text{occur}(e,t) \Rightarrow \text{occur}(f,t')$	exception
$\neg \text{occur}(e,t) \Rightarrow \neg \text{occur}(f,t')$	necessity

Temporal interval-based calculi

For a finer-grained discussion of SPAN entity properties and relations, we need to take account of their duration.

Allen's work on temporal interval logics.

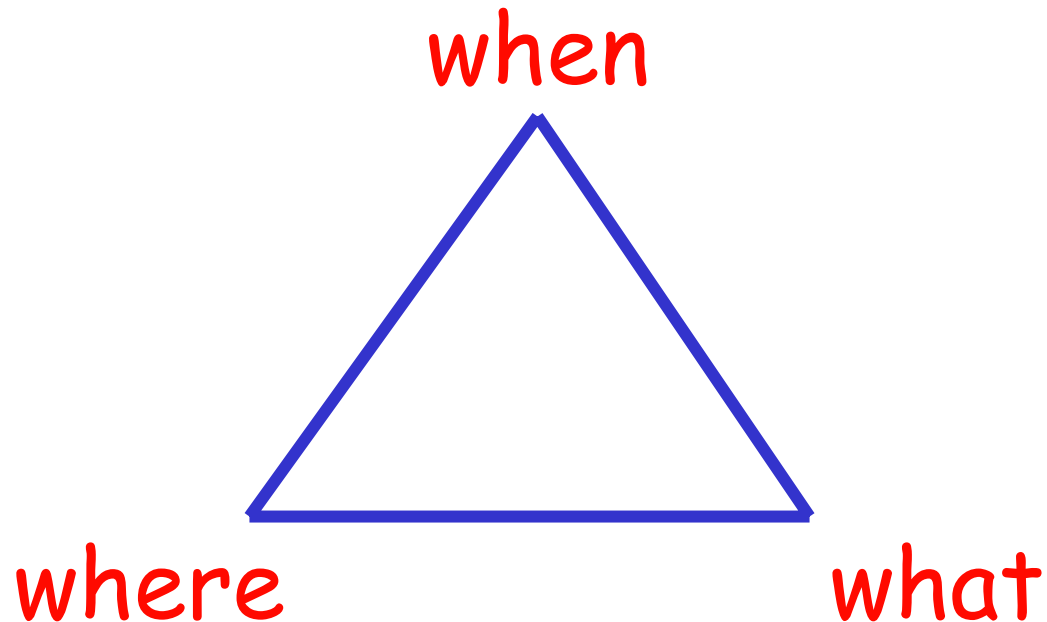
Leverages on event calculus.

Adds interval algebra.

Plus extra axioms that combine these properly, e.g.

$$\text{holds}(p, t) \equiv \forall t' (\text{in}(t', t) \Rightarrow \text{holds}(p, t'))$$

From the triad representation of ST-objects...



to ...

Event structure

time (when?)

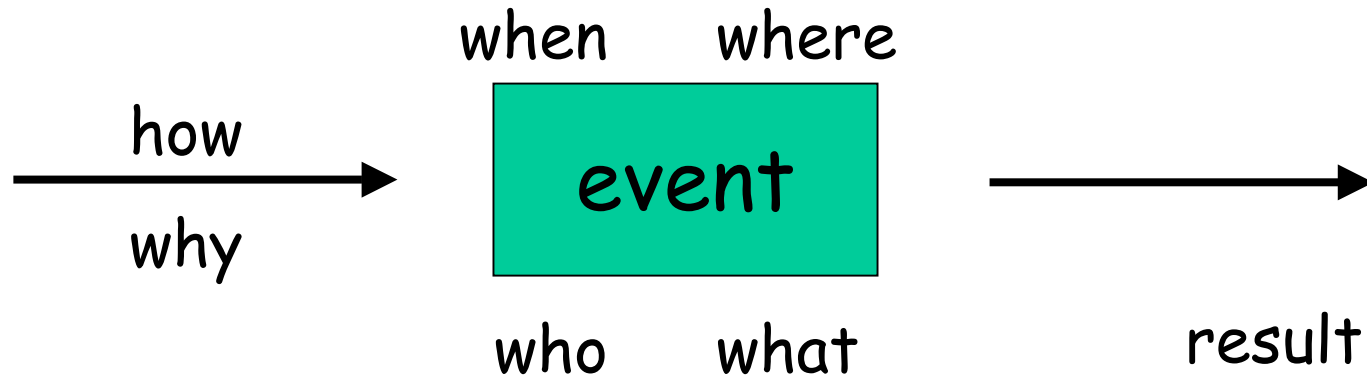
place (where?)

intention (why?)

causality (how?)

protagonist(s) (who?, what?)

goal (result?)



EVERYTHING

IS

PROCESS

Using computational process theory to model geo-events

There are well-developed process theories in computer science.

Petri, C.A., Fundamentals of a theory of asynchronous flow, 1963.

Milner, R. A calculus of communicating systems, 1980.

Hoare, C. Communicating sequential processes, 1985.

Riely, J. and Hennesy, M., A typed language of distributed mobile processes, 1998.

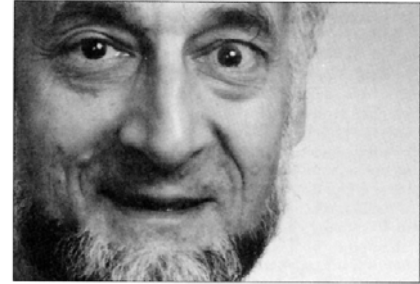
There is computer science research on formal models of mobility.

Cardelli, L. and Gordon, A. Mobile ambients, 1999.

Milner, R., Communicating and mobile systems, the π -calculus, 1999.

Link with foundations of computer science

(Milner's 93 Turing Award lecture)



sequential computing

program meaning = memory \rightarrow memory

function calculus

λ -calculus

distributed information systems

concurrency

interaction

process calculus

π -calculus

Basic process and mobility concepts

Process names and constructions

Process equivalence

Independence vs. reaction

Synchronous vs. asynchronous

Determinism vs. non-determinism

Operations

Composition $a.P$

Disjunction $P+Q$

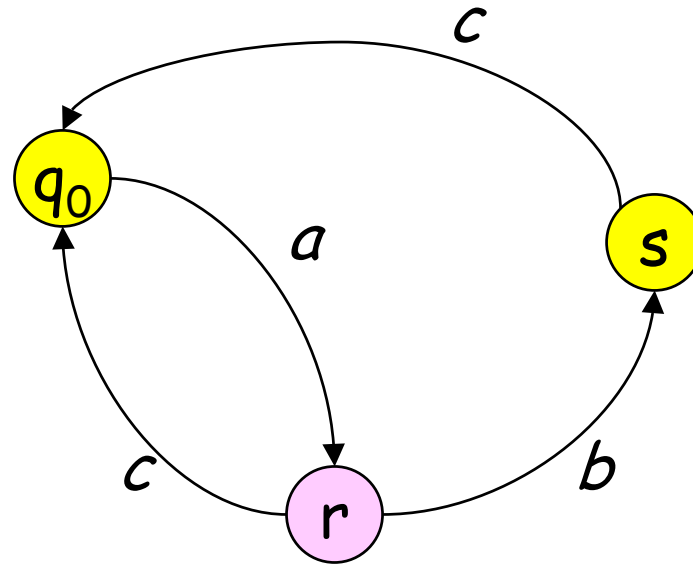
Parallelism $P|Q$

Reaction $((\text{in } a)P+Q)|((\text{out } a)R+S) \rightarrow P|R$

Replication $!P$

Ambient $n[P]$

Process model



This process is **deterministic**, as there is at most one transition (q, a, q') , for each pair (q, a) .

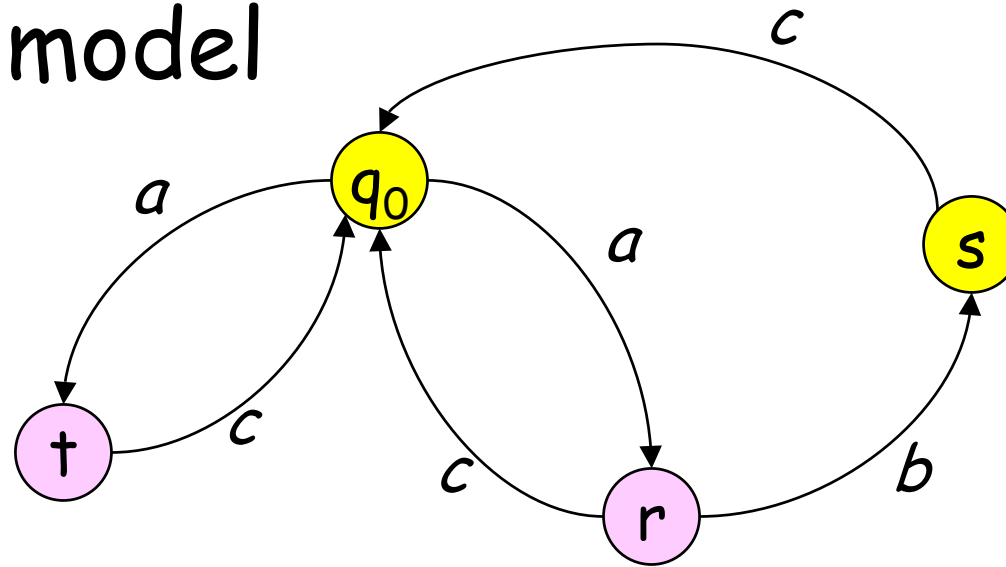
Process notation:

$$Q_0 == aR$$

$$R == bS + cQ_0$$

$$S == cQ_0$$

Process model



This process is **nondeterministic**, as there is more than one transition a with start state q_0 .

Process notation:

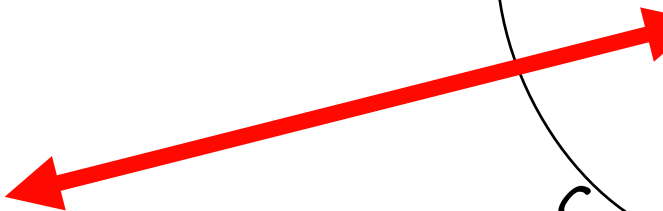
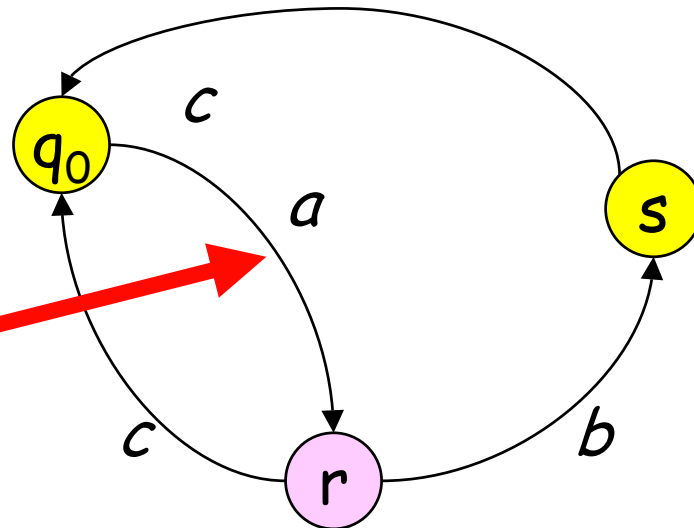
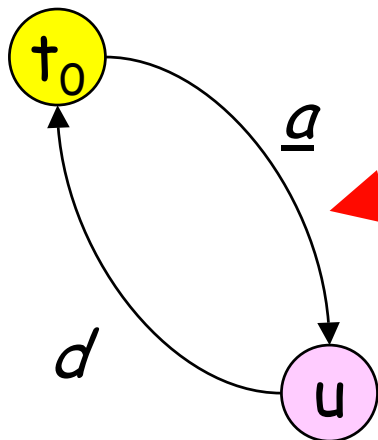
$$Q_0 == aR + aT = a(R+T)$$

$$R == bS + cQ_0$$

$$S == cQ_0$$

$$T == cQ_0$$

Process model



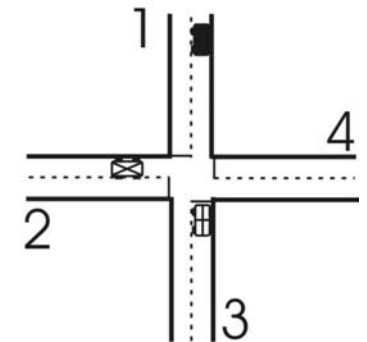
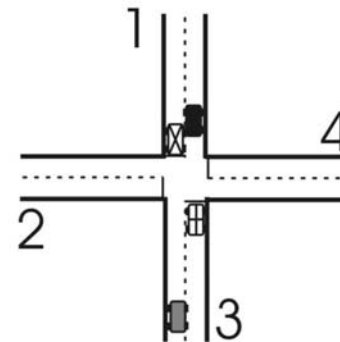
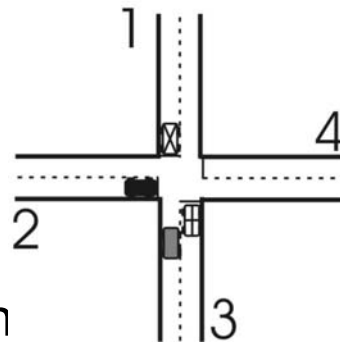
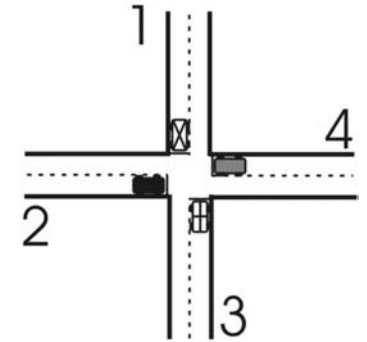
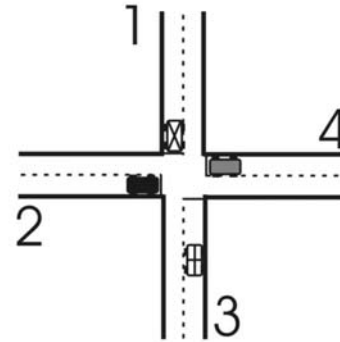
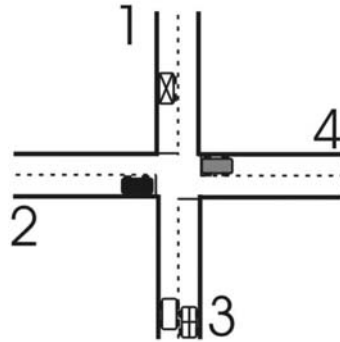
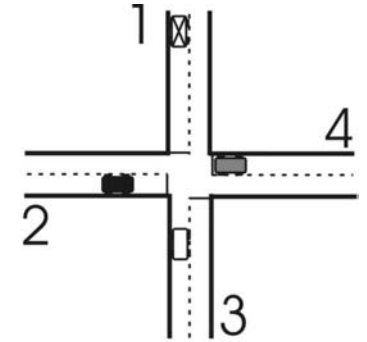
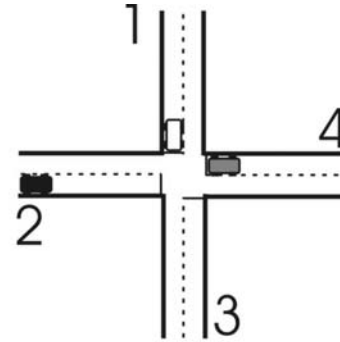
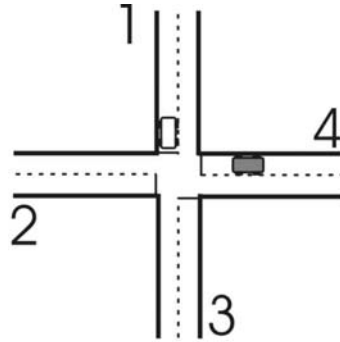
These processes communicate via input action a and output action \underline{a} . The combined process is $Q_0 \mid T_0$

Process notation:

$$\begin{aligned}
 Q_0 &== aR \\
 R &== bS + cQ_0 \\
 S &== cQ_0 \\
 T_0 &== \underline{a}U \\
 U &== dT_0
 \end{aligned}$$

$$\begin{array}{c}
 Q_0 \mid T_0 \\
 \downarrow \\
 U \mid R \\
 \downarrow
 \end{array}$$

Fourway stop



Fourway stop processes

$$X = \sum_i a_i X_i$$

$$X_i = \bar{b}_i X + \sum_{j \neq i} a_j X_{ij}$$

$$X_{ij} = \bar{b}_i X_j + \sum_{k \neq i, j} a_k X_{ijk}$$

$$X_{ijk} = \bar{b}_i X_{jk} + \sum_{l \neq i, j, k} a_l X_{ijkl}$$

$$X_{ijkl} = \bar{b}_i X_{jkl}$$

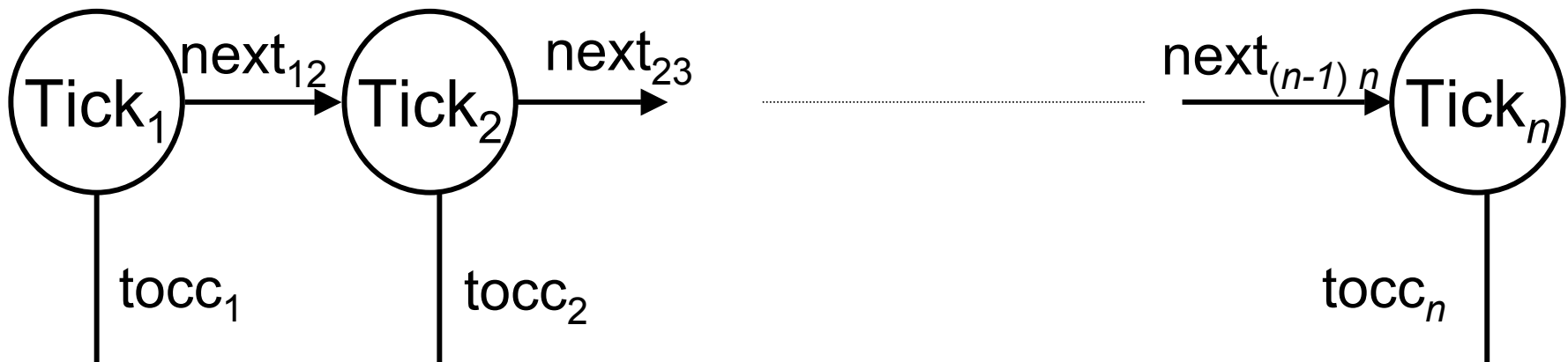
Pure process model of ST

Modeling (linear) time

Construct a collection of 'tick' processes,
 $\text{Tick}_1, \dots, \text{Tick}_n$

Two consecutive ticks share a common
channel.

There is also a 'tocc' channel through which
each 'tick' can be occupied.



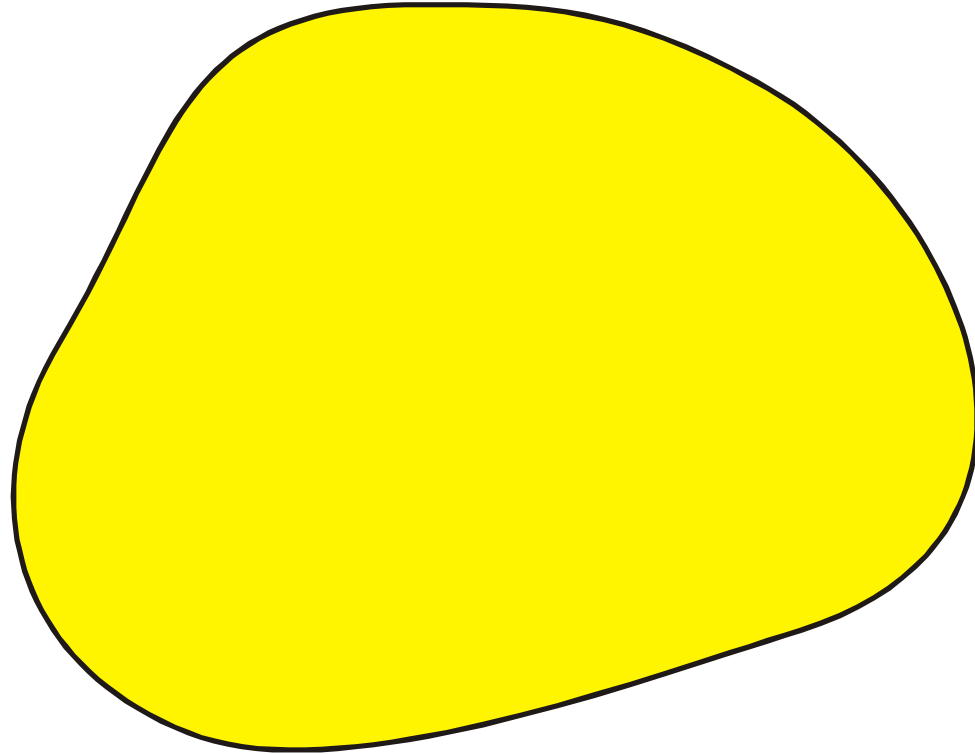
Modeling location

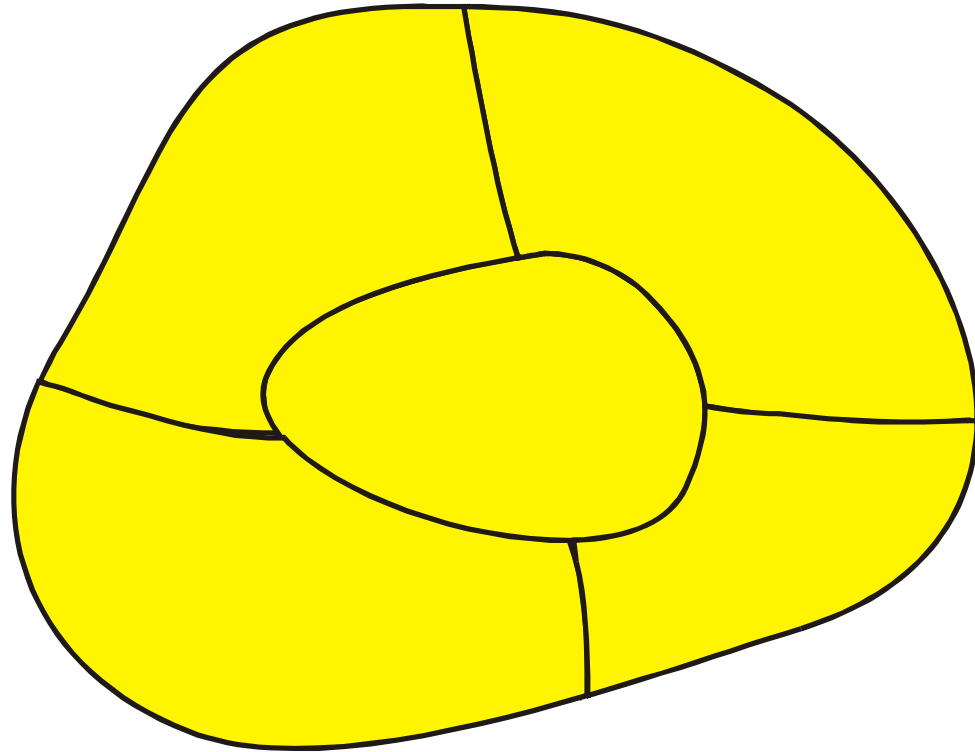
Assume a simple model of a region partitioned into a set of atomic locations.

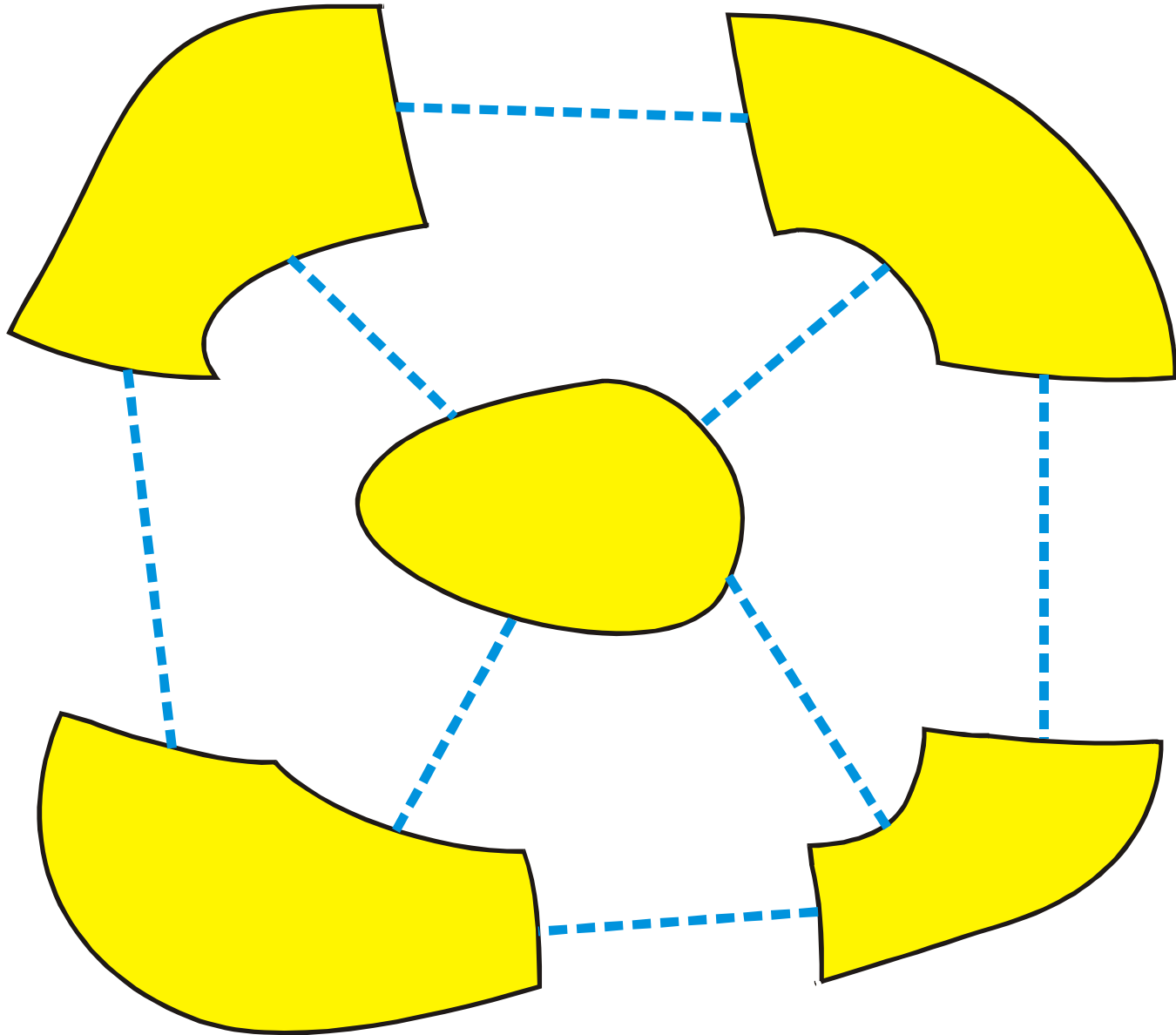
Construct a collection of 'loc' processes, Loc_1, \dots, Loc_n .

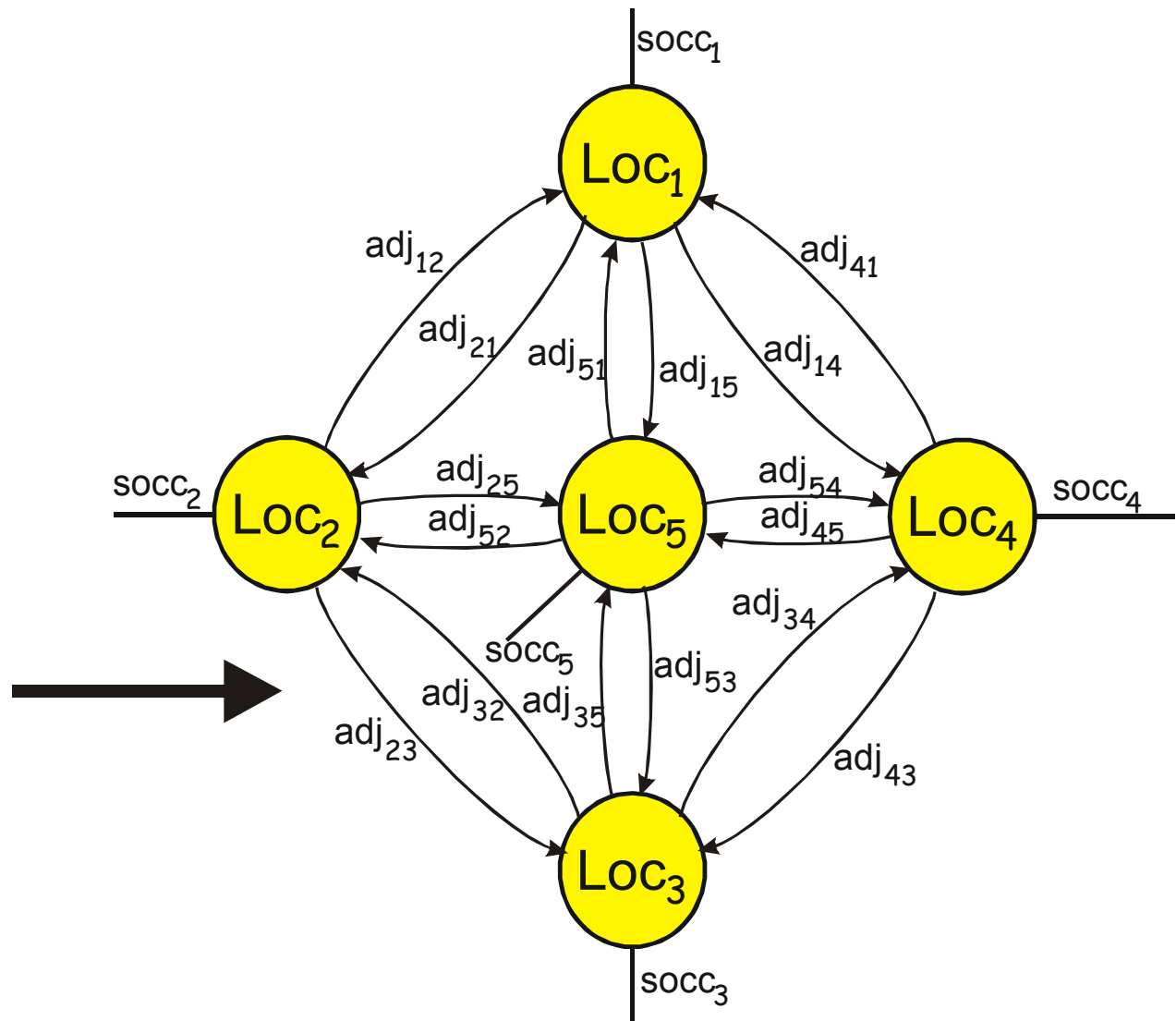
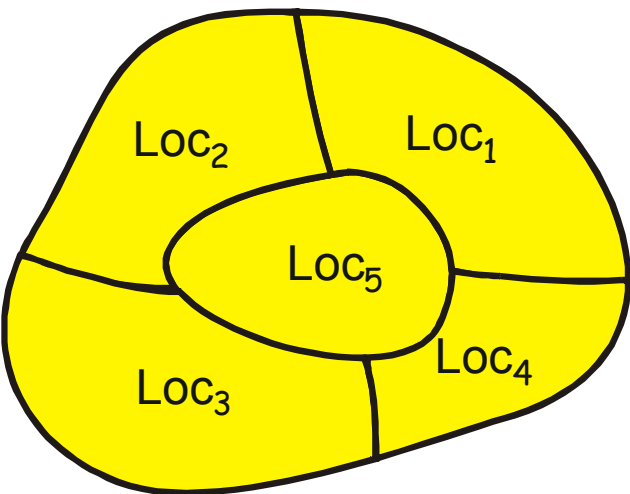
Two directionally adjacent locs share a common channel.

There is also a channel through which each location can be occupied.









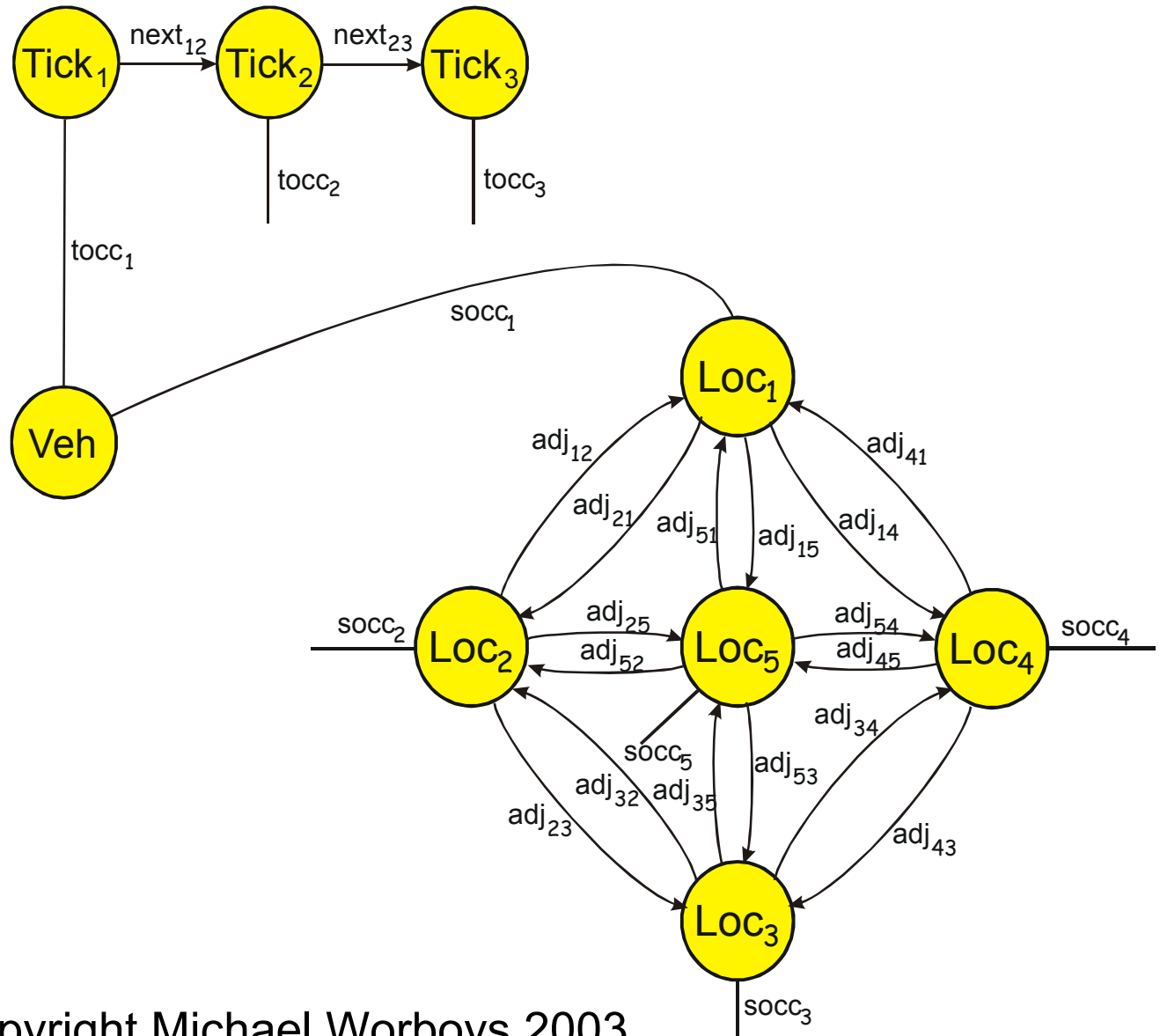
ST-entities

A **spatially referenced entity** is an entity that has at least one socc channel, capable of handshaking with a collection of locations.

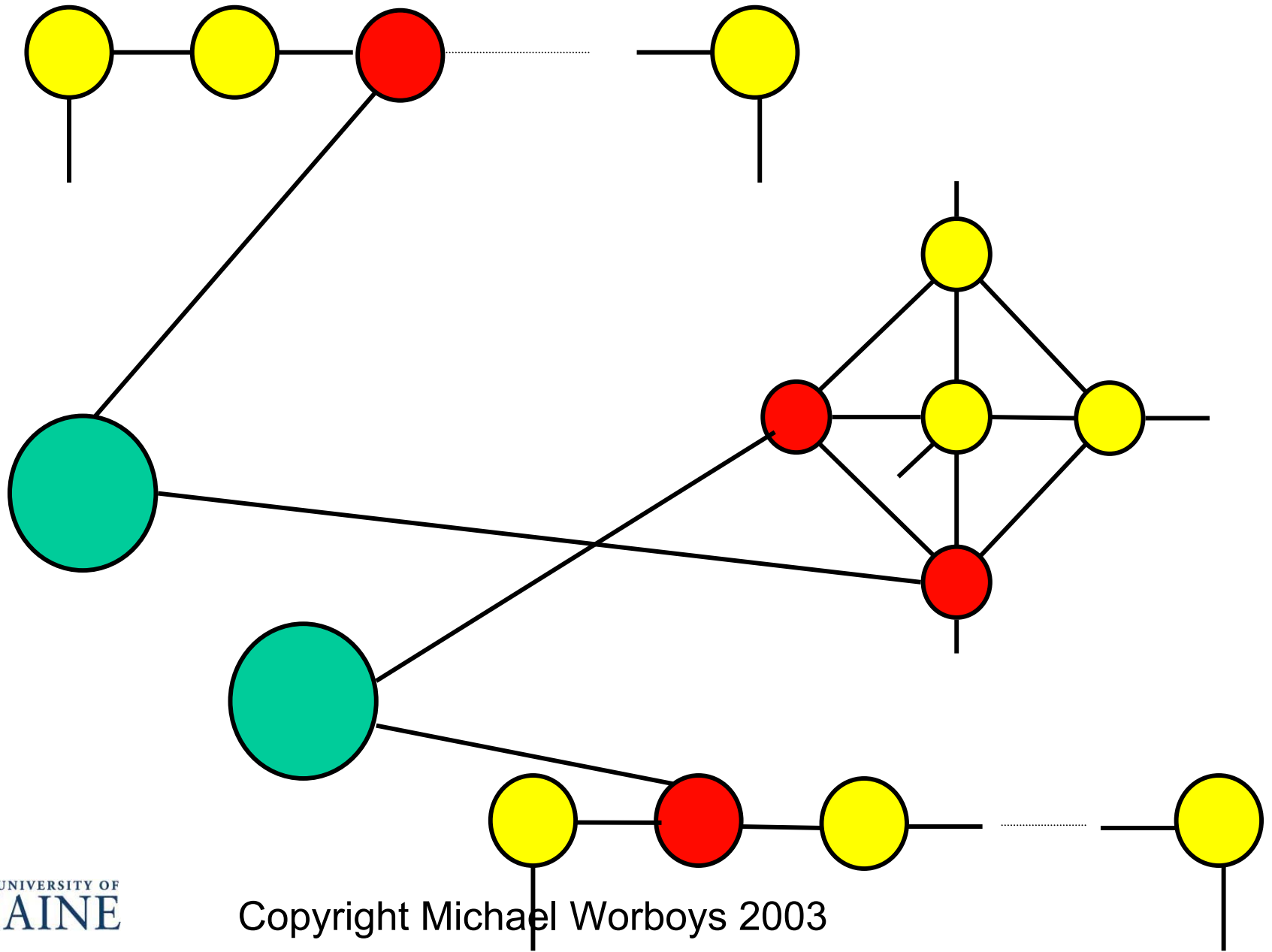
A **temporally referenced entity** is an entity that has at least one tocc channel, capable of handshaking with a collection of temporal processes.

An **ST-entity** is an spatially and temporally reference entity.

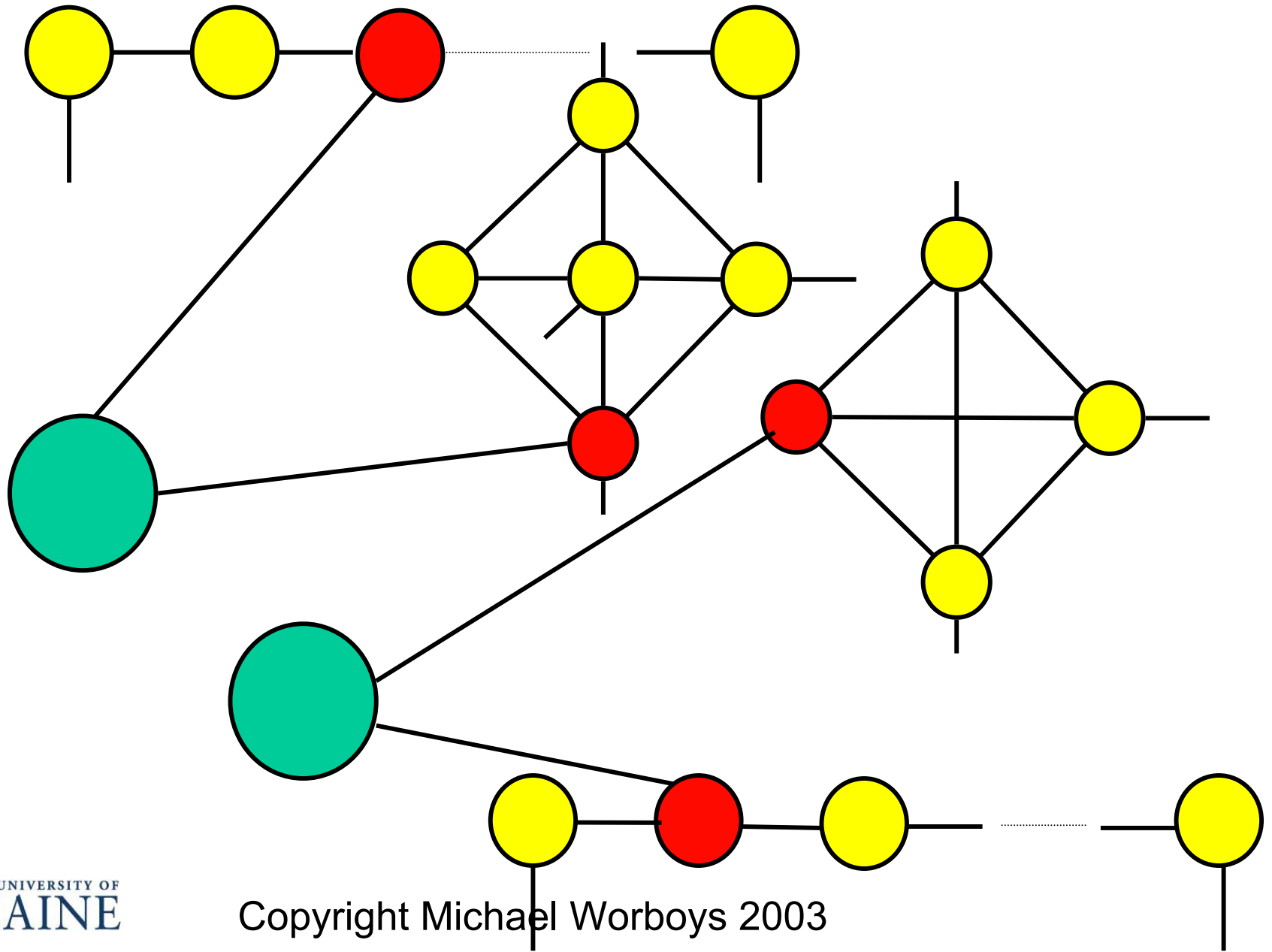
ST-entity



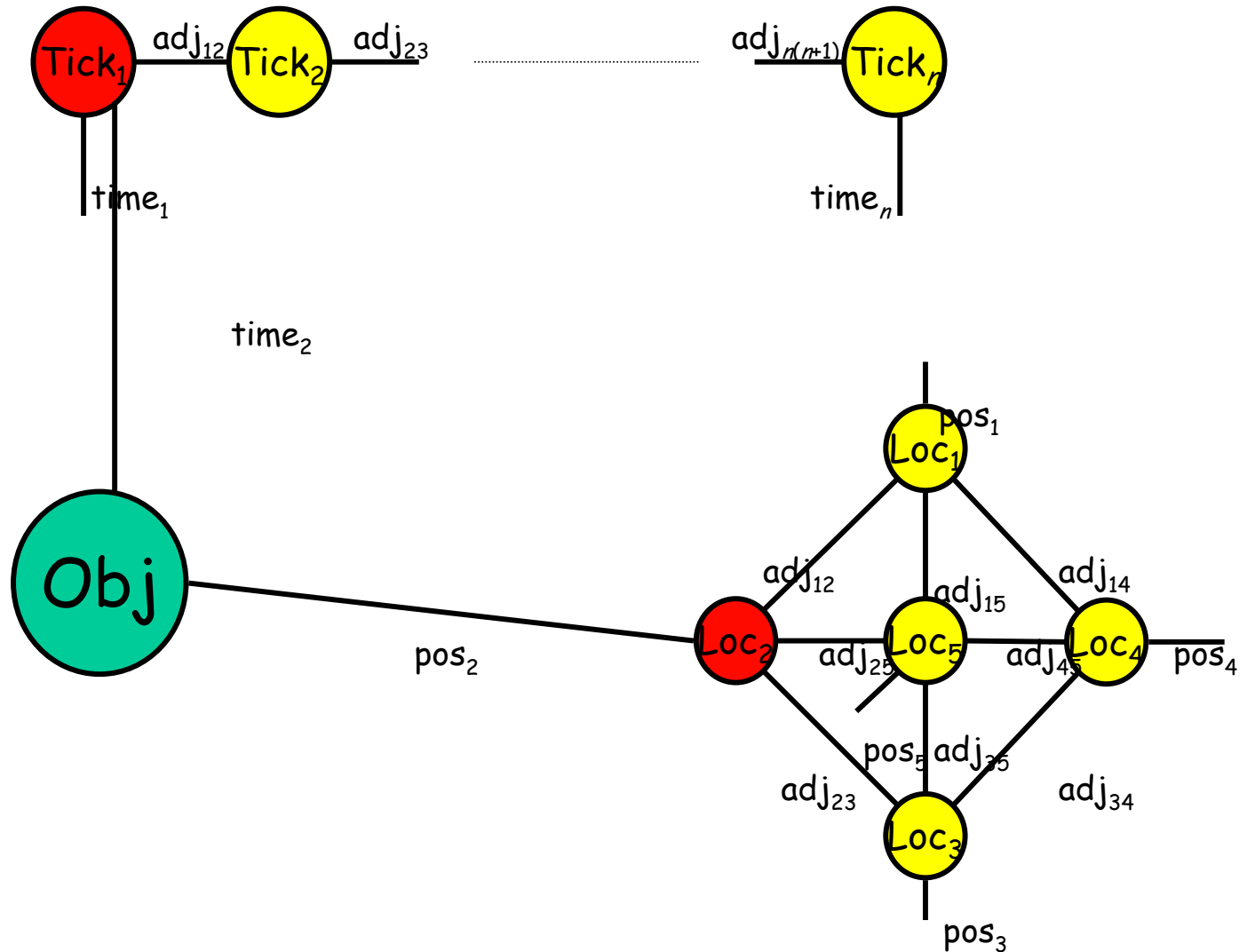
Asynchronic/syntopic process model



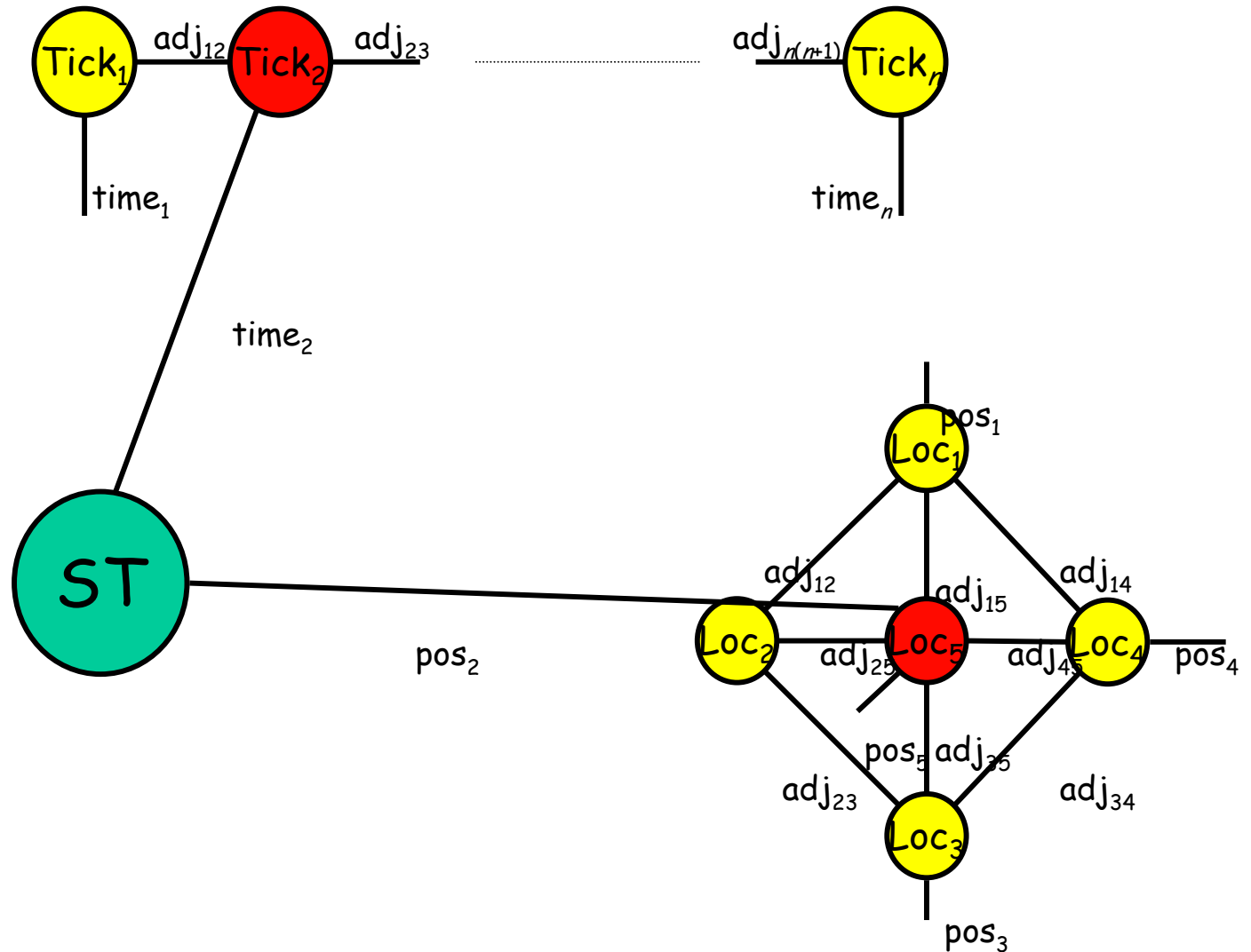
Asynchronic/asyntopic process model



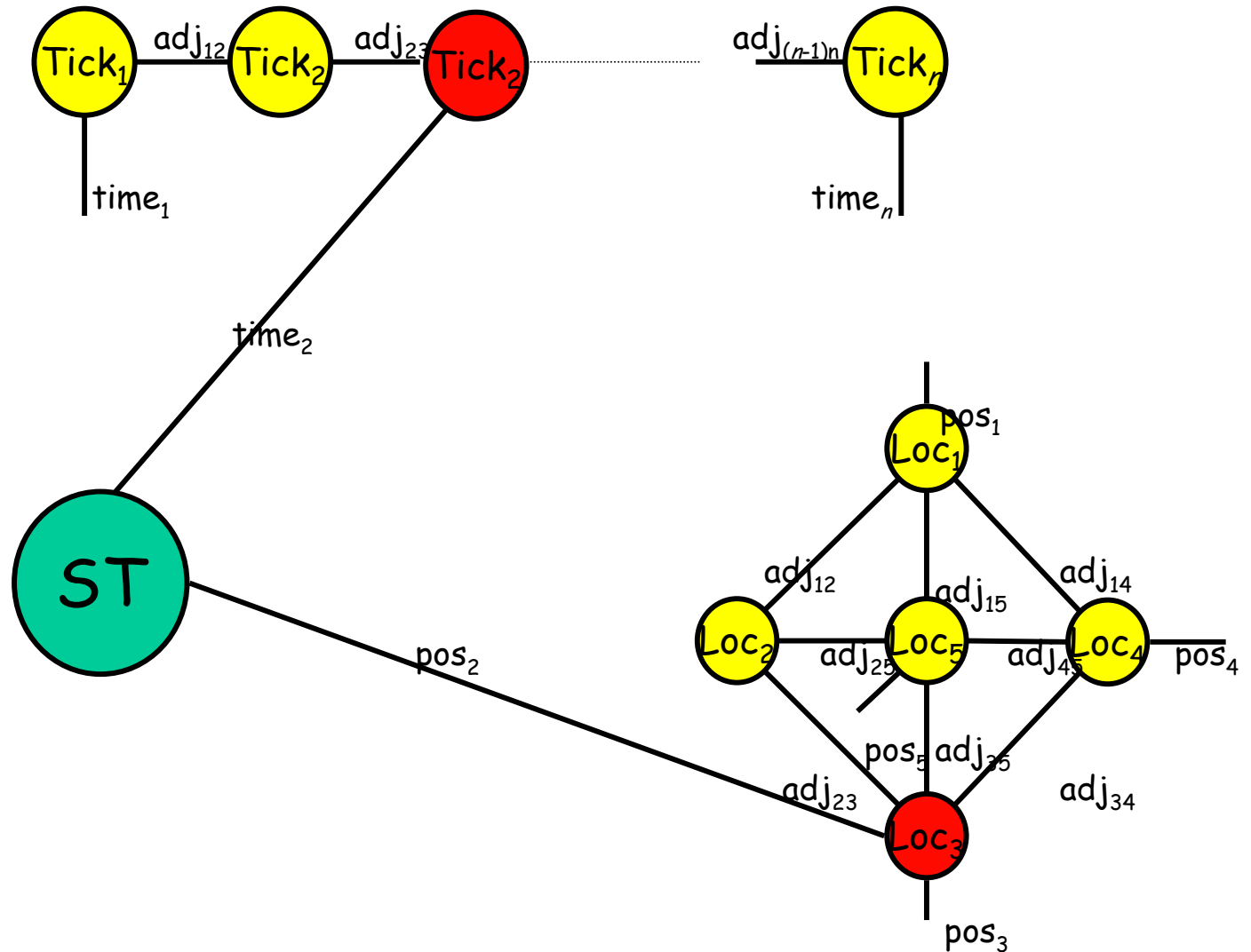
Modeling motion



Spatiotemporal object/process



Spatiotemporal object/process



The equations!

$$\text{Tick}_1 = \text{tstart}_1.\text{toCC}_1.\overline{\text{next}}_{12}.\text{Tick}_1$$

$$\text{Tick}_2 = (\text{tstart}_2 + \text{next}_{12}).\text{toCC}_2.\overline{\text{next}}_{23}.\text{Tick}_2$$

$$\text{Tick}_3 = (\text{tstart}_3 + \text{next}_{23}).\text{toCC}_3.\text{Tick}_3$$

$$\text{Loc}_1 =$$

$$(\text{sstart}_1 + \text{adj}_{21} + \text{adj}_{51} + \text{adj}_{41}).\text{socC}_1.$$

$$(\overline{\text{adj}}_{12} + \overline{\text{adj}}_{15} + \overline{\text{adj}}_{14}).\text{Loc}_1$$

$$\text{Loc}_2 =$$

$$(\text{sstart}_2 + \text{adj}_{12} + \text{adj}_{52} + \text{adj}_{32}).\text{socC}_2.$$

$$(\overline{\text{adj}}_{21} + \overline{\text{adj}}_{25} + \overline{\text{adj}}_{23}).\text{Loc}_2$$

$$\text{Loc}_3 =$$

$$(\text{sstart}_3 + \text{adj}_{23} + \text{adj}_{53} + \text{adj}_{43}).\text{socC}_3.$$

$$(\overline{\text{adj}}_{32} + \overline{\text{adj}}_{35} + \overline{\text{adj}}_{34}).\text{Loc}_3$$

$$\text{Loc}_4 =$$

$$(\text{sstart}_4 + \text{adj}_{14} + \text{adj}_{34} + \text{adj}_{54}).\text{socC}_4.$$

$$(\overline{\text{adj}}_{41} + \overline{\text{adj}}_{43} + \overline{\text{adj}}_{45}).\text{Loc}_4$$

$$\text{Loc}_5 =$$

$$(\text{sstart}_5 + \text{adj}_{15} + \text{adj}_{25} + \text{adj}_{35} + \text{adj}_{45}).\text{socC}_5.$$

$$(\overline{\text{adj}}_{51} + \overline{\text{adj}}_{52} + \overline{\text{adj}}_{53} + \overline{\text{adj}}_{54}).\text{Loc}_5$$

Connections with other work

Simulations of dynamic phenomena

Multi-agent systems

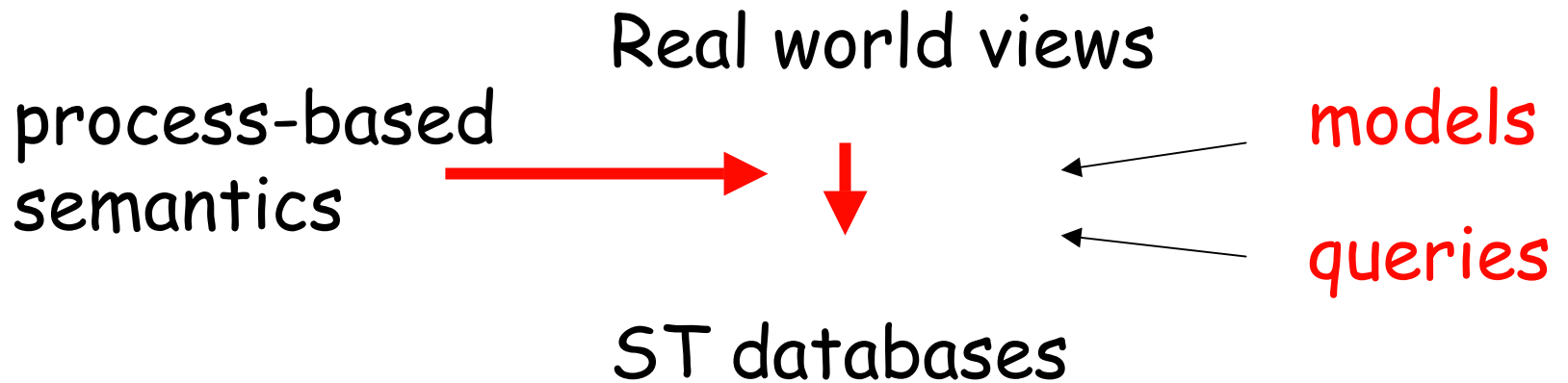
Event mining

Event notification systems

Geosensor systems (e.g. Smart Dust)

Moving object databases

Challenge: Overcome the impedance mismatch



More information

Web site:

<http://www.spatial.maine.edu/~worboys/>

Paper: Event-oriented approaches to geographic phenomena, 2004?

Book: *GIS, A Computing Perspective*, 2nd edition, 2004.

Special Issue of the *Journal of Spatial Cognition and Computation*, 2004.