

System Dynamics and Applied Agent Based Modeling

by Andrei Borshchev

Workshop
“Agent Based Modeling:
Why Bother?”

International System
Dynamics Conference
Boston, July 2005

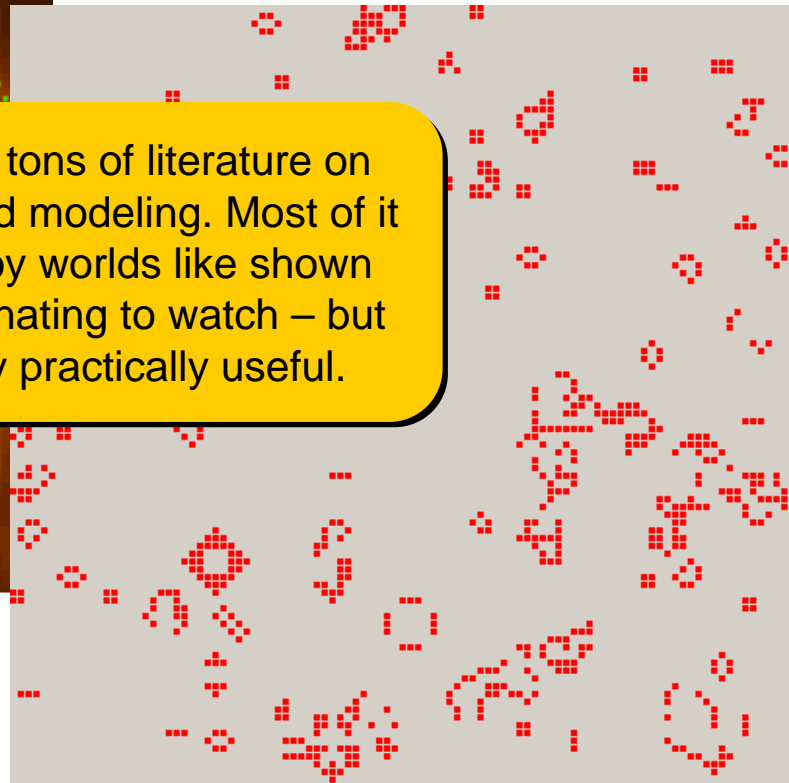


© 2002-2005 XJ Technologies www.xjtek.com

Warning!



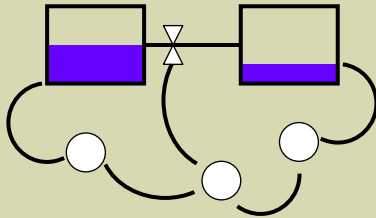
There are tons of literature on agent based modeling. Most of it is about toy worlds like shown here: fascinating to watch – but not really practically useful.



Modeling from different perspectives

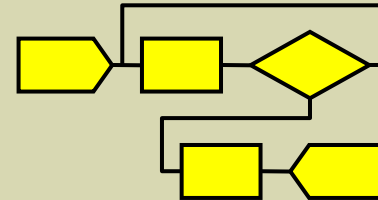
System Dynamics Perspective

Key aggregate variables,
Global feedbacks



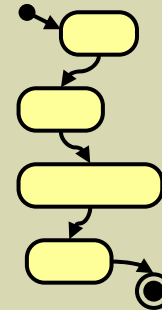
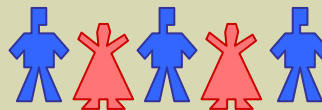
Discrete Event Perspective

Processes: sequence of
operations, resources



THE
SYSTEM

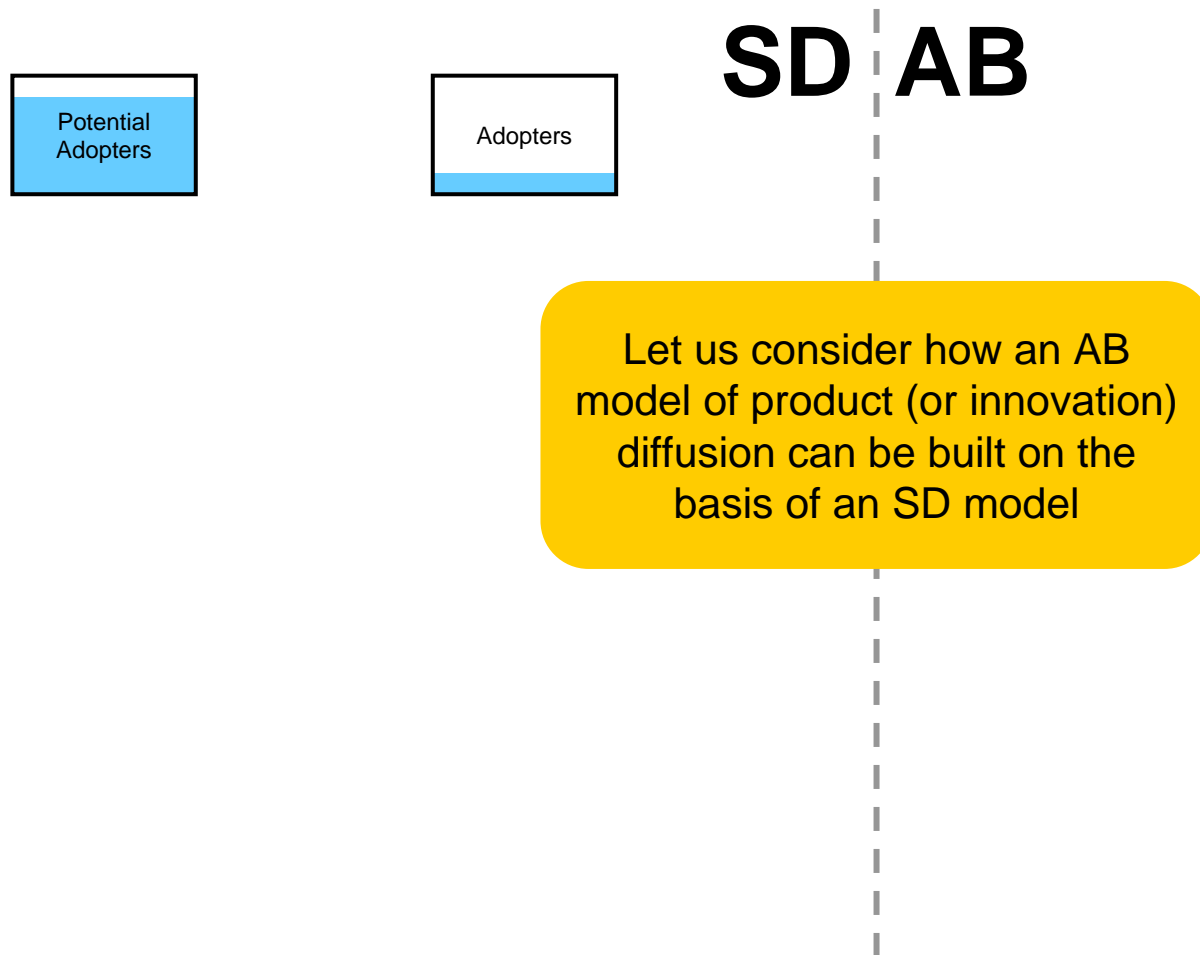
Individual parameters
and state variables,
Personal decisions



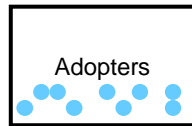
Agent Based Perspective



From SD to AB: model of diffusion



First step: disaggregate

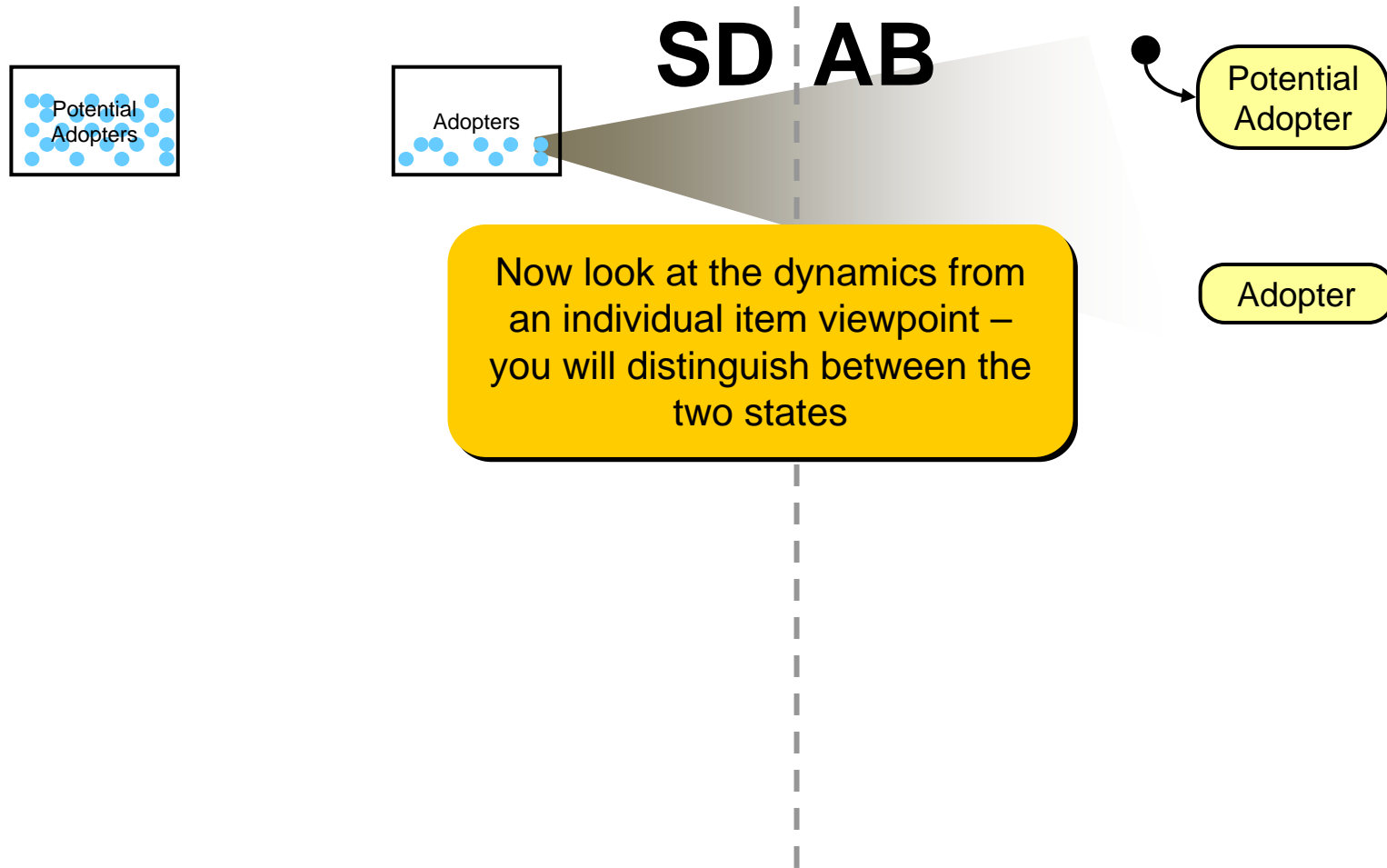


SD | **AB**

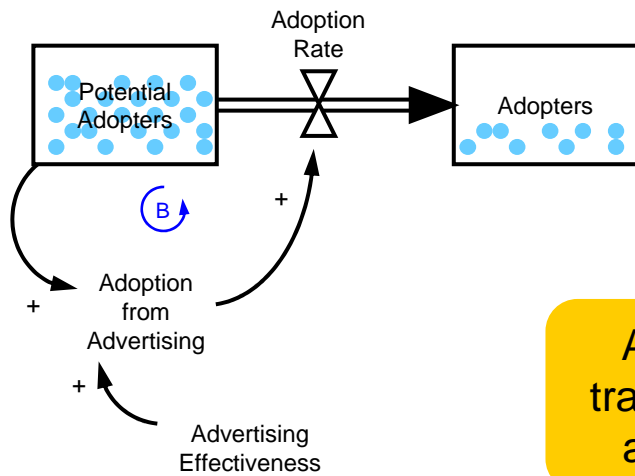
Imagine stocks are not tanks with liquid but boxes with discrete items



Think in terms of States...

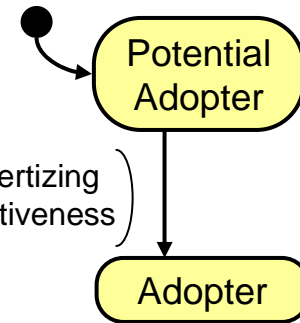


...and transitions



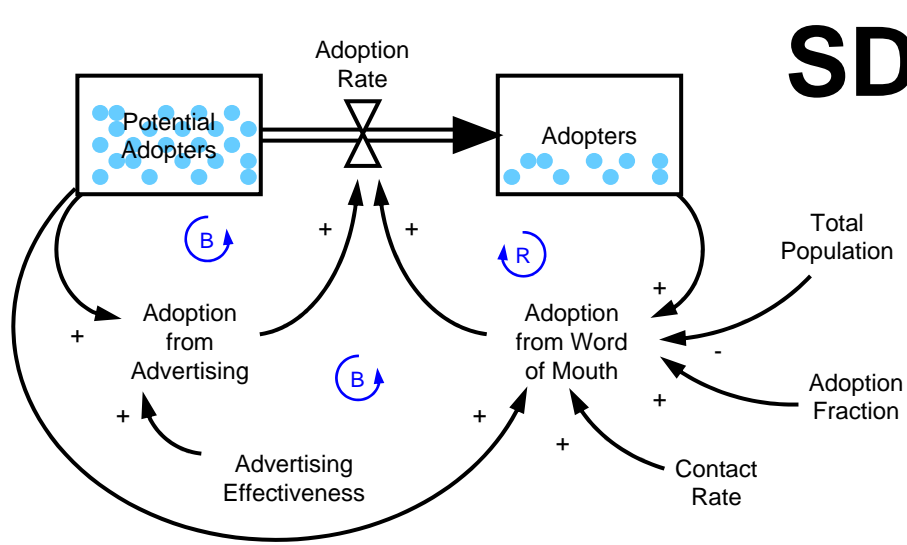
SD AB

exponential (Advertising Effectiveness)

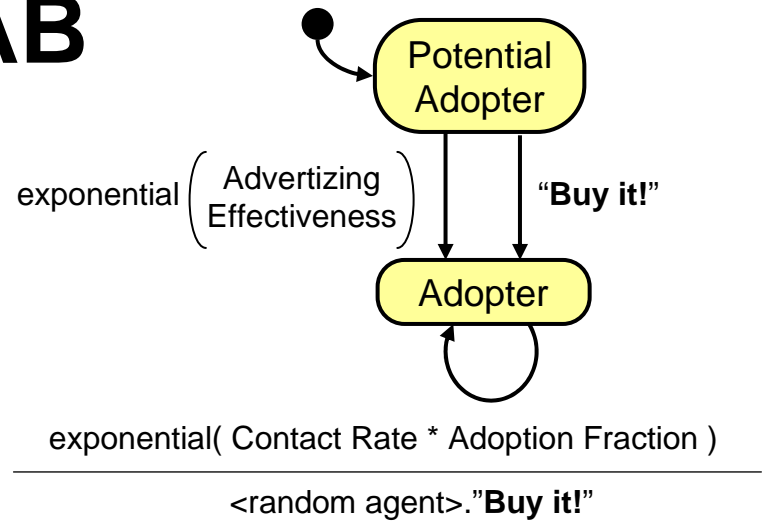


Adoption from Ad is a transition happening with a (stochastic) timeout

Use direct interaction between agents

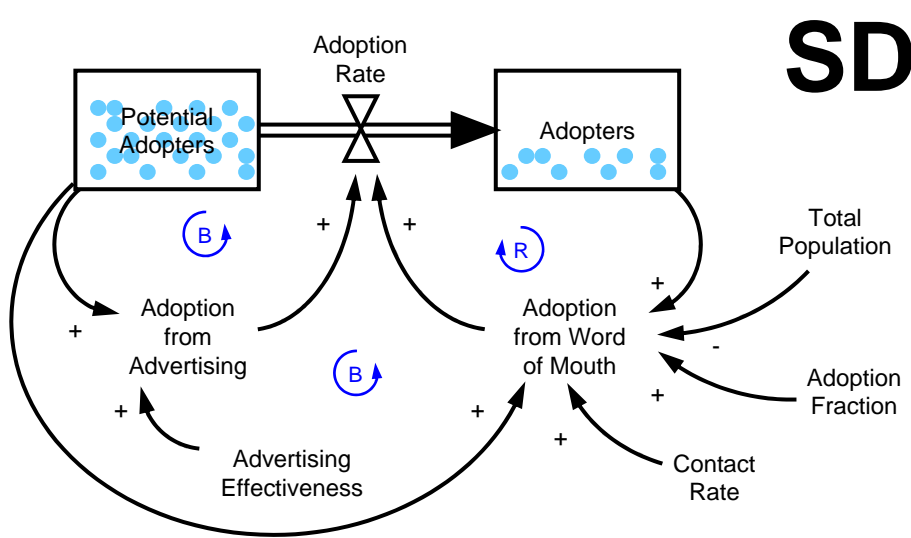


SD AB

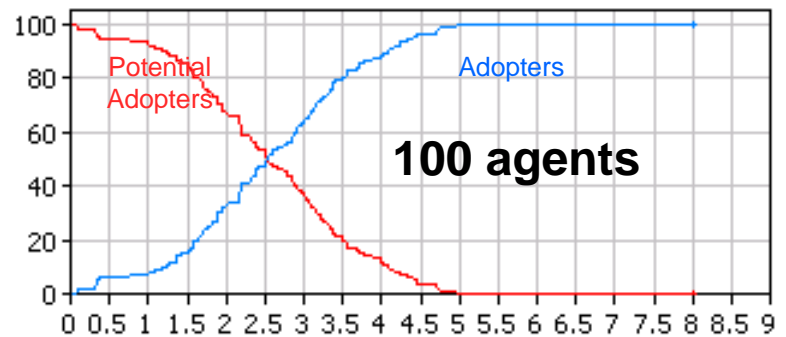
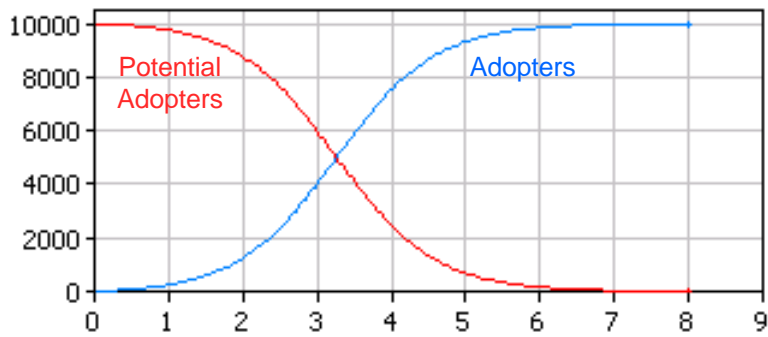
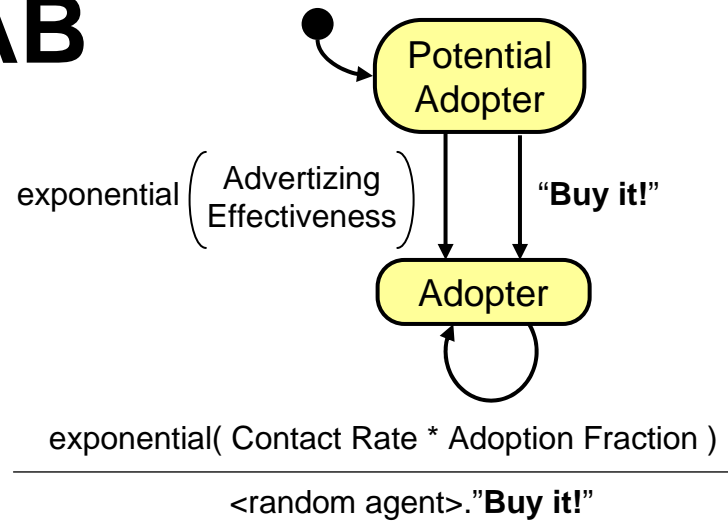


Adoption from WOM is
 a) agents telling other agents "Buy it!"
 b) Other agents reacting to this by taking a transition

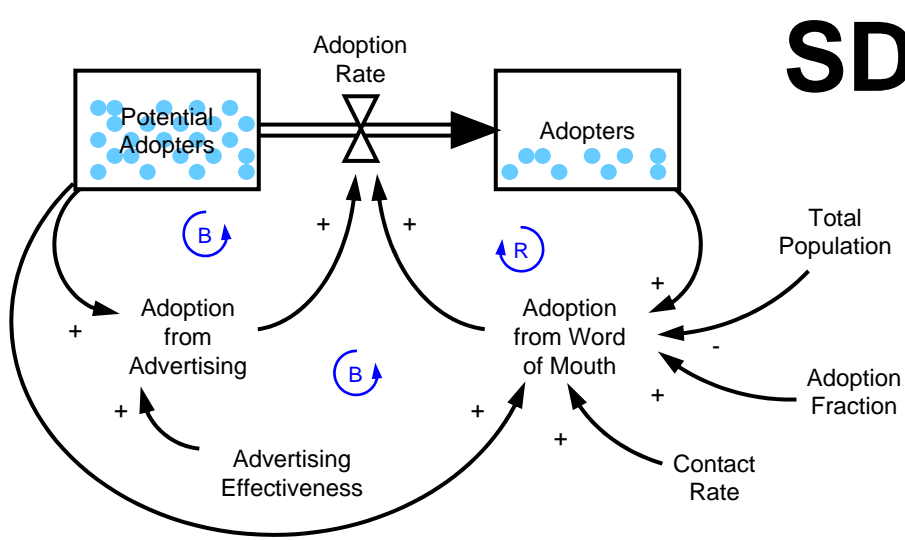
Simulation results: few agents



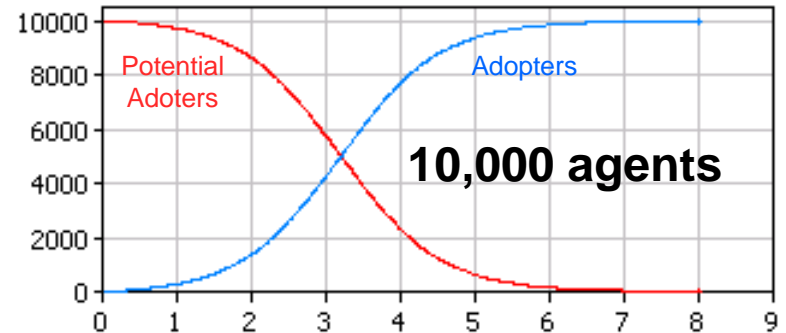
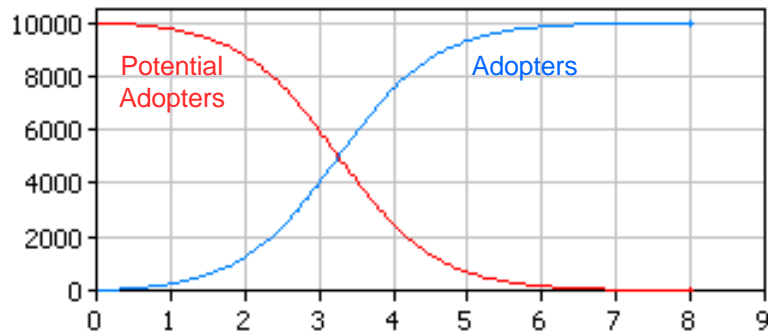
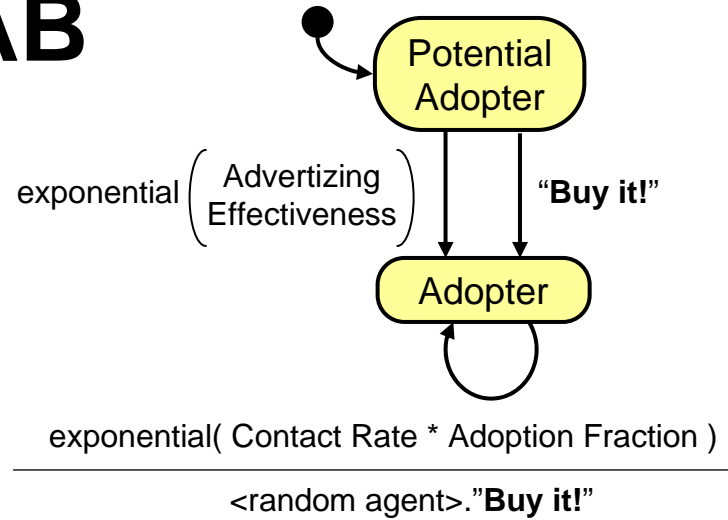
SD AB



Simulation results: more agents



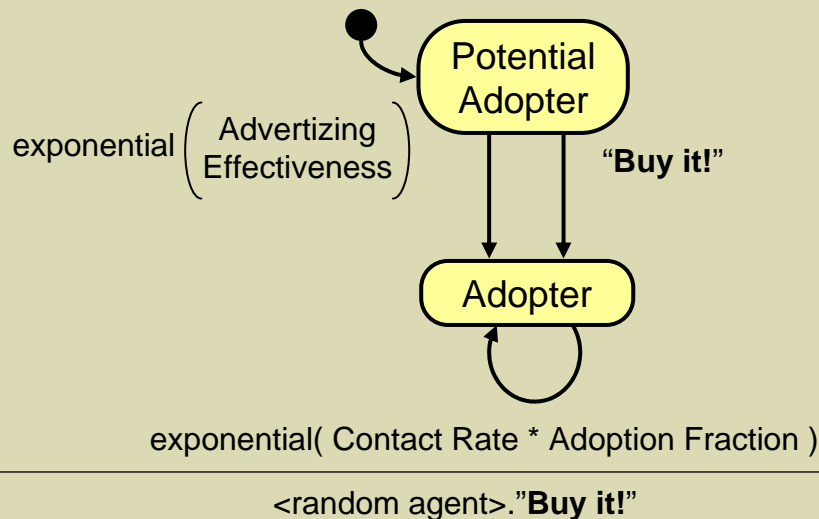
SD AB



Capturing more with AB model

What if WOM effect of a person depends on how recent is a purchase (adoption)?

Person

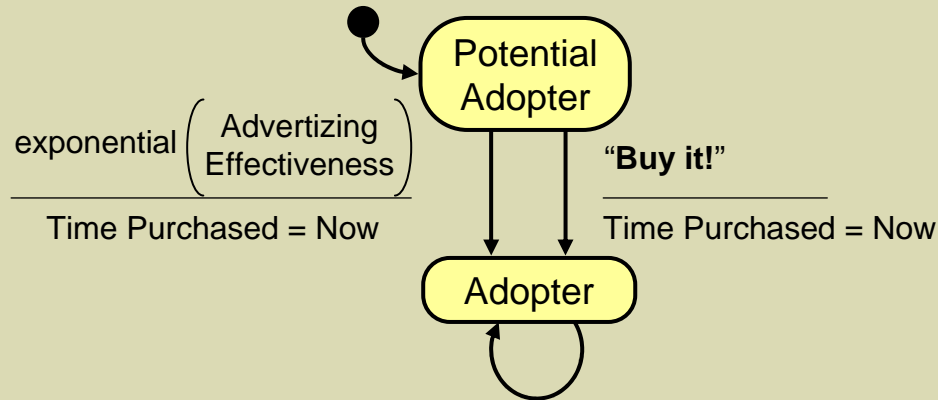


We can store individual information

No problem! We can remember the time of purchase in an agent's variable and let WOM effect depend on it!

Person

- Time Purchased



$\frac{\text{exponential}(\text{Contact Rate} * \text{Adoption Fraction}(\text{Now} - \text{Time Purchased}))}{\text{<random agent>."Buy it!"}}$

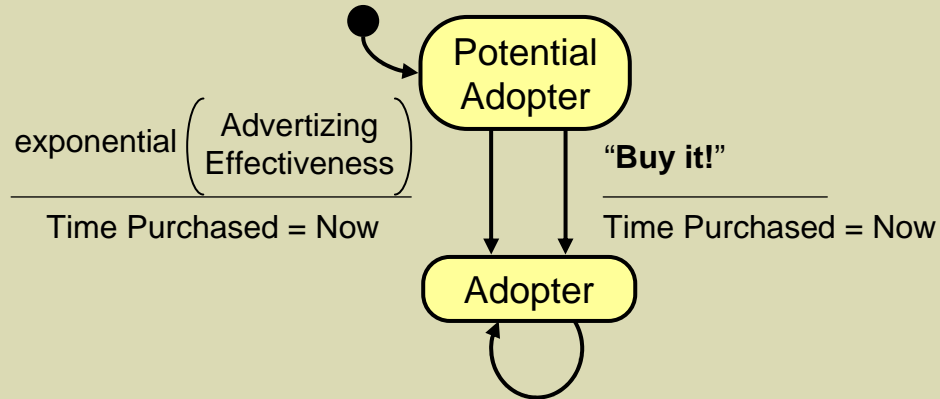
...

Same for Age – just remember the birth date

Person

● Time Purchased

● Birth date

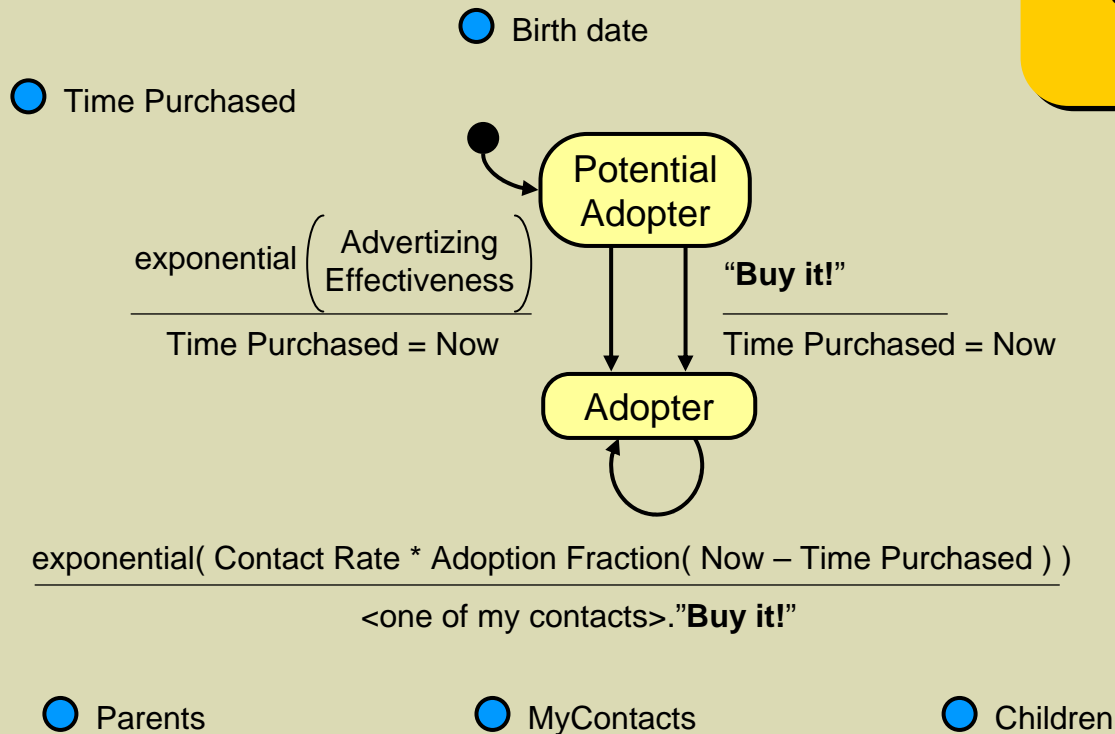


$\frac{\text{exponential}(\text{Contact Rate} * \text{Adoption Fraction}(\text{Now} - \text{Time Purchased}))}{\text{Time Purchased = Now}}$
<random agent>."Buy it!"

We can maintain social networks

People only have a limited number of contacts? We can model any kind of social network!

Person



We can model co-behaviors!

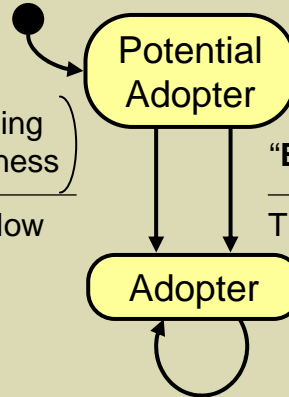
Need to model the (changing) level of education? Include another statechart concurrent to the agent purchase behavior!

Person

● Time Purchased

● Birth d

$\frac{\text{exponential} \left(\text{Advertising Effectiveness} \right)}{\text{Time Purchased} = \text{Now}}$



$\frac{\text{"Buy it!"}}{\text{Time Purchased} = \text{Now}}$

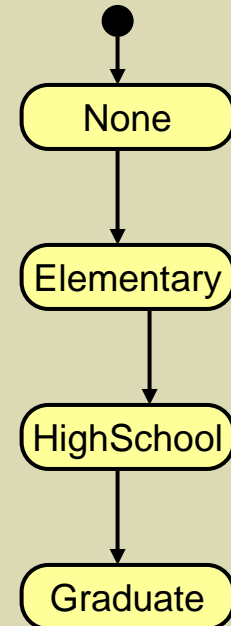
$\frac{\text{exponential}(\text{Contact Rate} * \text{Adoption Fraction}(\text{Now} - \text{Time Purchased}))}{\text{<one of my contacts>."Buy it!"}}$

● Parents

● MyContacts

● Children

Education

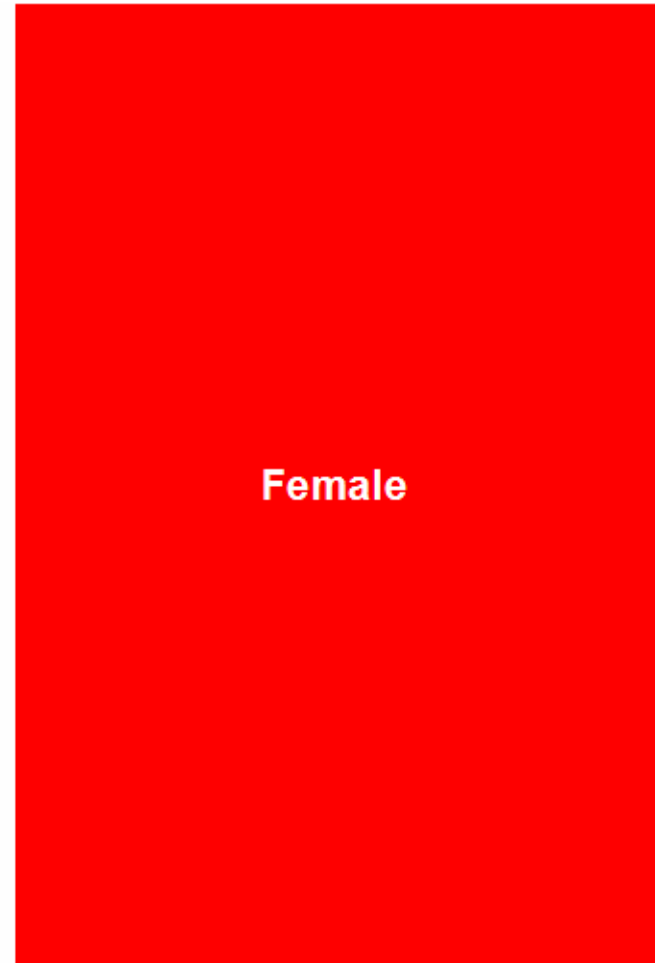
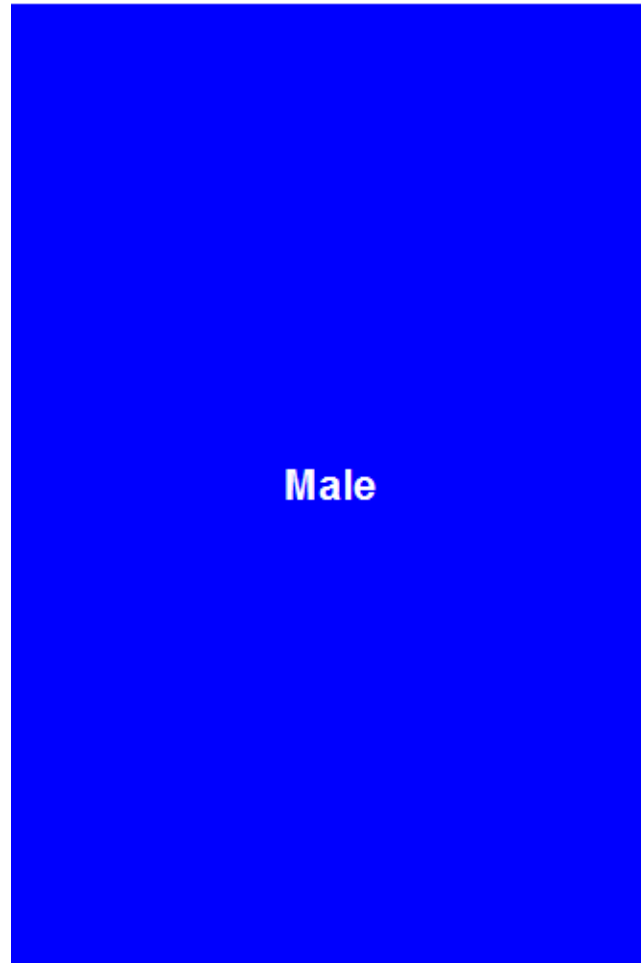


Can you do that in SD? You can try...

Consider a population...

People

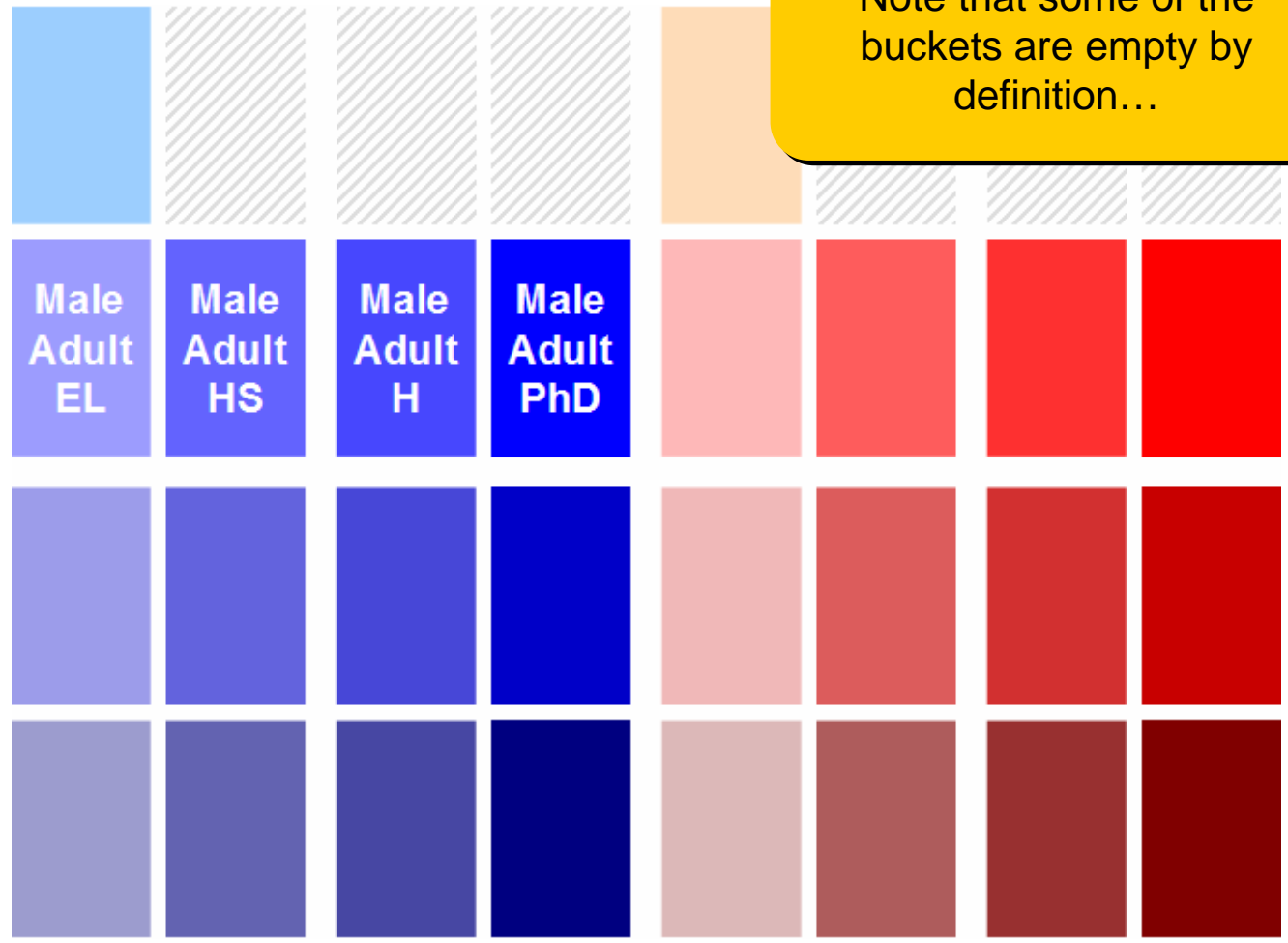
... + Gender



... + Age

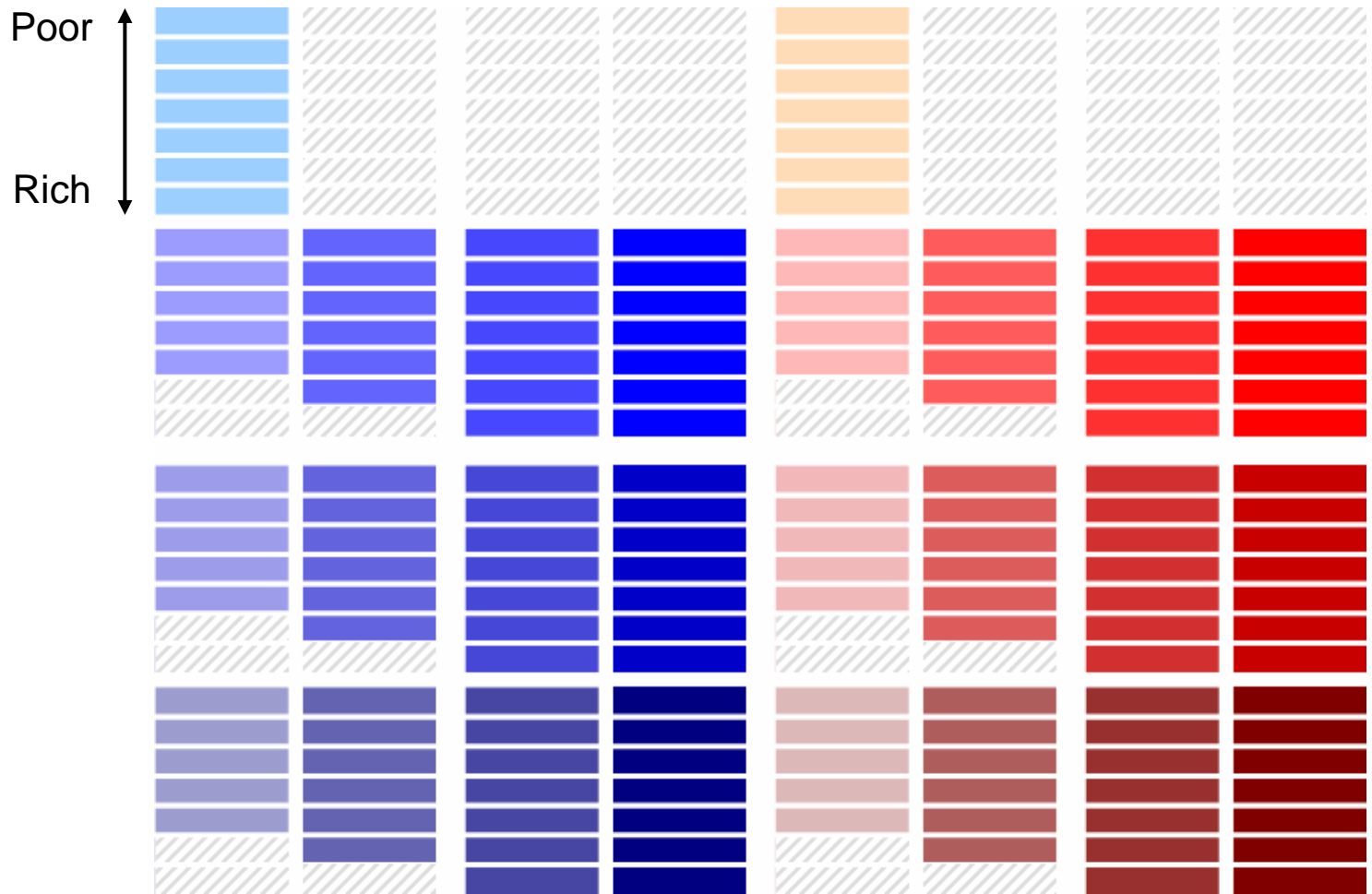
Male Children	Female Children
Male Adult	Female Adult
Male Middle Age	Female Middle Age
Male Senior	Female Senior

... + Education



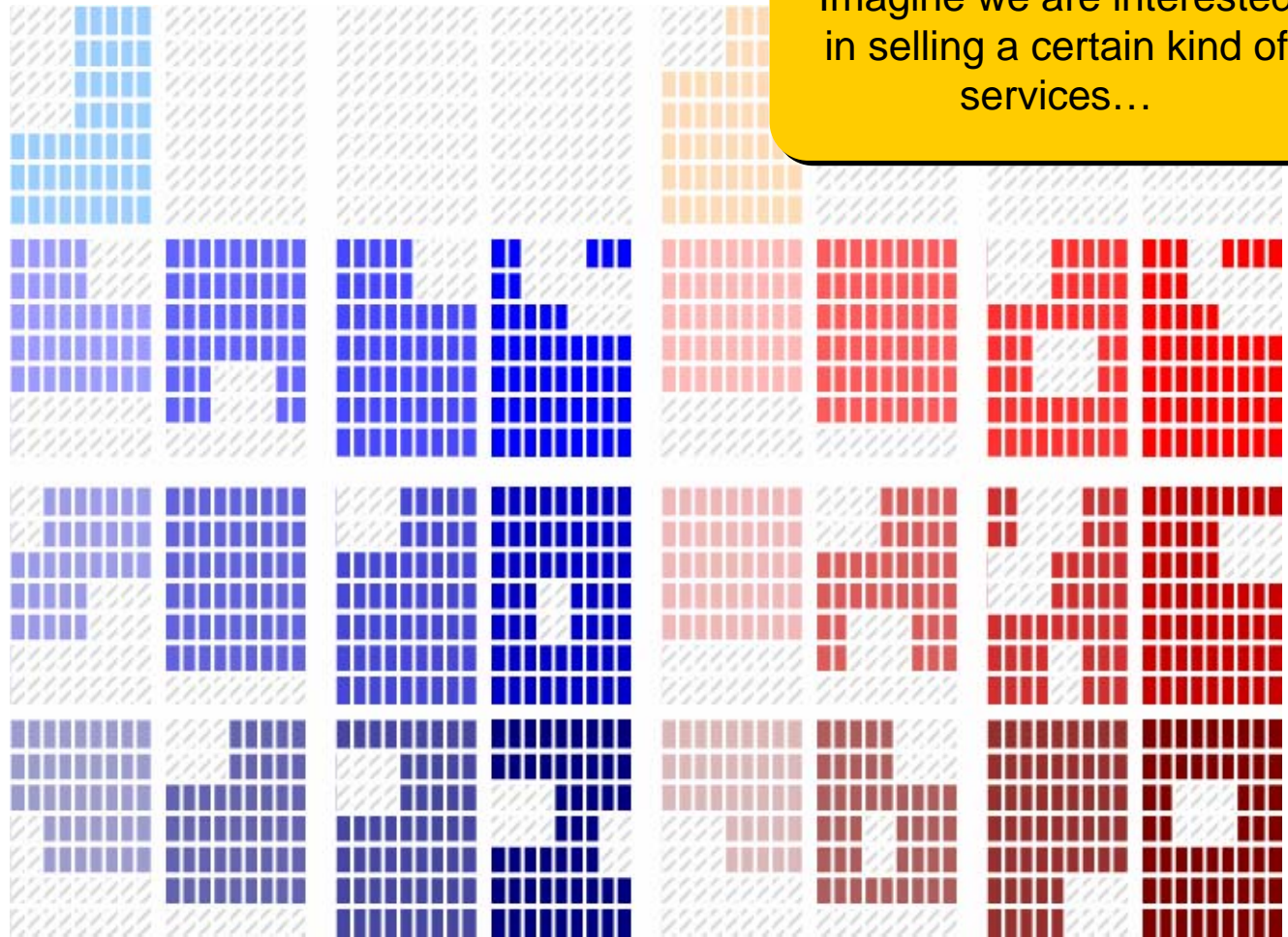
Note that some of the buckets are empty by definition...

... + Wealth

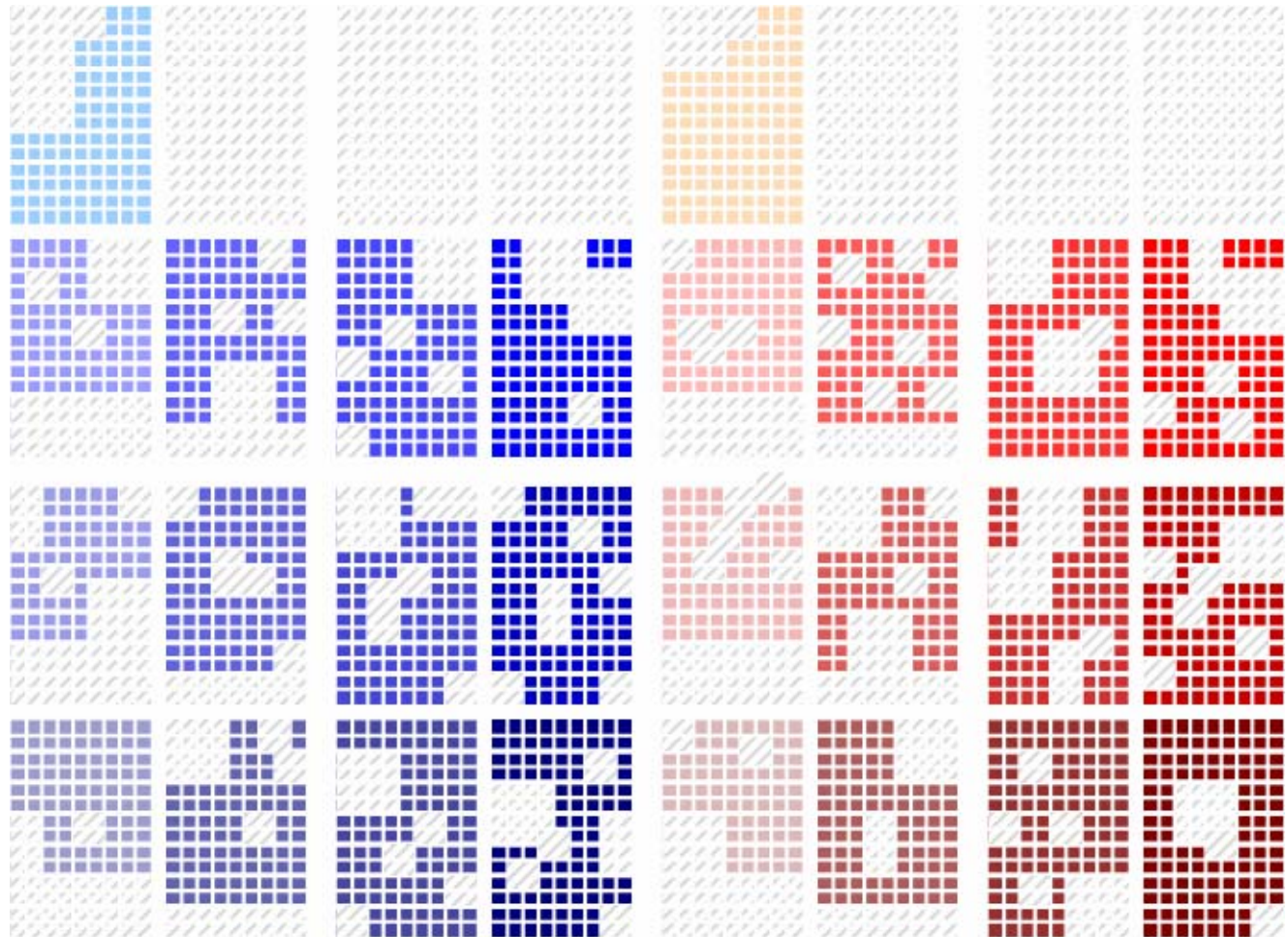


... + Has used our services within N months

Imagine we are interested in selling a certain kind of services...



... + ???



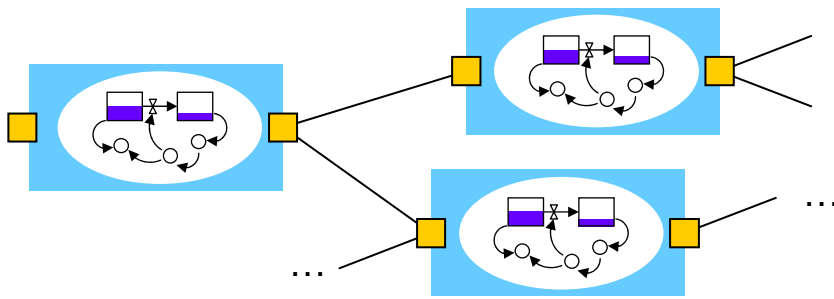
... and finally:

- You may end up having more buckets in the stock than there are people in the region/city/country/world
- In this case agent based model will not only be more compact and adequate, it will be even computationally efficient

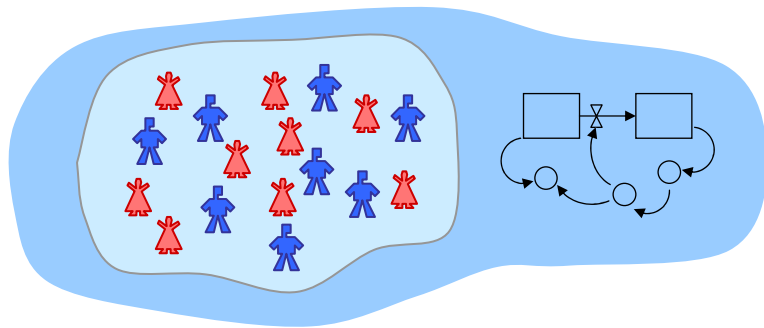


Is AB a replacement for SD?

- No! There is a huge class of problems best modeled with SD
- But: there are problems best addressed with AB
- And: in many cases combined, multi-approach modeling is the answer:



System Dynamics Sub-Models inside discretely communicating Agents
Application example: Supply Chain.

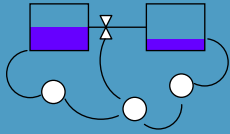


Agents live in an Environment modeled in System Dynamics way
Application example: City Population



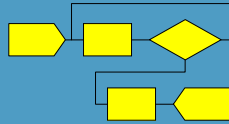
Traditional tools: support one paradigm

SD



VenSim
PowerSim
iThink
ModelMaker

DE



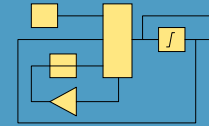
Arena
Extend
SimProcess
AutoMod
PROMODEL
Enterprise
Dynamics
FlexSim
eMPlant
...

AB



[Academic
software:]
Swarm
RePast
AgentSheets
ASCAPE
SeSam
NetLogo
...

DS



MATLAB
VisSim
LabView
Easy 5
...

The challenge

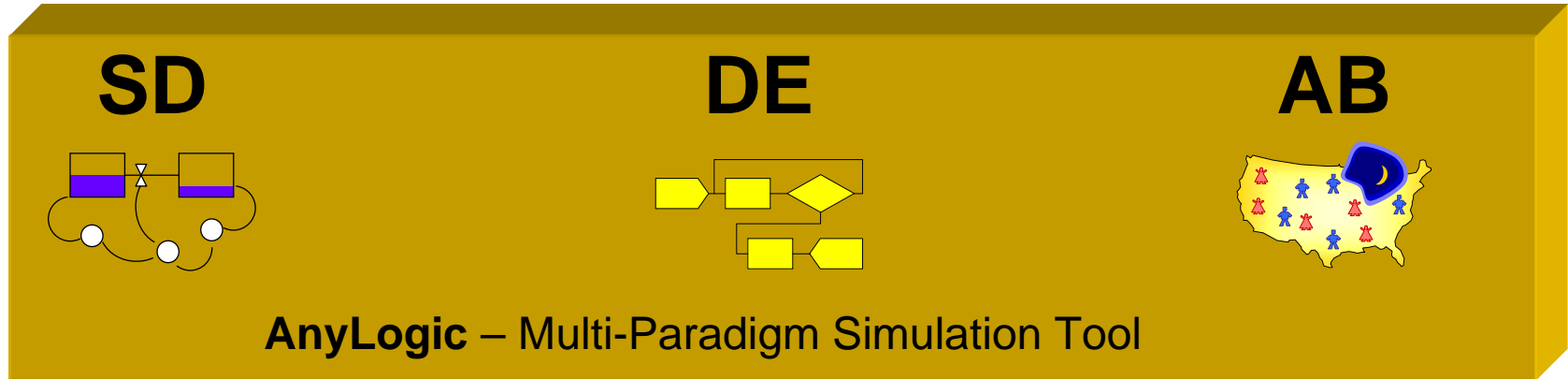
- The increasing demand for global business optimization have caused leading modelers to look at AB and combined approaches to get deeper insight into complex interdependent processes having very different natures

Therefore

- There is a request for platforms that would allow for integration and efficient cooperation between different modeling paradigms

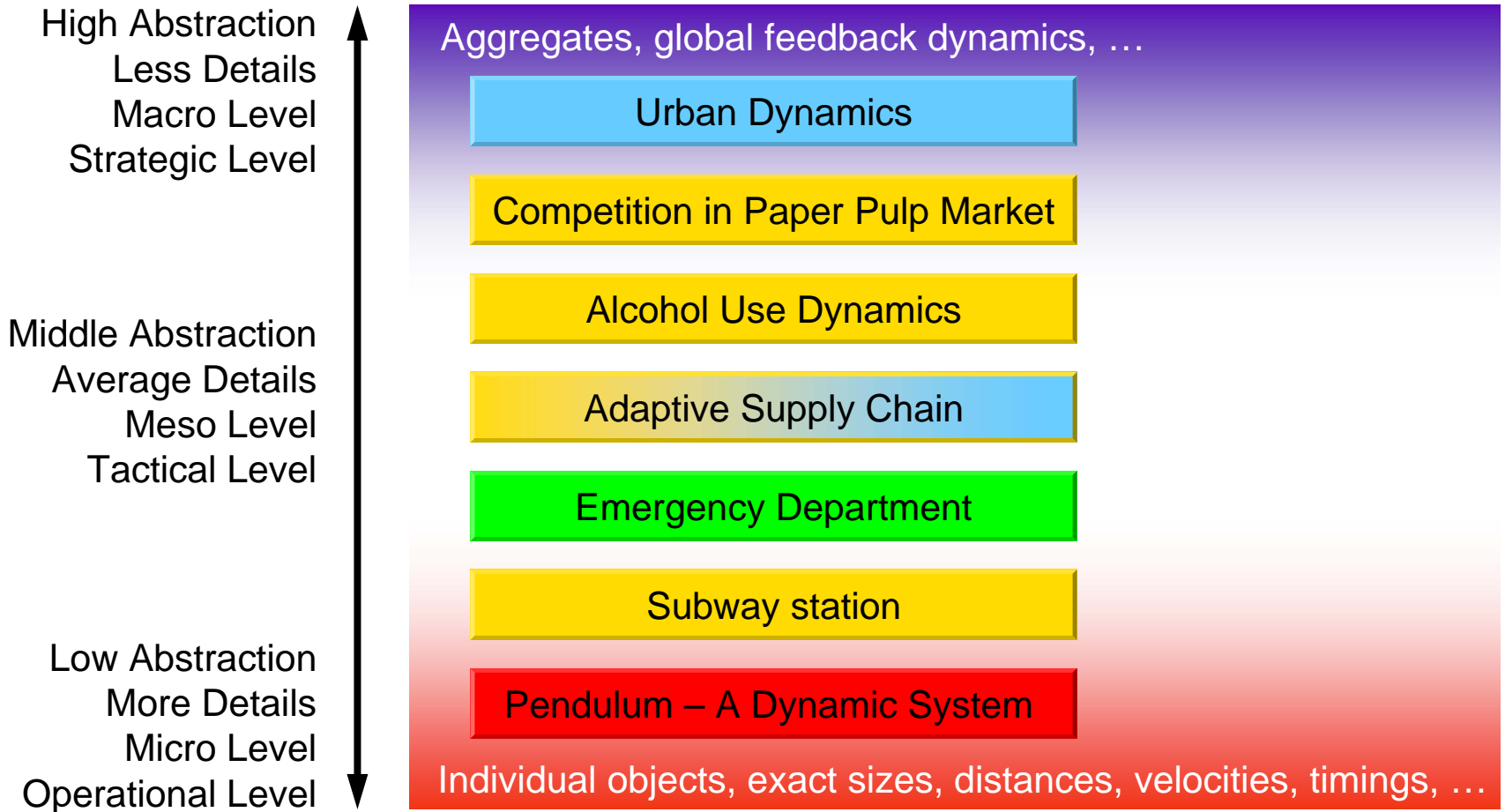


AnyLogic

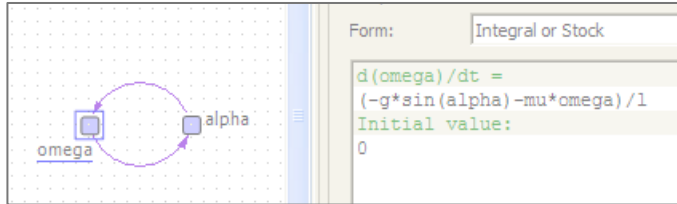


- You can easily vary and adjust the level of abstraction
- You can switch from one approach to another
- You can mix approaches
- All that on one solid object-oriented platform

AnyLogic example models

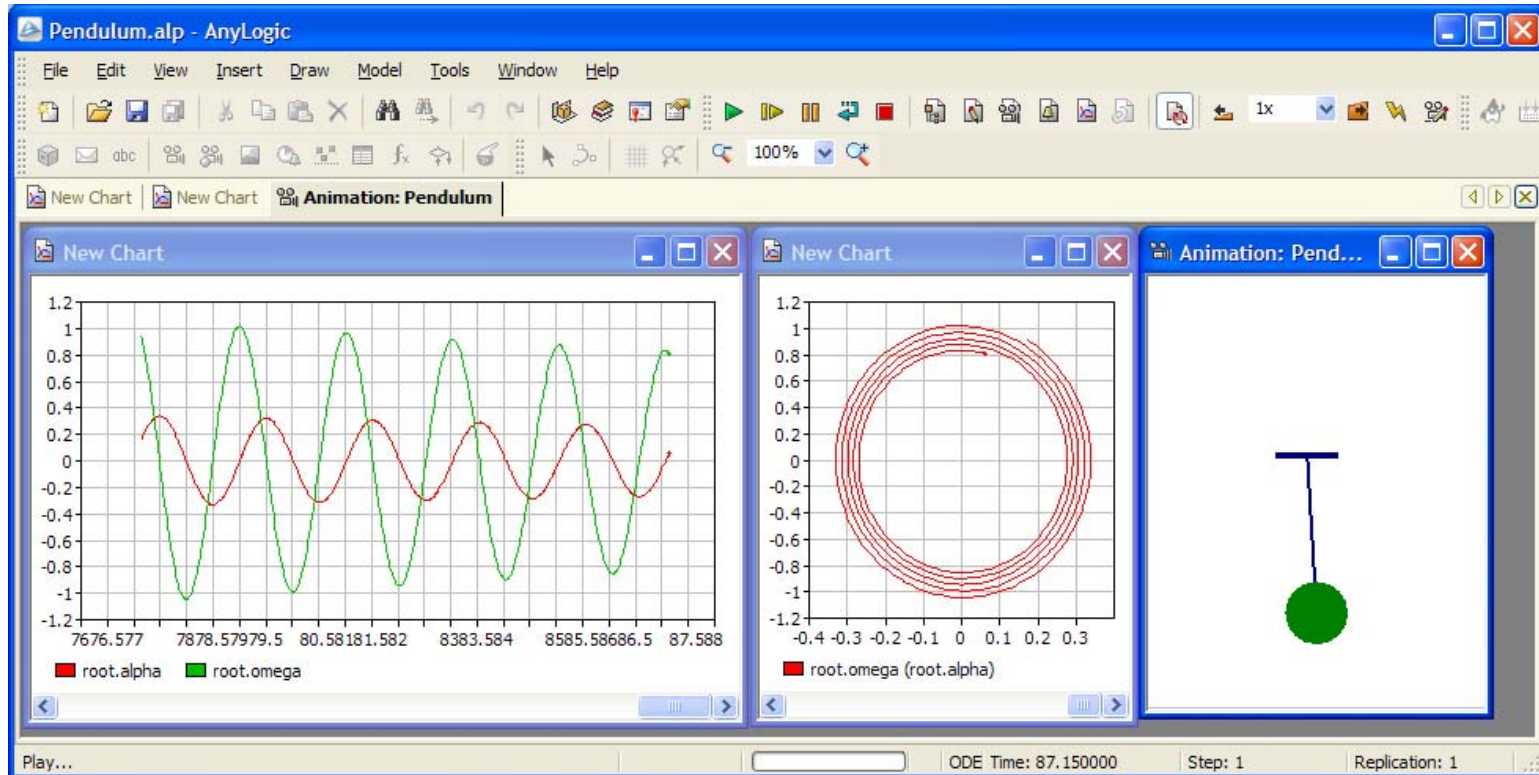


Lowest abstraction level: dynamic system

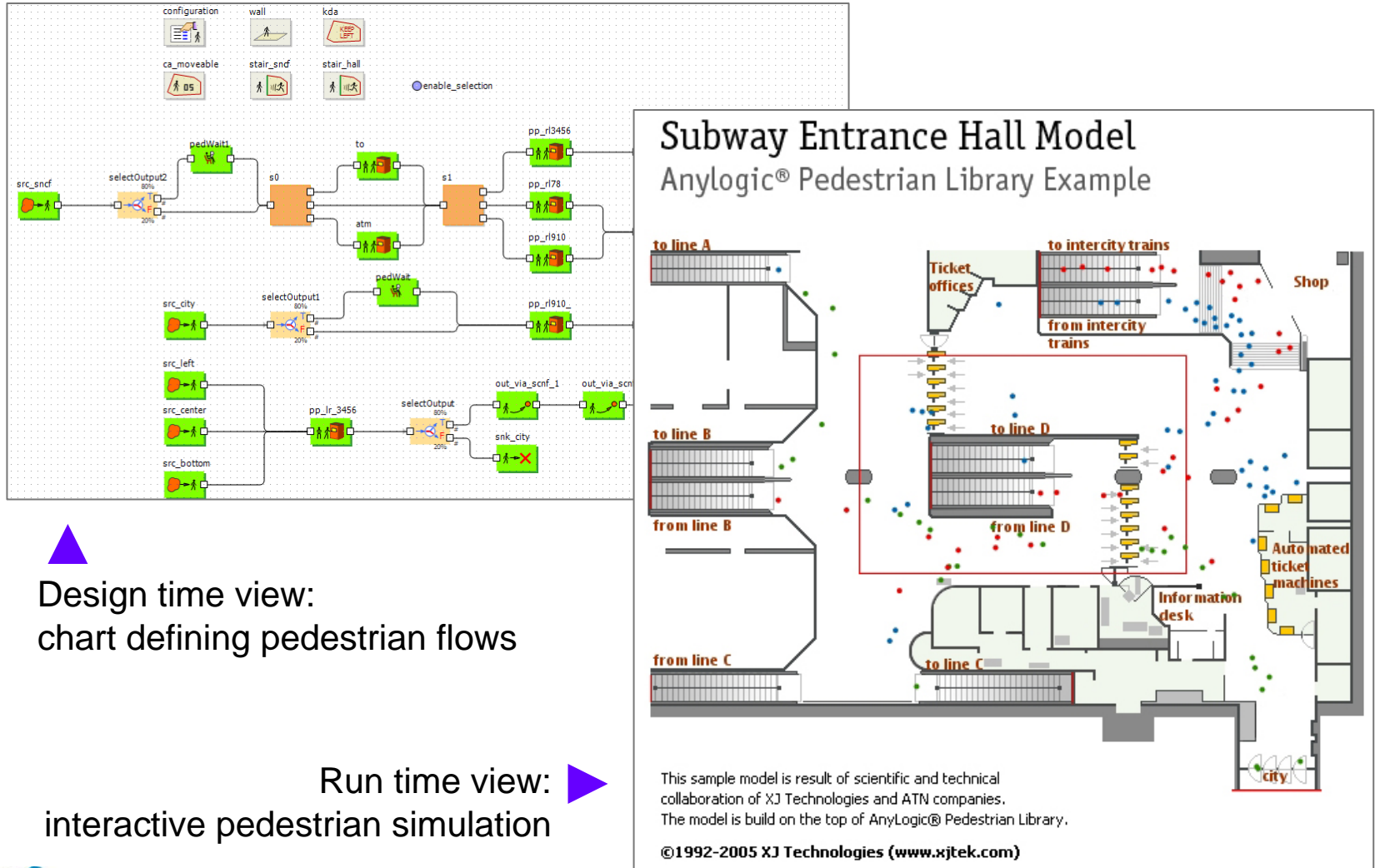


◀ Design time view: differential equations

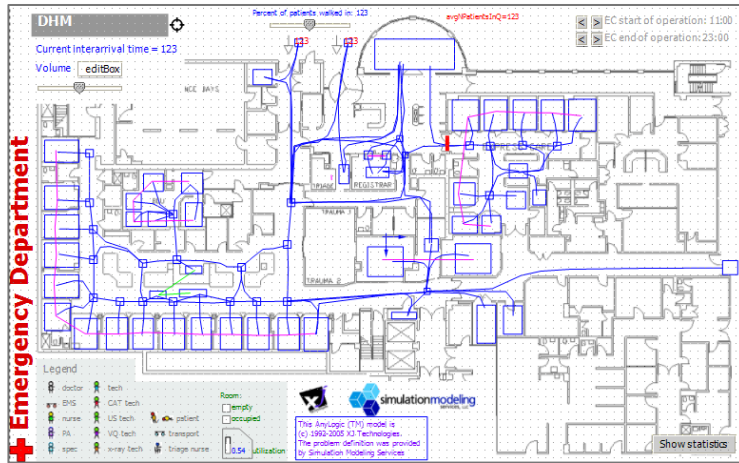
Run time view: charts and animation



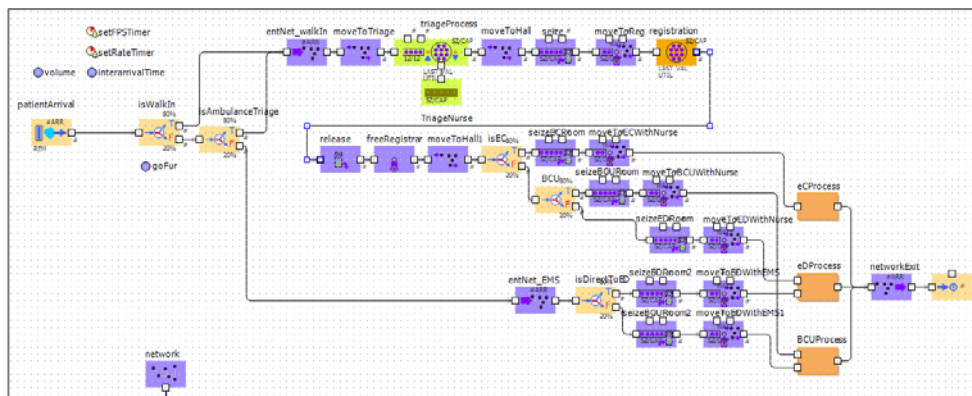
Pedestrian dynamics: Subway station



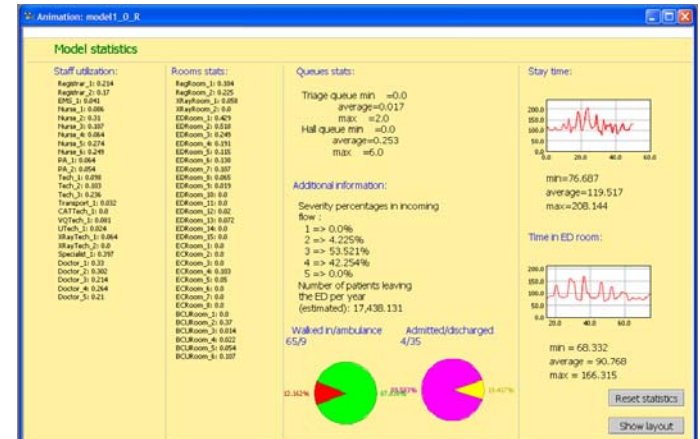
Discrete event: Emergency department



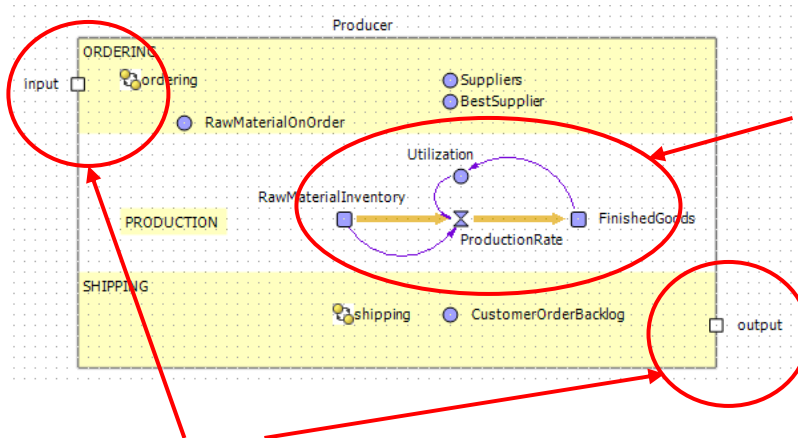
- ▲ Design time view: layout markup
- ▼ Design time view: process flowchart



- ▲ Run time view: process animation
- ▼ and statistics



SD+AB: Supply chain

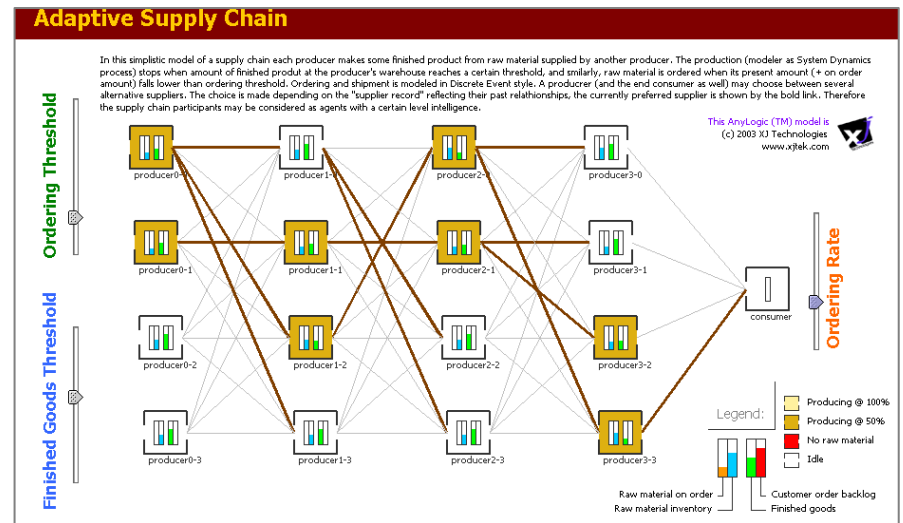


SD model of production process

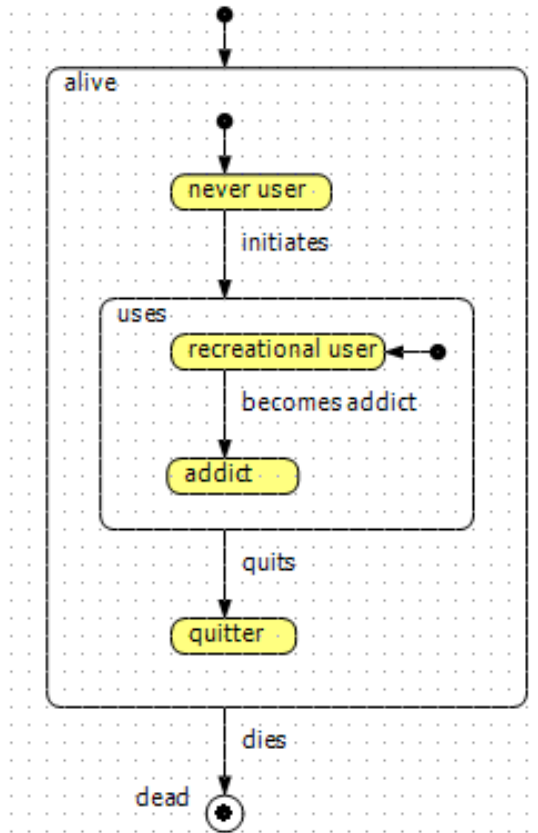
Design time view (Producer)

Discrete model of communication with suppliers and customers

Run time view: ordering pattern

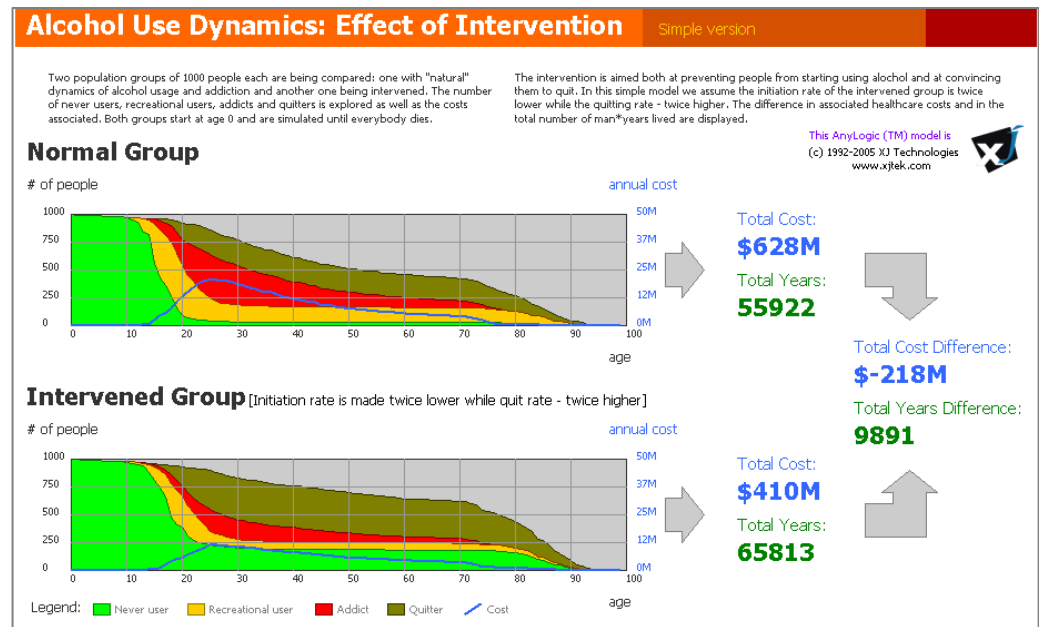


Agent based: Alcohol use dynamics



Design time view:
statechart defining individual person behavior

Run time view: control and intervened group dynamics and financial outcome

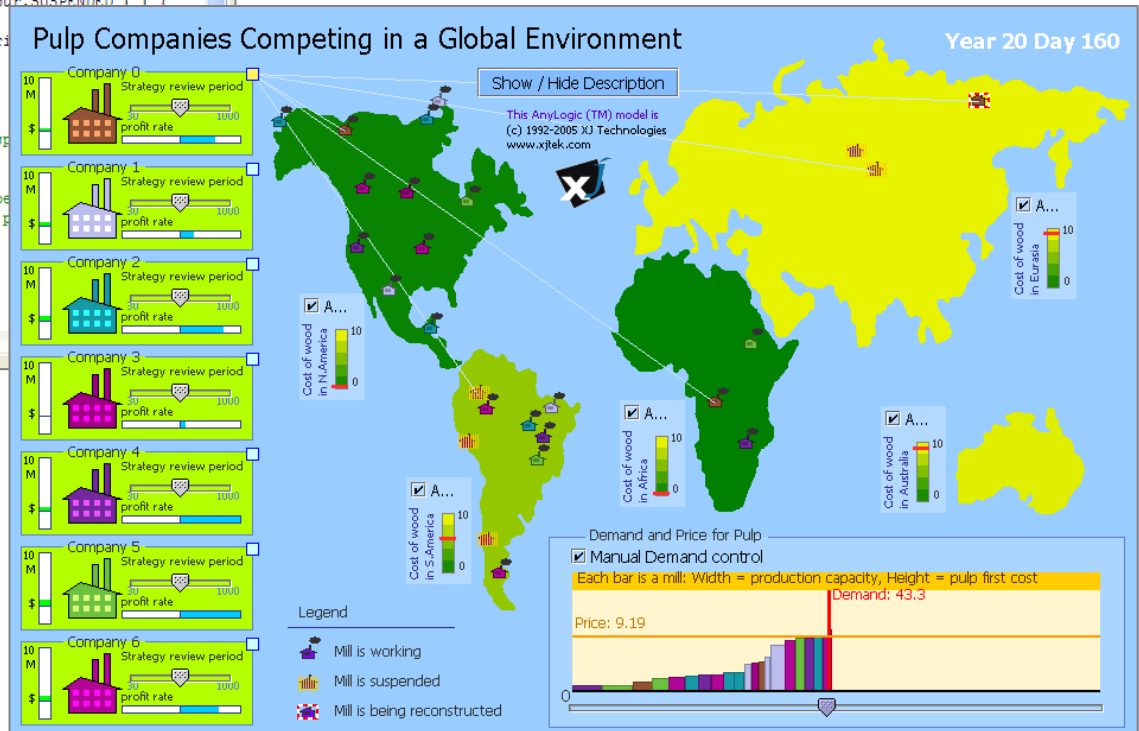


Agent based: Competition in global market

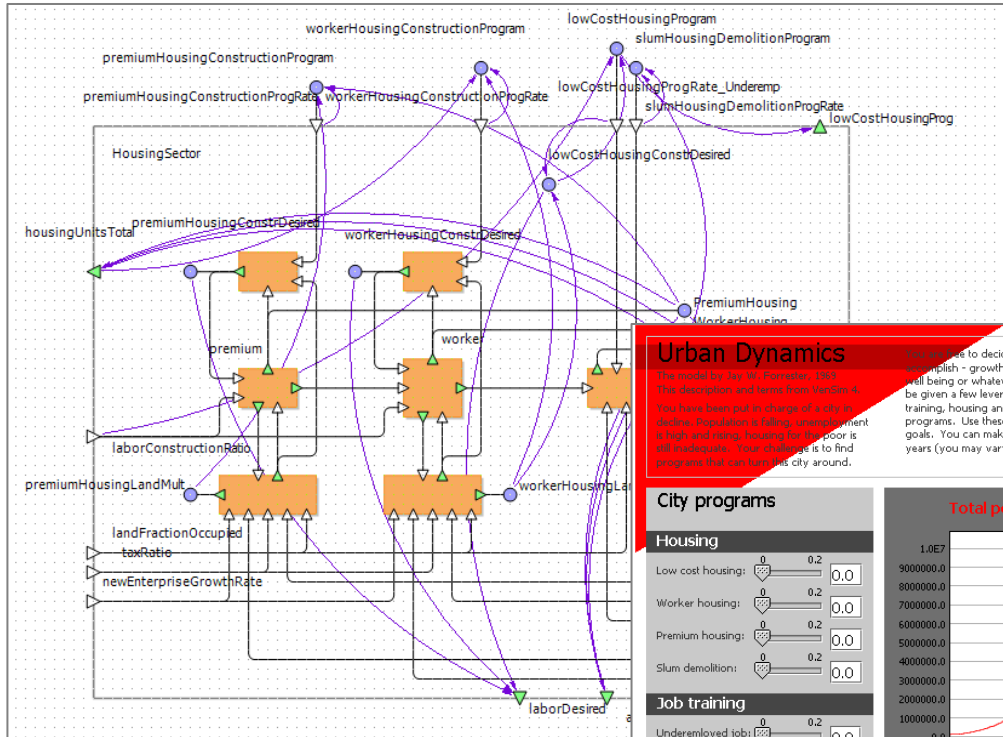
```
Function body:  
// Get root object  
Model model = (Model)(Engine.getRoot());  
  
// Apply strategy to the existing company mills  
for( int i=0; i<mills.size(); i++) {  
    Mill mill = mills.item(i);  
  
    if( mill.behaviour.isStateActive( mill.behaviour.WORKING ) ) {  
  
        if( mill.costOfWood + mill.getProcessingCost() > price ) {  
            // Suspend unprofitable working mill  
            mill.port.receive( "SUSPEND" );  
        }  
  
    } else if( mill.behaviour.isStateActive( mill.behaviour.SUSPENDED ) ) {  
  
        if( mill.costOfWood + mill.getProcessingCost() < price ) {  
            // Resume profitable suspended mill  
            mill.port.receive( "RESUME" );  
        } else {  
            if( mill.technologyLevel < 4.5 ) {  
                // Reconstruct reconstructable unprofitable suspended mill  
                mill.port.receive( "RECONSTRUCT" );  
            } else {  
                // Close unprofitable suspended mill that has been  
                // reconstructed many times but has not become profitable  
                // Unregister the mill at the region  
                for( int j=0; j<model.regions.size(); j++)  
                    model.regions.item(j).mills.remove( mill );  
                // and unregister at the model  
                model.mills.remove( mill );  
            }  
        }  
    }  
}
```

Design time view:
company strategy function

Run time view: geo based competition
visualization



System dynamics: Urban dynamics



Design time view:
hierarchical OO
stock and flow diagram

Run time view:
"Flight simulator"

Urban Dynamics

The model by Jay Forrester, 1971. This description and terms from Venkatesh. You have been put in charge of a city in decline. Population is falling, unemployment is high and aging housing for the poor is still inadequate. Your challenge is to find programs that can turn this city around.

The purpose of the game is to see if your actions have their intended effect, and attempt to understand why they work, or fail.

This AnyLogic (TM) model is (c) 1992-2005 XJ Technologies www.xjtek.com

City programs

Housing

Low cost housing:

Worker housing:

Premium housing:

Slum demolition:

Job training

Underemployed job:

Underemployed train:

Labor training:

Business development

Business construction:

Business demolition:

Tax subsidy:

Time step: years

STEP

Total population: 5.54 M

Underemployed crowding: 81.784

NOW CHANGE PARAMETERS AND PRESS STEP

Underemployed: 55.917%

Unemployment rate: 23.123%

© 2002-2005 XJ Technologies www.xjtek.com

35

Summary

- Choosing modeling approach and the level of abstraction adequate to the goals of the modeling project is a key to success
- Using a flexible, multi-paradigm platform
AnyLogic multiplies your capabilities and saves significant amount of model development efforts



Thank you!

- Questions?