Dynamic Discrete-Event Systems with Instances for the Modelling of Emergency Response Protocols

Lenko Grigorov and Karen Rudie
Dept. Electrical and Computer Engineering,
Queen's University, Kingston, Canada

with gratitude to
Emergency Management Ontario, Frontenac County,
City of Kingston, KFL&A Public Health

Emergencies

- Types
  - Contagious disease outbreaks
  - Seasonal floods and fires, earthquakes
  - Contamination, bridge collapse
- Response
  - Government agencies
  - Guidelines, protocols, legal frameworks
  - First responders are the affected people

Motivation

- Communication
  - Will Public Health receive the report from the hospital (at all, on time)?
- Cost/benefit optimization
  - How many more lives will be saved by vaccinating everyone vs. only the vulnerable?
- Scalability
  - How many people can be evacuated without calling for provincial assistance?

Emergency response protocols

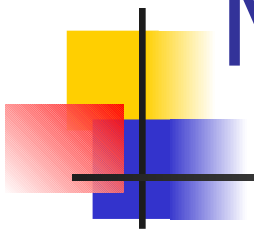
- Describe sequences of steps that need to be taken
- Steps can have
  - Duration
  - Costs
  - Benefits
  - Probability
- Much like augmented DES

Properties of emergencies

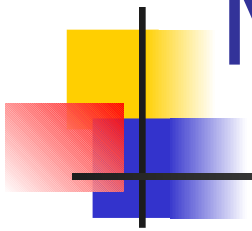
- Large number of participants
- Dynamic nature
- Unpredictable

$\Rightarrow$ Classical DES cannot be used

Model requirements



1. Easy to create and understand
2. Can describe a dynamic system
3. Compact



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Petri nets!

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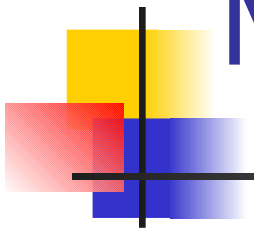
Petri nets!

Who was the nurse that attended the patient with MDR-TB?

Model requirements



1. Easy to create and understand
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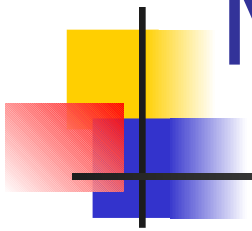
3. Compact *but preserves identities*

Model requirements



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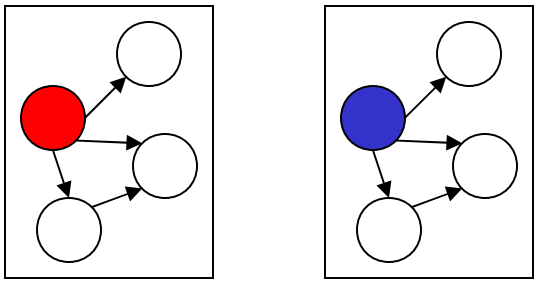
Dynamic DES with Instances

- Dynamic DES
- Template design

Dynamic Discrete-Event Systems



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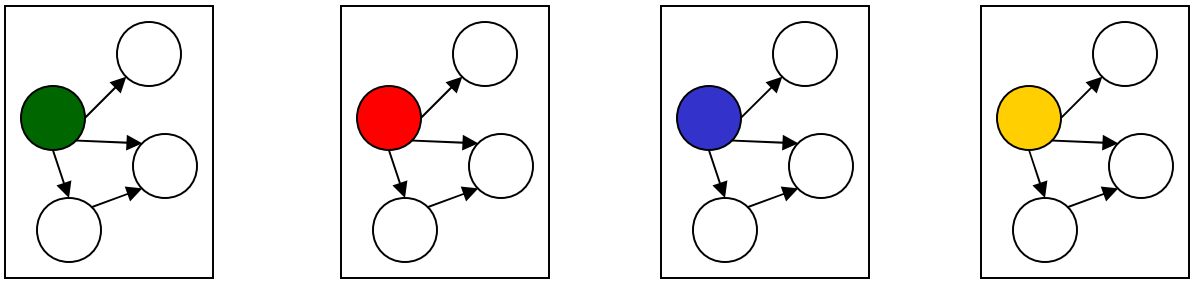

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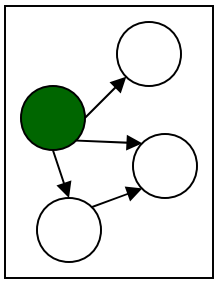
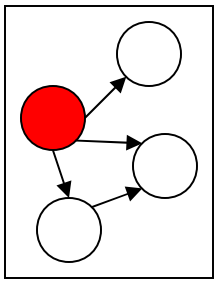
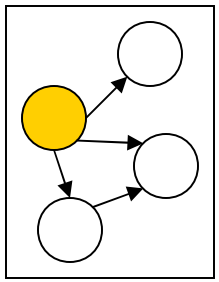

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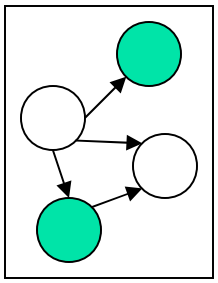
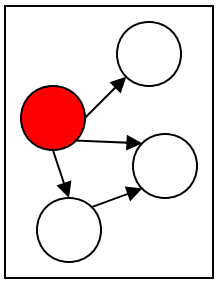
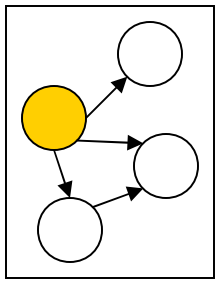
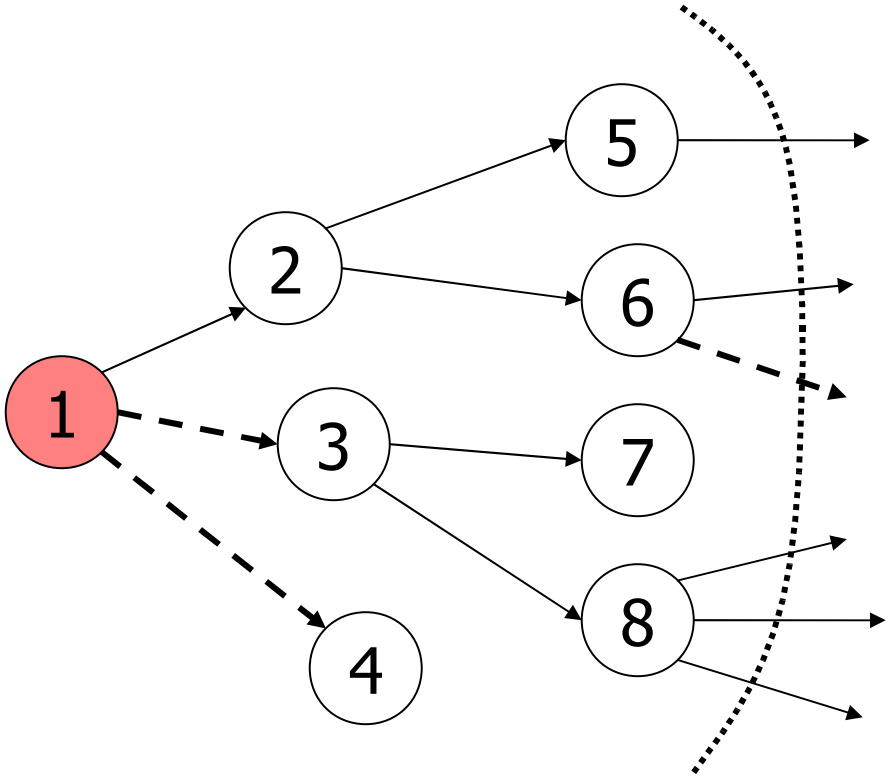






Online control using a look-ahead tree



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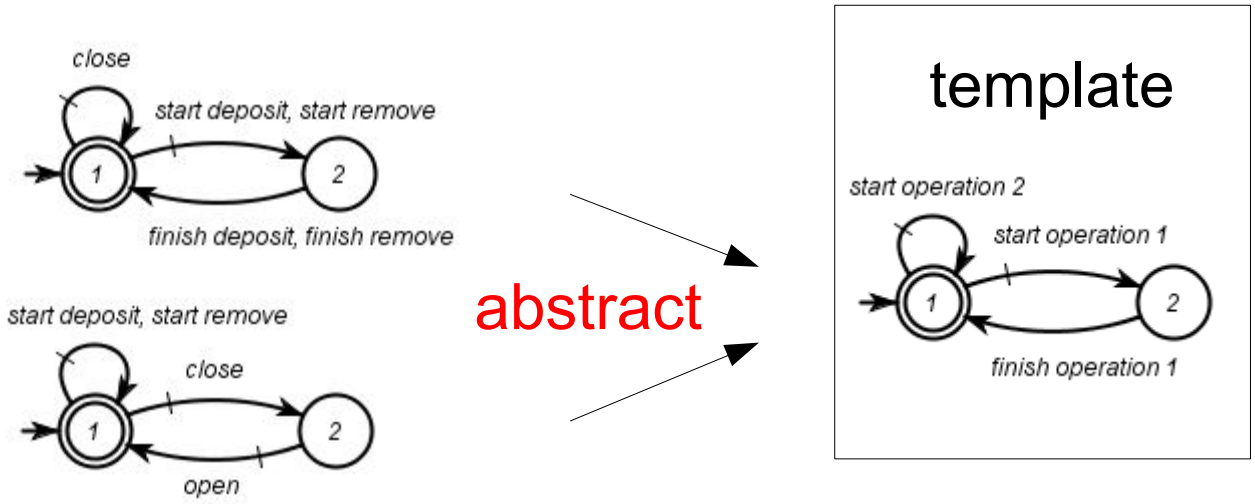
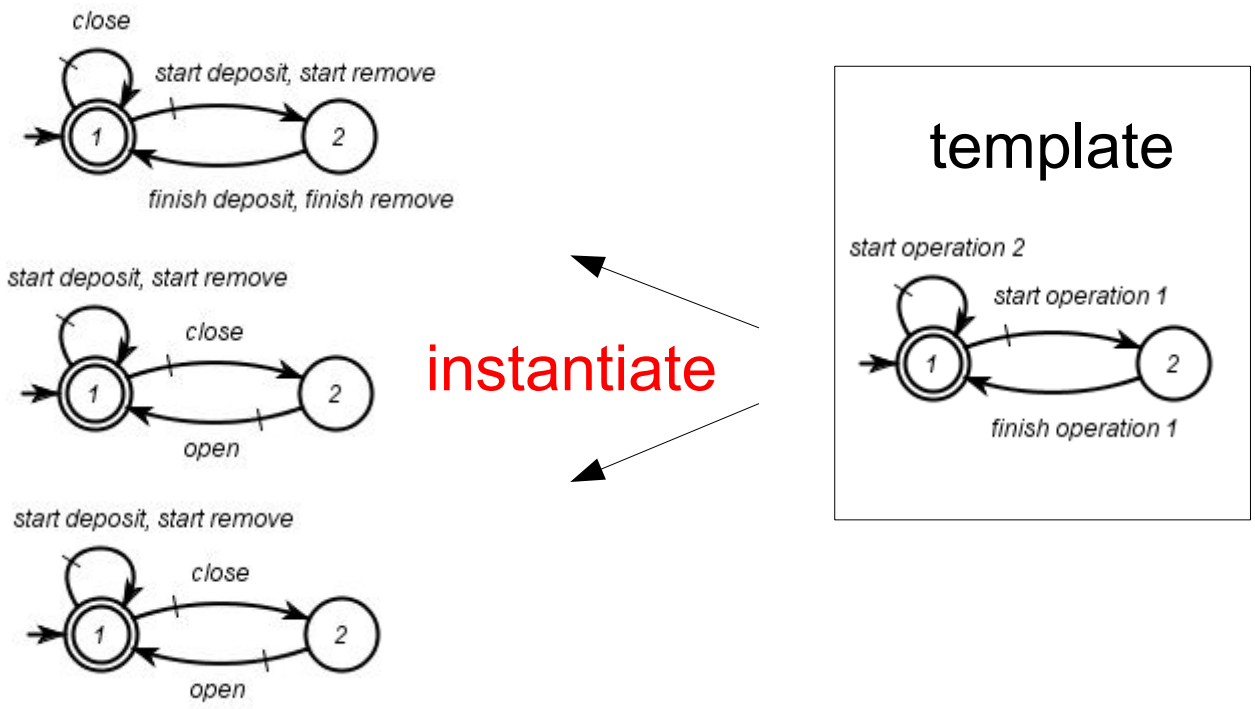
Roles (templates)

- Abstract common behavior



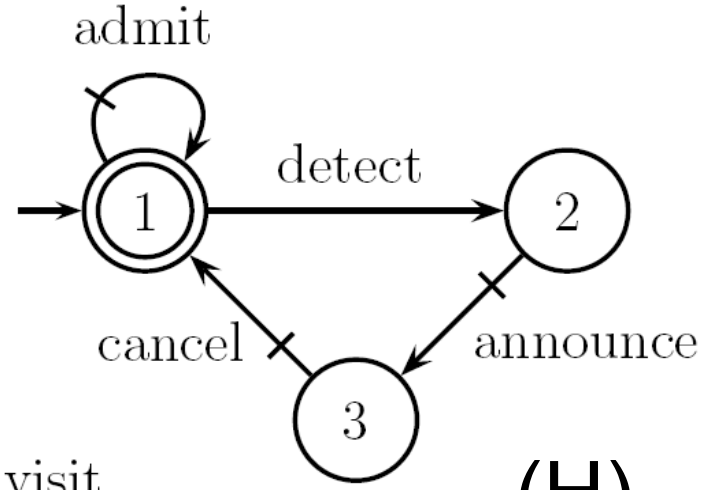
Actors (instances)

- Instantiate existing templates



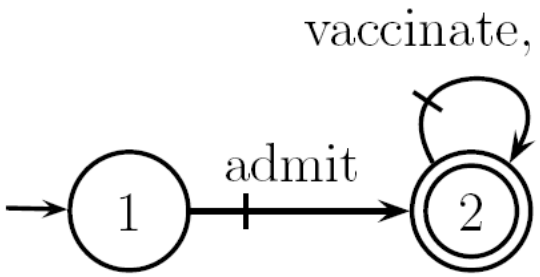
Simple example

- Long-term care home



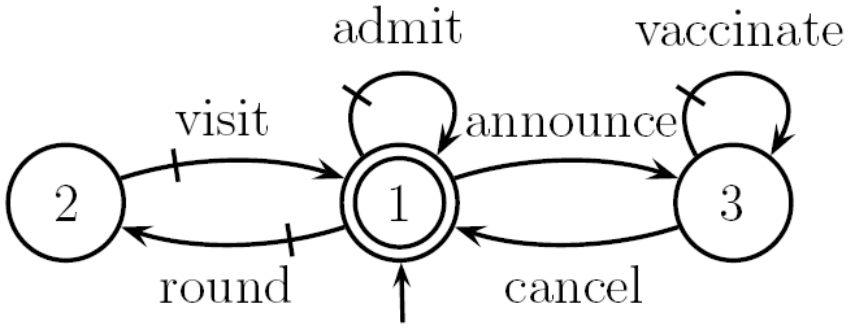
(H)

- Patient



(P)

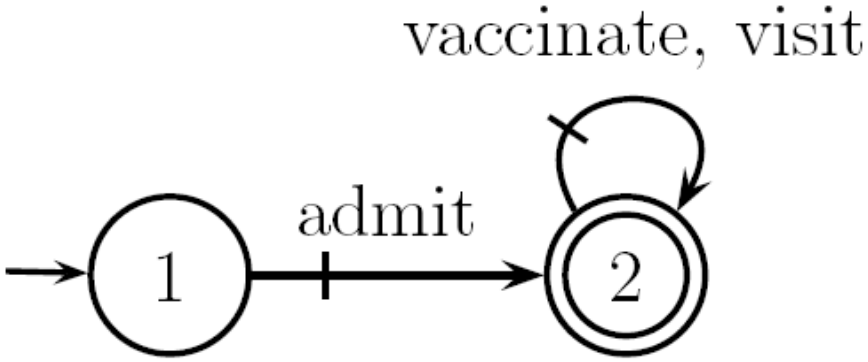
- Nurse



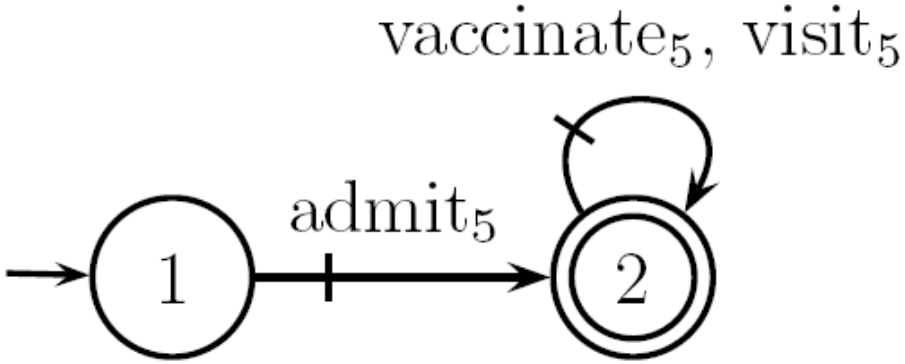
(N)

Instantiation

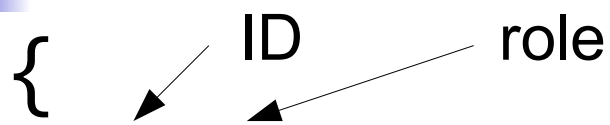
- Role



- Actor with ID=5



Global system



{

(1, H), long-term care home

(2, N), nurse

(3, N), nurse

(4, P), patient

(5, P), patient

(6, P) patient

}

Synchronization patterns

- For event σ:

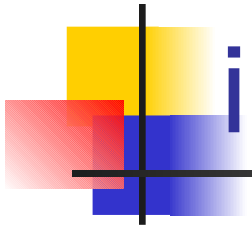
$\pi(\sigma) = \varnothing$ or {(role1, *), (role2, *), …}

- $\varnothing$ means no synchronization
- * can be
  - all – all instances must participate
  - many – all available but at least one
  - any – all available, if any
  - one – exactly one instance must participate

Examples of sync patterns

- π(admit) = {(H, one), (N, one), (P, many)}
- π(announce) = {(H, one), (N, all)}
- π(detect) = $\varnothing$
- π(vaccinate) = {(N, one), (P, one)}
- π(visit) = {(N, one), (P, any)}

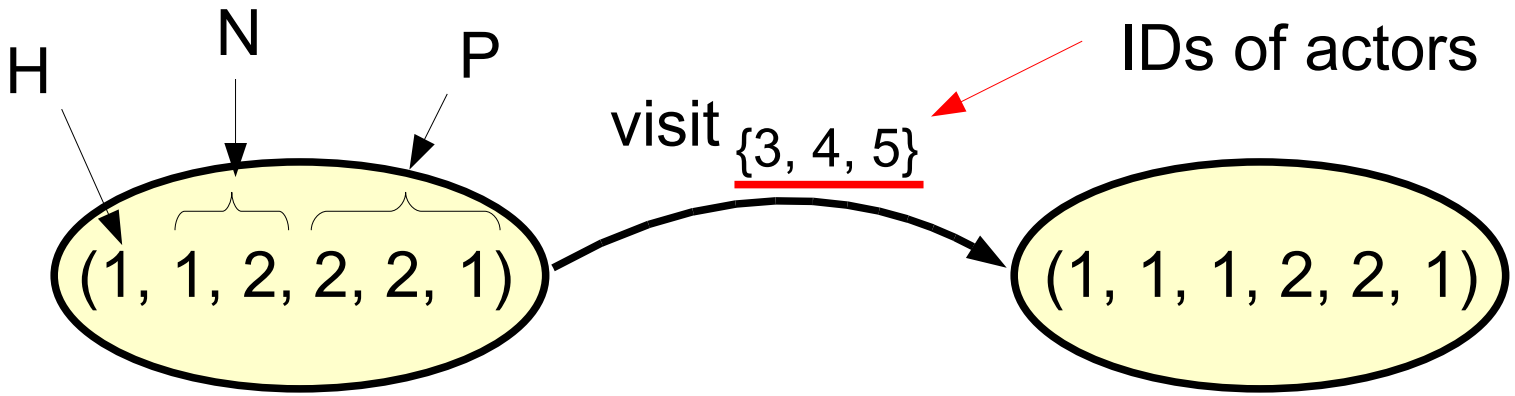
Synchronous product of instances



- Similar to synchronous product operation
- Generates the global system from:
  - Roles
  - Instances
  - Synchronization patterns
- Implements the semantics of the synchronization patterns

Global model

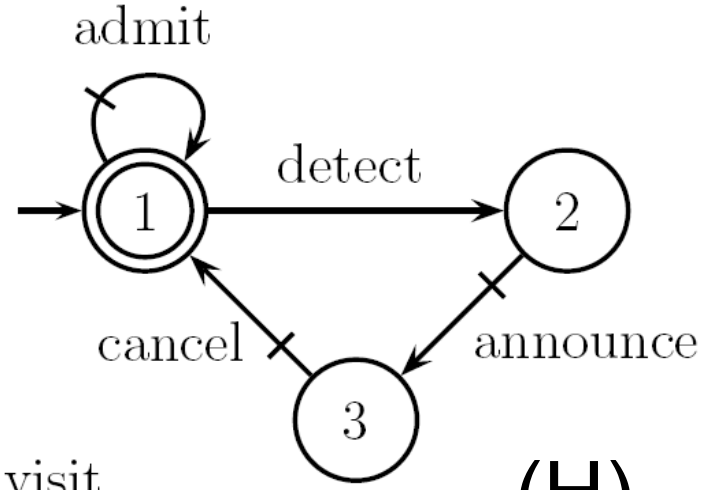
- Identity-preserving transitions



π(visit) = {(N, one), (P, any)}

Simple example

- Long-term care home



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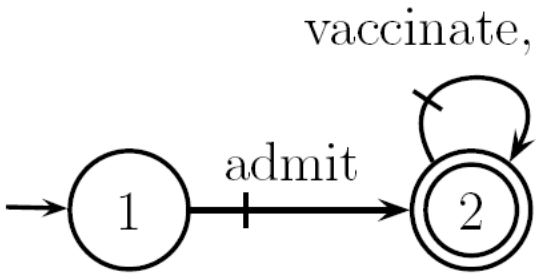

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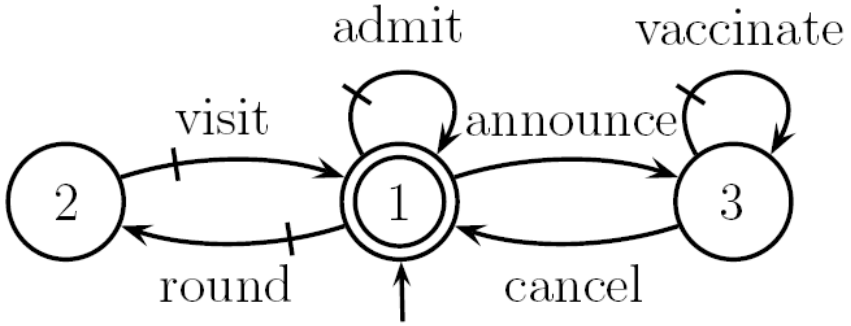

(N)

Global model

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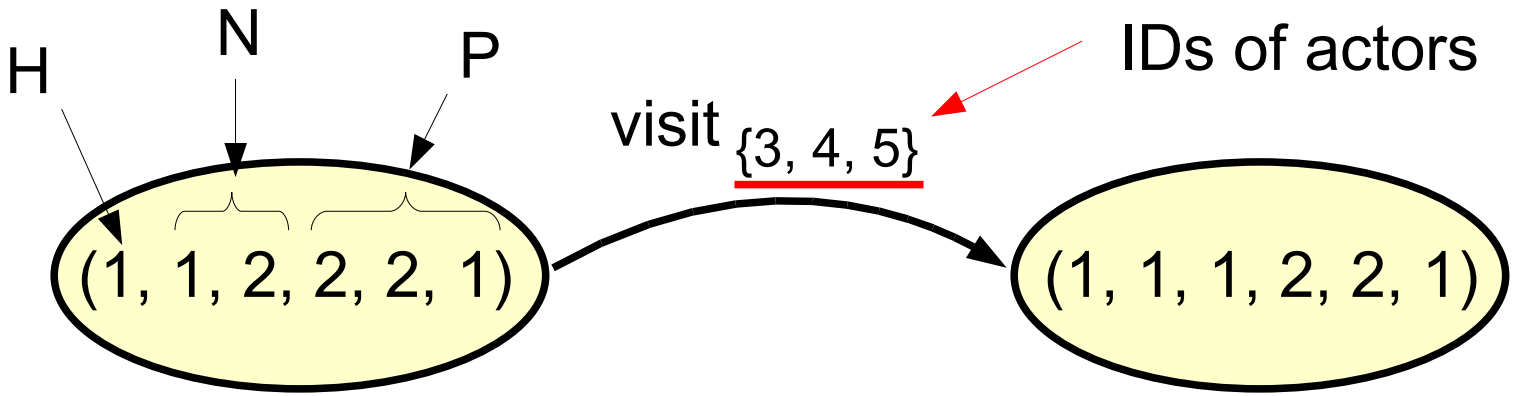


π(visit) = {(N, one), (P, any)}

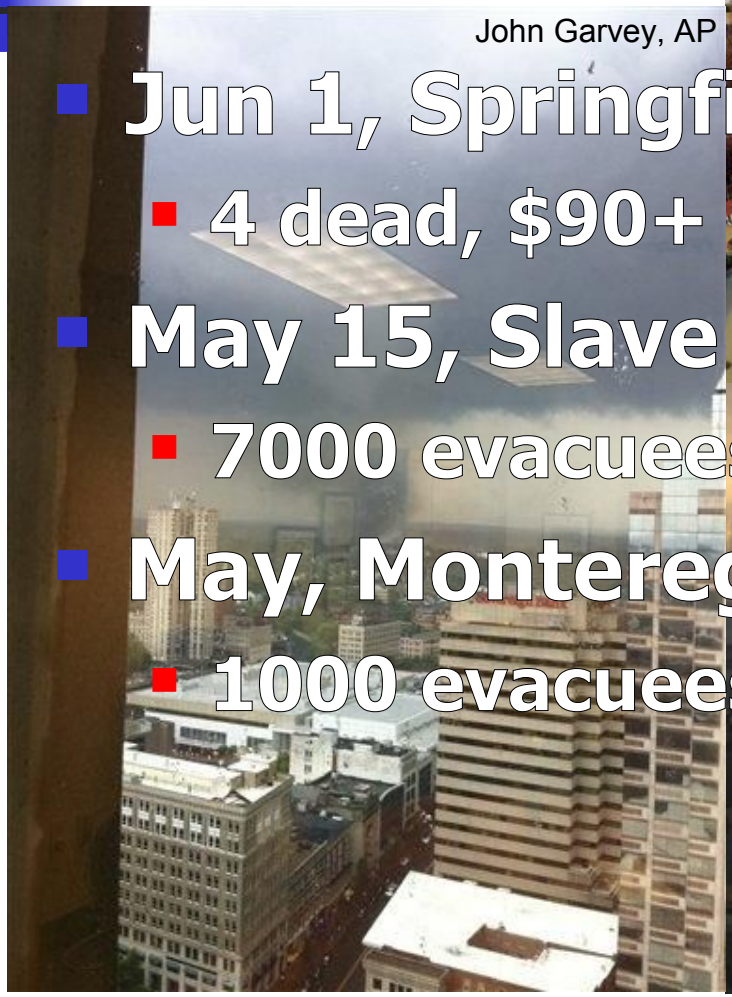
Things we can express

- The workload of nurses must be fair, i.e., within a time interval, there should not be a discrepancy larger than one in the number of tasks a nurse has completed.
- Nurses are assigned patients.
- All visitors are informed about the regulations on patient visits.
- All nurses who have interacted with the patient Joe Smith must undergo a screening procedure.

Summary

- The proposed model is simple, dynamic, compact and preserves instance identity
- Future work
  - How can we take advantage of the model symmetries during the analysis? (STS?)
  - The model needs to be extended with cost, duration, probability...

Emergencies



John Garvey, AP

Bernard Brault, AP

Shane O'Brien

- Jun 1, Springfield, MA, Tornado
  - 4 dead, $90+ million damages
- May 15, Slave Lake, AB, Forest fire
  - 7000 evacuees, 40% of town burned
- May, Monteregie, QC, Flood
  - 1000 evacuees, 3000 homes damaged