Social and Behavioral Simulation WSC'15

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Simulating the Micro-level Behavior of Emergency Departments for Macro-level Features Prediction

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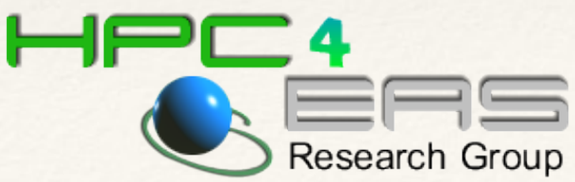


INTRODUCTION

➢ Emergency Department (ED) is the main entrance to healthcare system, the Efficiency and Quality of Service (QoS) in ED have big influence to the whole healthcare system.

➢ Patients arrive the ED without prior appointment, some of them with unstable conditions and must be treated quickly!

➢ Some EDs are overcrowding and work with limited budget.

➢ ED is a complex system with many constraints!

➢ … …

Problems to solve

To make decisions to solve these problems, there are many questions should be answered first to support the decision *(since EDs are stochastic environment and have time-dependent behavior, the decisions are not straightforward)*, **e.g.,**

- If the number of patient arrival doubled, what will happen?
- If we put 20 more careboxes (beds), how the overcrowding could be?
- The budget will decrease, how QoS will be affected? which staff can be reduced? doctors? nurses? ... ?
- … …

How c Simulation **ect of a decision without the commitment of any physical resources or interruption of the system?**

My Agenda

- ☛ Introduction
- ☛ The Emergency Department Simulator
- ☛ Demo about Micro-to-Macro to insight the system
- ☛ Conclusion and Future work

What is an ED simulator?

☞ Emergency Department:

- Complex Adaptive System.

☞ Model:

- **Agent-Based Model**;
- Generalized and Adaptable.

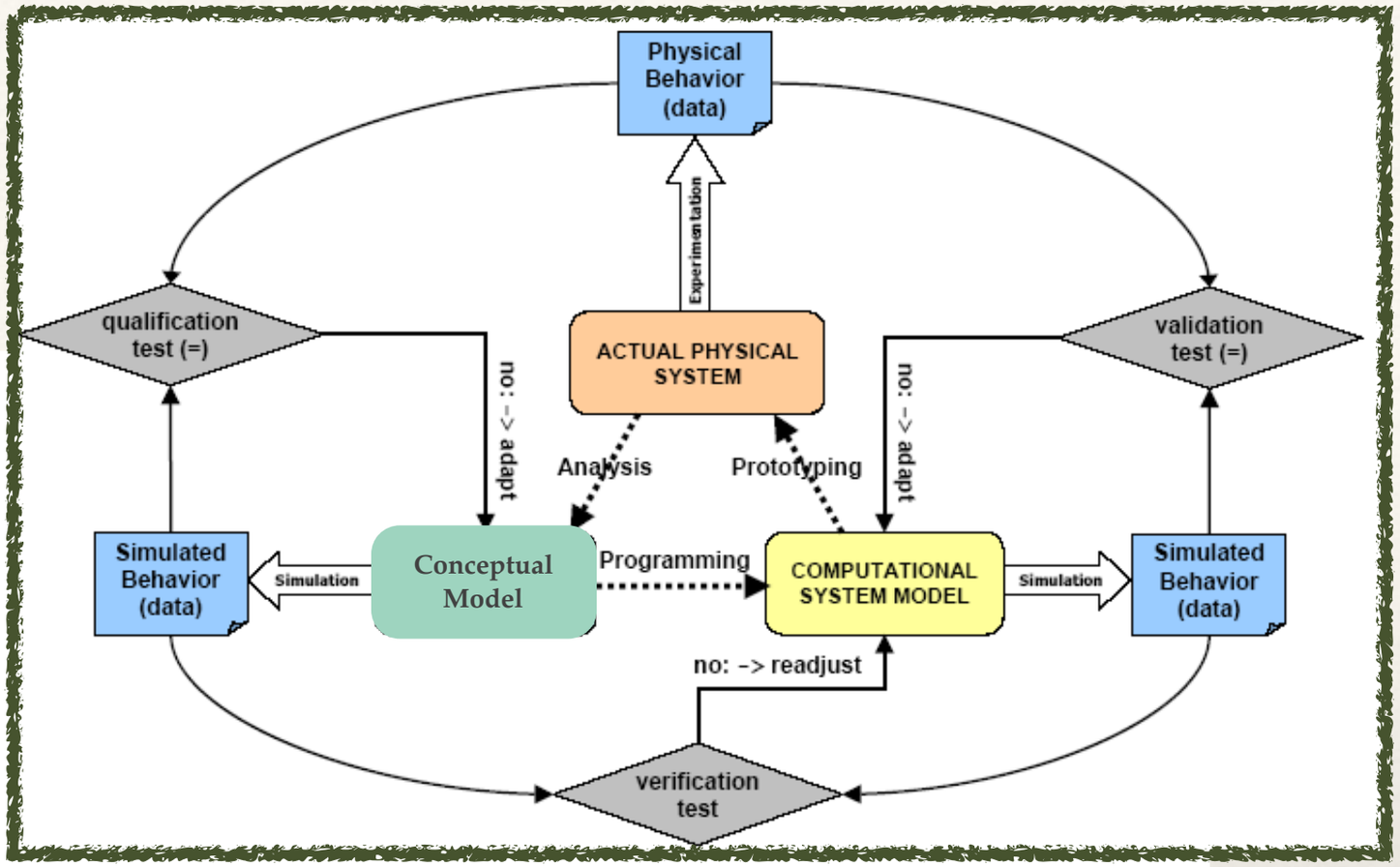
A complex system is one in which there are multiple **interactions** between many different **components**, low-level interactions among components **emerge** collective high-level results.

Emergent Property: an observation about a system that we might not anticipate from the separate study of its individual components (Holland, 1998; Strogatz, 2003).

As the **components** of a system **interact** with each other, and **influence** each other through these interactions, the system as a whole exhibits emergent behavior (Roetzheim). This characteristic makes the output of a system difficult to understand and predict.

☞ Execution:

- Model was implemented in Netlogo;
- HPC has been used to deal with the probabilistic agent model and study more scenarios in acceptable time frame.



One Typical ED (Parc Tauli) in **Spain** for Model Verification

THE EMERGENCY DEPARTMENT SIMULATOR

Edit Delete Add Button slower view updates continuous Settings...

setup

go

step-run

finished %
4.67

# of p in B
25

ticks: 68126

3D

WR-Admin Adm WR1 Triage WR2 Int. Test Lab. Test Ext. Test Staff Room Area B

Area B

CareBox

Area A

Hospital

occupancy-rate

100

occupancy rate(%)

0

0

time

71100

docA docB nurA nurB lab int-t

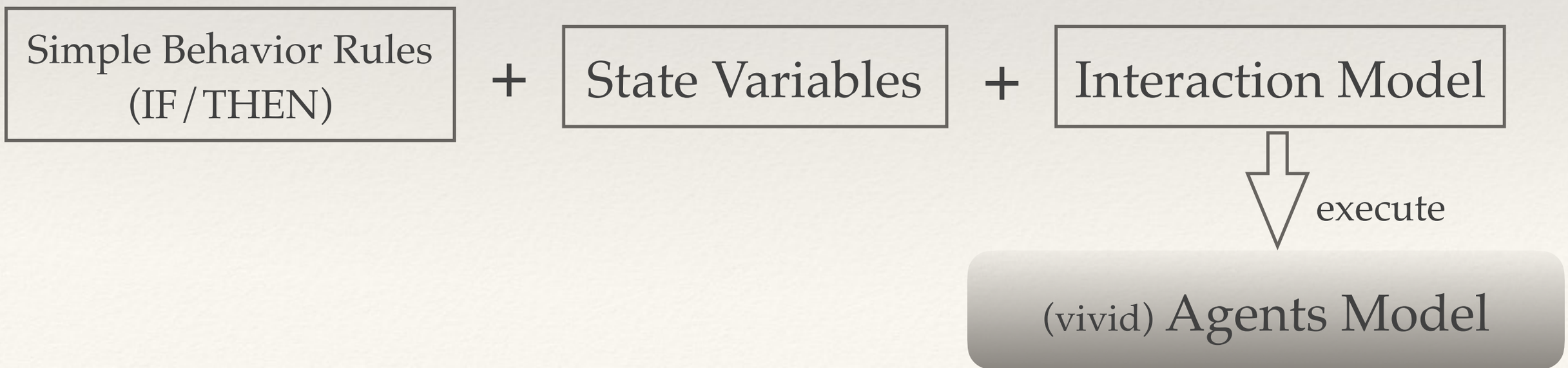
Staff/equipments Occupancy

How does it work?

Agent-Based Modeling & Simulation

¿Why?

- It can provide a way to see the forest through the trees and, **insight** is often more **important** than sheer numbers.
- Customizable/Flexible to study ED related problem, e.g., propagation of nosocomial infection, in which the principal way of the transmission is the frequent interaction between patients and healthcare staff.. (**no** system level knowledge needed, could **focus** in individual level).
- To have **transparency** in prediction, not "black box" prediction. (to know the **root cause** of systematic behavior, i.e., **exploratory**, **descriptive** and **explanatory** feature.).



Agent Model - Micro Behavior rules

Table 2: Behavior rules of patients.

IF	THEN
notified by IS (before entering treatment area).	go to the corresponding place in the notification.
no requests from IS (before entering treatment area).	keep staying in waiting room.
no requests from IS or healthcare staff.	keep staying in carebox (for patients in area A).
no interaction requested by nurse or doctor.	keep staying in waiting room (for patients in area B).
notified by IS (in area B).	go to diagnosis room or medical image test-room as indicated in the notification.
has any problem.	ask nurse through IS (the IS will notify the corresponding nurse).

Patient

Table 3: Behavior rules of registration staff / triage nurse.

IF	THEN
time to work.	interact with colleague in previous shift, take over materials from them.
no patient in front of the desk/window.	wait for patient (IDLE)
one patient with the same queue number as notified in IS waiting in front of the desk.	interact with patient for registration/triage.
shifting of duty time is up.	accomplish work at hand, interact with colleague in following shift, hand over requested material.

Triage nurse
Admission staff

AGENT MODEL - MICRO BEHAVIOR RULES

Table 4: Behavior rules of doctors.

IF	THEN
time to work.	interact with doctor in previous shift, take over patients from them.
no task assigned by IS (task queue is empty).	stay in their office (IDLE).
IS notified a new patients in cb_i.	move to cb_i, perform first-interaction, make treatment plan.
IS notified: the test report for one of the patients in D_i^P is ready to review.	review medical test report, walk to the carebox if necessary, and make follow-up treatment plan (do more test, drug therapy, discharge or admit to hospital).
scheduled drug therapy time of any patient in D_i^P is up.	walk to the carebox, check effect of drug therapy, and make follow-up treatment plan.
shifting of duty time is up.	accomplish work at hand, interact with doctors in following shift, hand over all the patients in D_i^P.

Doctor

Table 5: Behavior rules of nurses.

IF	THEN
time to work.	interact with nurse in previous shift, take over patients from them (in area A).
no task assigned by IS (task queue is empty).	stay in the nurse room.
doctor assigned laboratory test to one of the patients in set N_i^p	walk to carebox N_i^{cb} (in area A), taking sample from patient.
drug therapy assigned to one of the patients in set N_i^p by doctor.	go to the pharmacy, take pill and then walk to the place of patient for treatment.
Periodic checking time is up.	Check every patient's body condition in set N_i^p.
doctor discharged one patient in set N_i^p.	help patient leaving ED.
shifting of duty time is up.	accomplish task at hand, interact with nurses in following shift, hand over all the patients in set N_i^p.

Nurse

Agent Model - Micro Behavior rules

Table 7: Behavior rules of laboratory test-room.

IF	THEN
no sample in the queue.	waiting for sample (IDLE).
new sample(s) waiting in the queue, and there are free analyzing machine(s).	detach sample(s) to free machine(s).
analyzing machine(s) completed the analysis	catch results and send to the corresponding doctor through IS.
daily machine maintenance time is up.	start maintaining when machine completes current task.

Table 6: Behavior rules of medical image test-room.

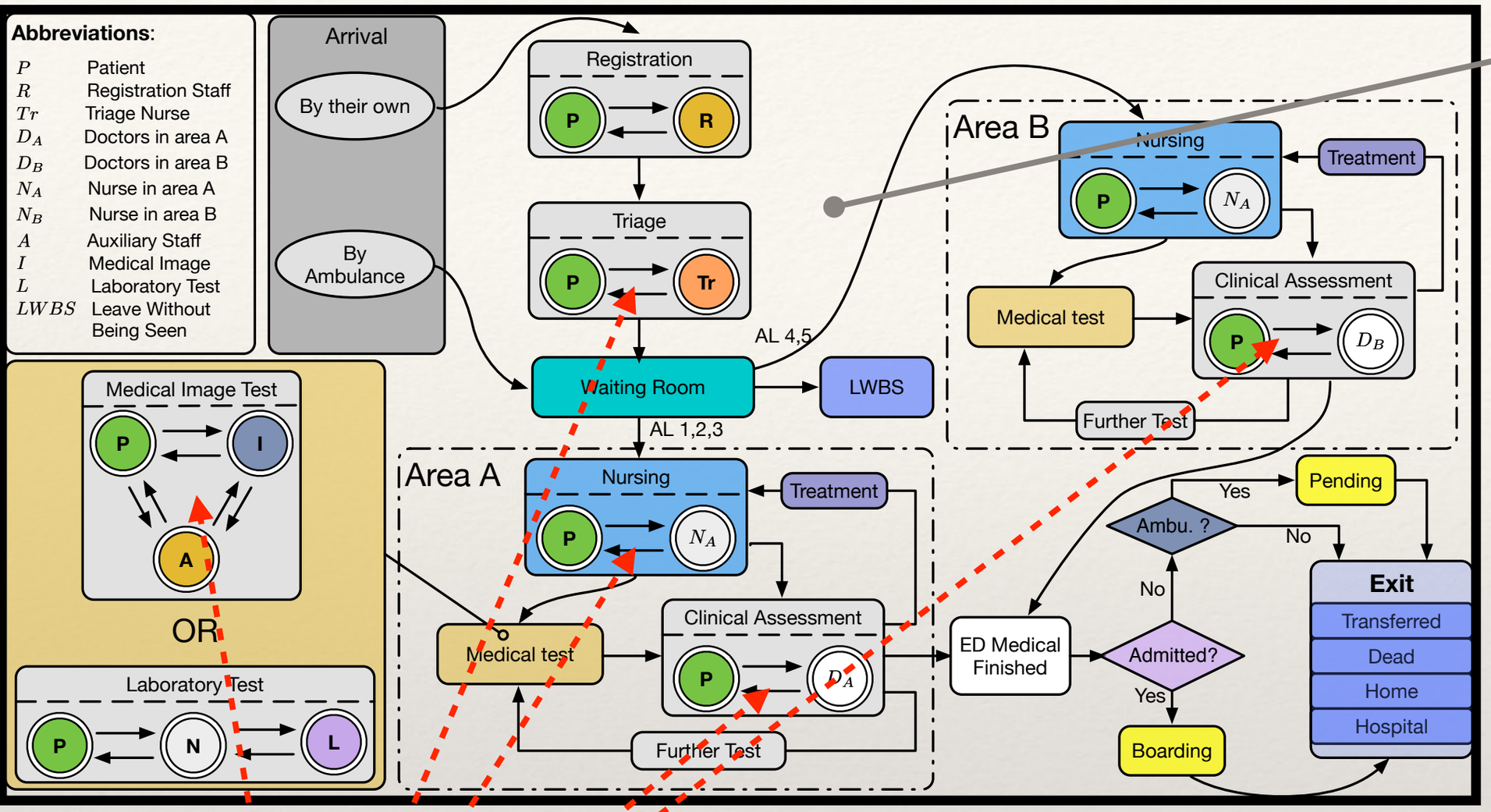
IF	THEN
no patient waiting outside.	waiting for patient (IDLE).
patient with auxiliary staff waiting outside, and test-room is ready.	interact with patient and accompanied auxiliary staff.
physical test finished.	process test results, and send to the corresponding doctor through IS.

How it works (Rules + State Variables => state)

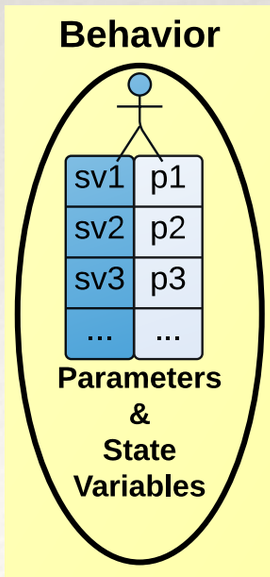
Conceptual Model

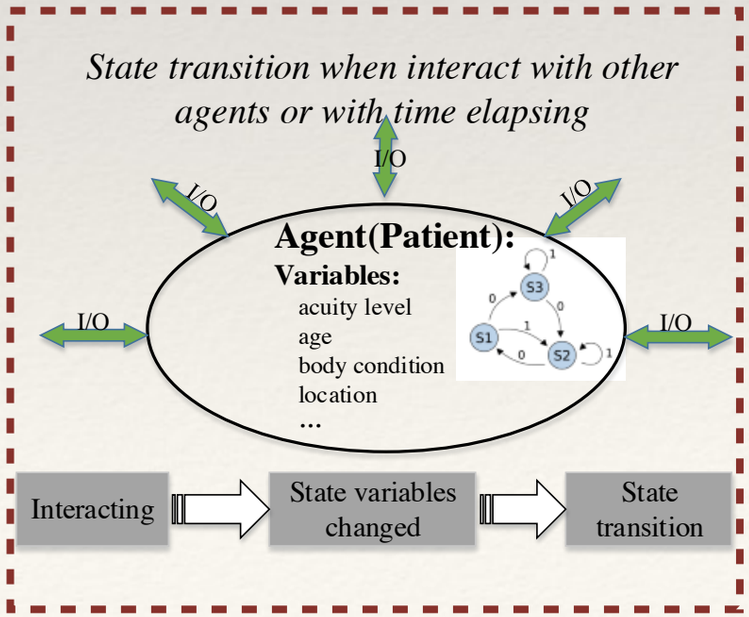
Abbreviations:

P	Patient
R	Registration Staff
Tr	Triage Nurse
D_A	Doctors in area A
D_B	Doctors in area B
N_A	Nurse in area A
N_B	Nurse in area B
A	Auxiliary Staff
I	Medical Image
L	Laboratory Test
$LWBS$	Leave Without Being Seen



Interaction





How it works (Rules + State Variables)

Table 8: Part of a patient's interaction log.

State	Source State	Destination state	Input
...	...	...	...
S_t	Waiting for service (free care-box).	Waiting for service (Doctor's diagnosis).	Notice from IS with a free care box.
S_{t+1}	Waiting for service (doctor's diagnosis)	Accepting Service(meet with doctor)	Doctor arrive at patient's care-box.
S_{t+2}	Accepting Service(meet with doctor)	Waiting for service (X-Ray test service)	Doctor order X-Ray test for patient.
S_{t+3}	Waiting for service (X-Ray test service)	Accepting Service(X-Ray test service)	X-Ray service available.
S_{t+4}	Accepting Service(X-Ray test service)	Waiting for service (Doctor's review of the test result)	X-Ray service finished.
...	...	...	...

Table 1: A part of a nurse's state transition.

State index	Source State	Destination state	Input
...	...	...	...
S_t	Waiting for task.	Meet with patient(take blood sample).	blood test task from IS
S_{t+1}	Meet with patient.	Waiting for task.	sample take finished
S_{t+2}	Waiting for task.	Meet with patient(for treatment)	treatment task from IS.
S_{t+1}	Meet with patient.	Waiting for task.	treatment task finished
S_{t+3}	Waiting for task.	Meet with patient(help discharging)	Discharging task from IS.
...	...	...	...

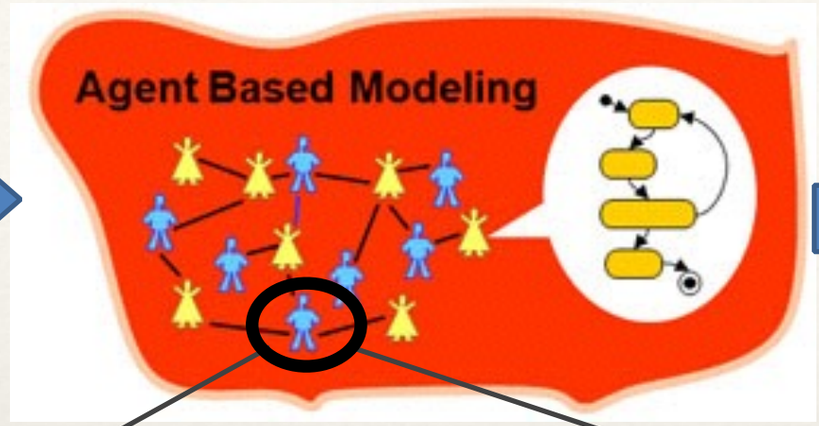
How it works (Transform, input -> output)

Patients

- Sanitary staff
- Physical Resources
- …

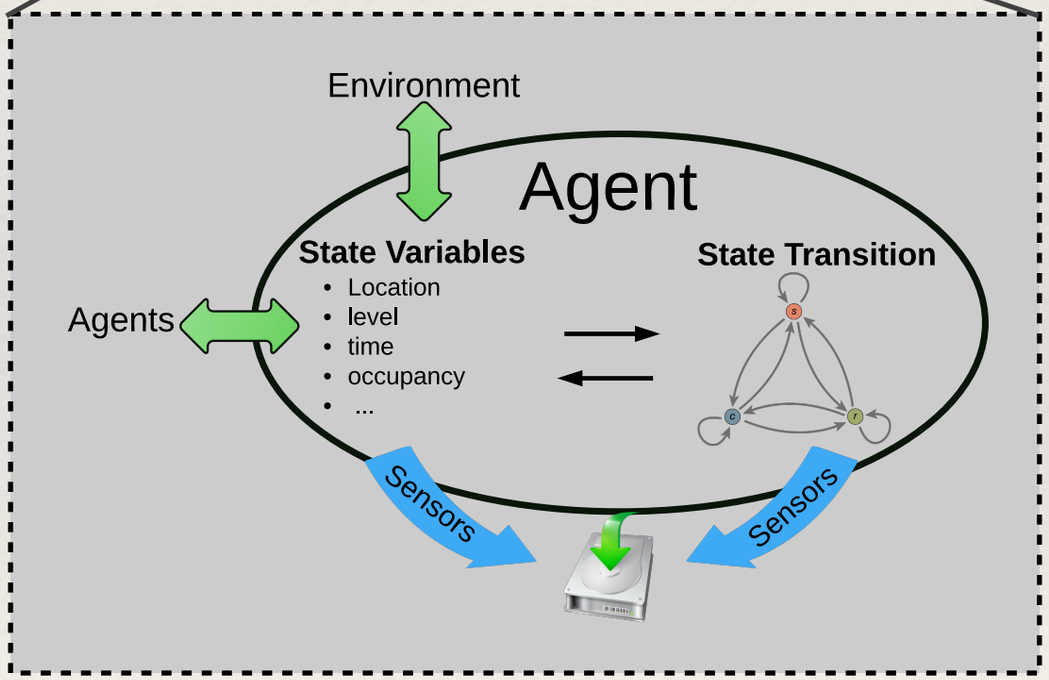
Configuration

scenario



Sensors

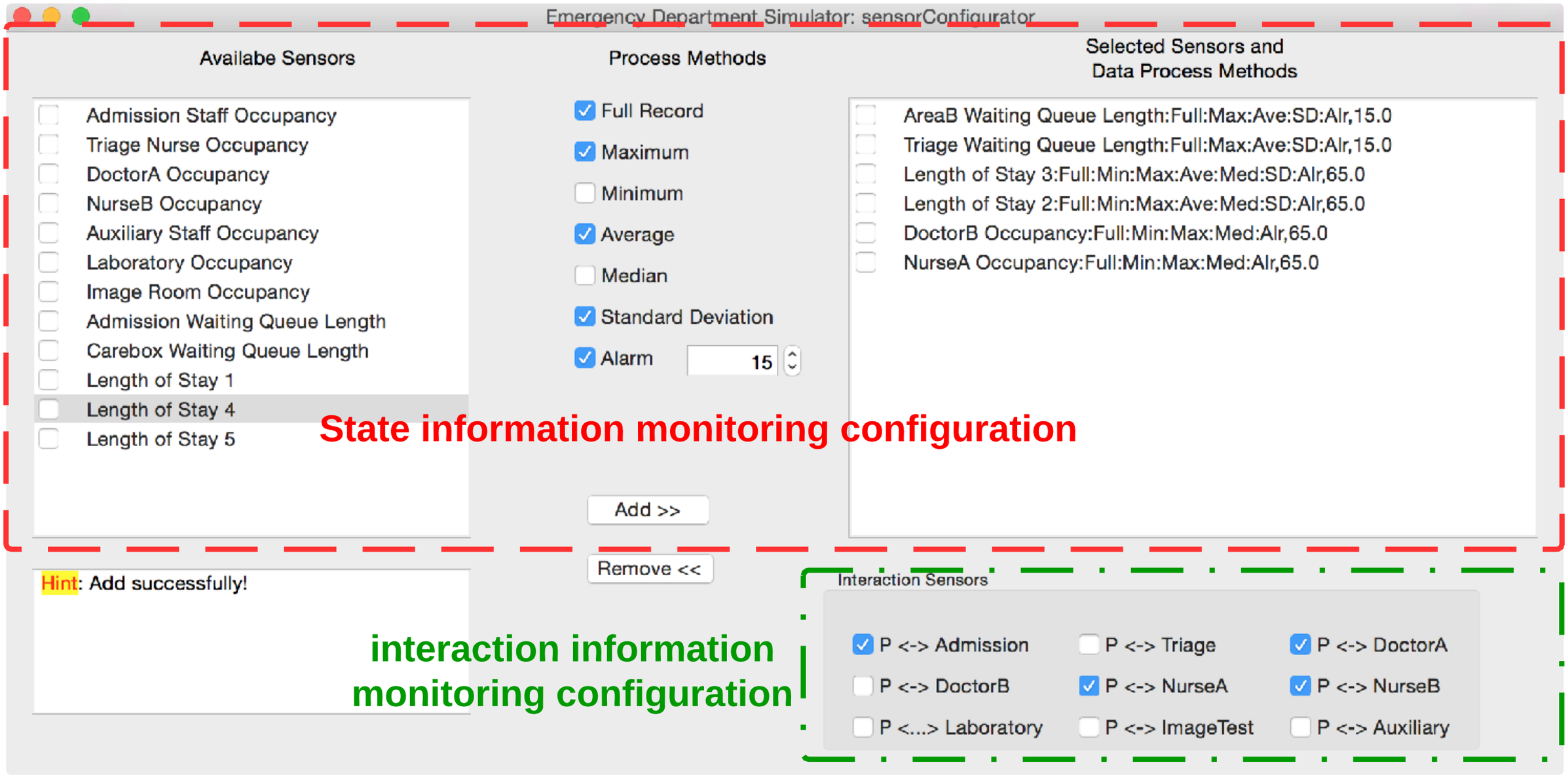
Interaction information



Reflect

Quantitative KPIs

Sensor configuration GUI



Agents' Interaction Records

1	who	what	when(minute)	where	why	how long(second)
86179	(doctorb 76) and (patient 16279)	first-visit	70446	doctorB's room	default	1200
86180	(doctorb 74) and (patient 16283)	first-visit	70447	doctorB's room	default	900
86181	(nursea 80) and (patient 16158)	go-home	70447.5	carebox	default	150
86182	(doctorb 75) and (patient 16277)	first-visit	70448	doctorB's room	default	210
86183	(doctorb 78) and (patient 16222)	treatment-finished	70449	doctorB's room	default	1320
86184	(doctora 69) and (patient 16211)	test-result-review	70449.5	carebox	default	330
86185	(doctorb 73) and (patient 16281)	first-visit	70449.5	doctorB's room	default	1290
86186	(admission 1) and (patient 16285)	admission	70451.5	admission desk	default	300
86187	(doctora 67) and (patient 16199)	test-result-review	70451.5	carebox	default	120
86188	(nursea 80) and (patient 16199)	laboratory test	70453.5	carebox	default	1080
86189	(nursea 84) and (patient 16211)	go-hospital	70455	carebox	default	1290
86190	(doctora 69) and (patient 16262)	test-result-review	70455.5	carebox	default	450
86191	(doctorb 77) and (patient 16154)	treatment-finished	70455.5	doctorB's room	default	510
86192	(doctora 66) and (patient 16033)	test-result-review	70456.5	carebox	default	300
86193	(doctorb 72) and (patient 16247)	test-result-review	70457	doctorB's room	default	360
86194	(admission 2) and (patient 16288)	admission	70460	admission desk	default	240
86195	(doctora 71) and (patient 16236)	treatment-finished	70462	carebox	default	390
86196	(doctorb 74) and (patient 16180)	test-result-review	70462.5	doctorB's room	default	360
86197	(doctora 70) and (patient 16284)	first-visit	70464.5	carebox	default	480
86198	(doctorb 72) and (patient 16285)	first-visit	70465.5	doctorB's room	default	300
86199	(doctorb 77) and (patient 16228)	treatment-finished	70465.5	doctorB's room	default	180

Extract

Length of Stay, Occupancy, Length of Waiting, Efficiency, …

Design of your experiments

ED Simulator

configuration

- ✓admission staff
- ✓triage nurse
- ✓nurse
- ✓doctor
- ✓auxiliary
- ✓carebox
- ✓laboratory test
- ✓internal test
- ✓external test
- ✓hospital ward
- ✓ambulance.
- ✓…

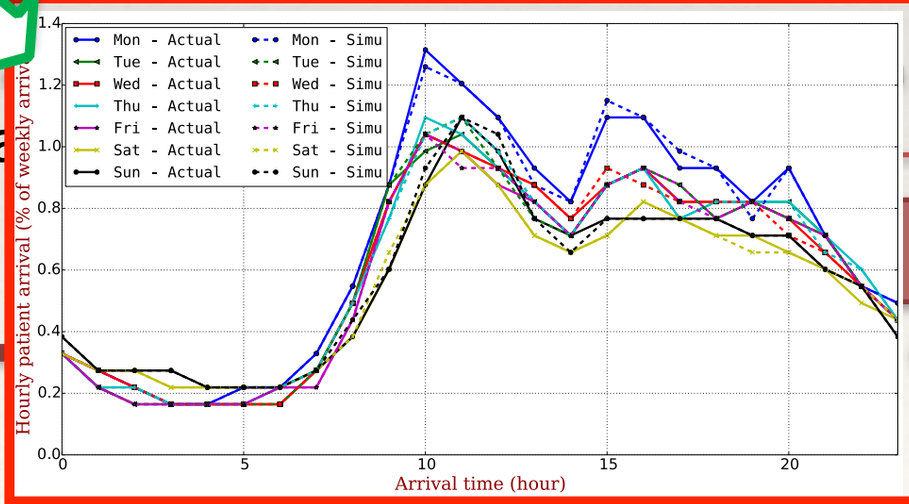
patient(input)

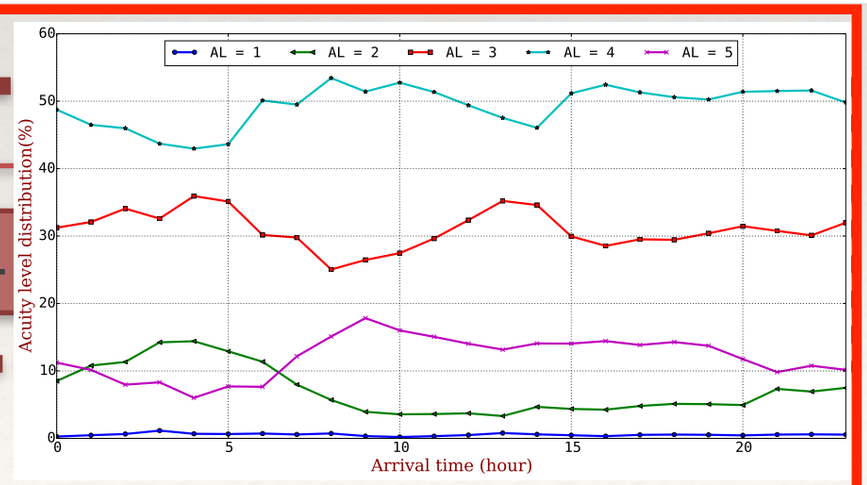
scenario

Resource	Capacity (#)		Avg. Attention Time (AT, minutes)		AT Distributic
	day	night	first interaction	follow-up	
junior admission staff	3	2	5		Gamma
senior admission staff	2	0	3		Gamma
junior triage nurse	3	1	8		Gamma
senior triage nurse	2	1	6		Gamma
junior doctor in area A	2		20	15	exponential
senior doctor in area A	4		15	13	exponential
junior nurse in area A	5		25	18	exponential
senior nurse in area A	5		20	14	exponential
doctor in area B	2		8	7	exponential
senior doctor in area B	5		6	5	exponential
junior nurse in area B	4		11	7	exponential
senior nurse in area B	4		7	5	exponential
medical imaging test room	5	2	45		Beta
laboratory test place	4	2	30		Beta
carebox in area A	50		-		-
chair in area B	60		-		-
auxiliary nursing staff	3		15		exponential

Statistical Model

Should Execute Many Times for One Scenario





Scenario = ED-Model-Configuration + Input (Patient)

Application Framework for Knowledge Discovery

Simulator User, to discover macro-level system features

Macro Level Simulator(Application)

Data Process Layer(Adaptation)

Monitoring Layer(Sensor)

Micro Level Simulator
(Agent Based Model)
[**Core**]

configurable

requirement oriented

Abstraction Path

simulation scenarios[s1, s2, s3...]

Set Scenario(s) → Simulate → Analysis → KPIs

Design of Experiments

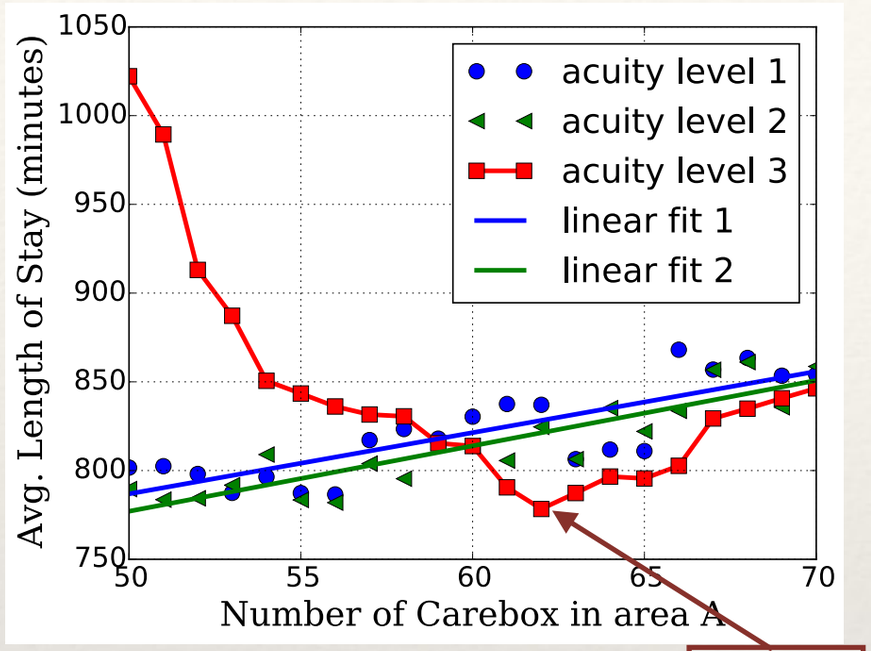
Interaction Info.

Predictions

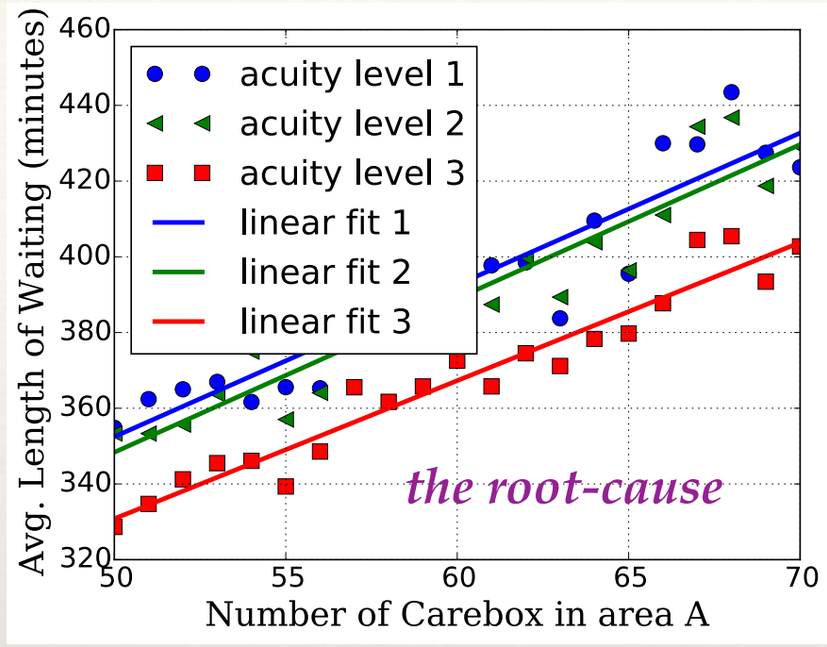
Demo No. 1

The emergency department system is **overcrowding**,
WHAT-IF
we add 20 beds to the system?

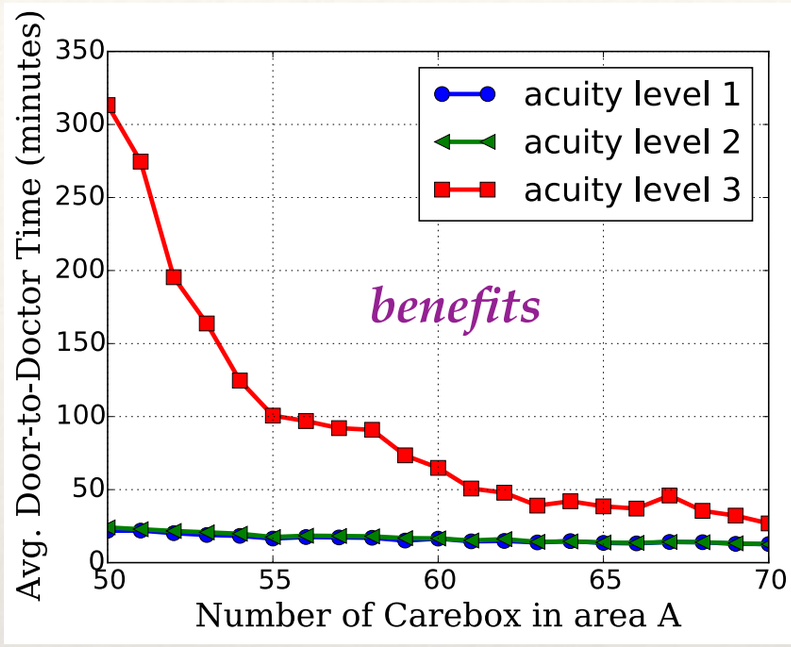
The influence of additional carebox on patients' behavior (Area A).



(a) length of stay

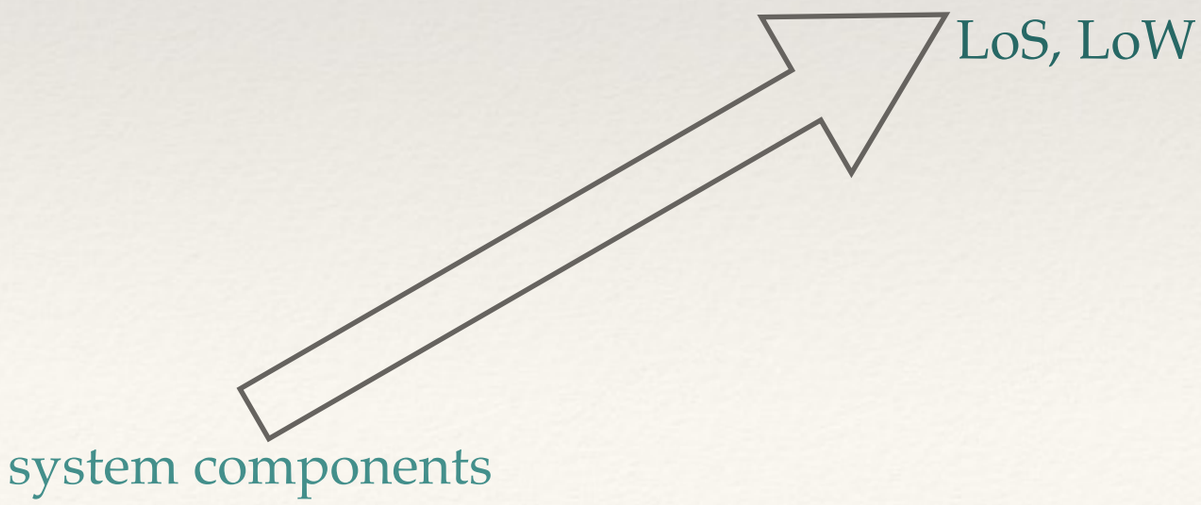


(b) length of waiting time (in treatment area)



(c) door-to-doctor time

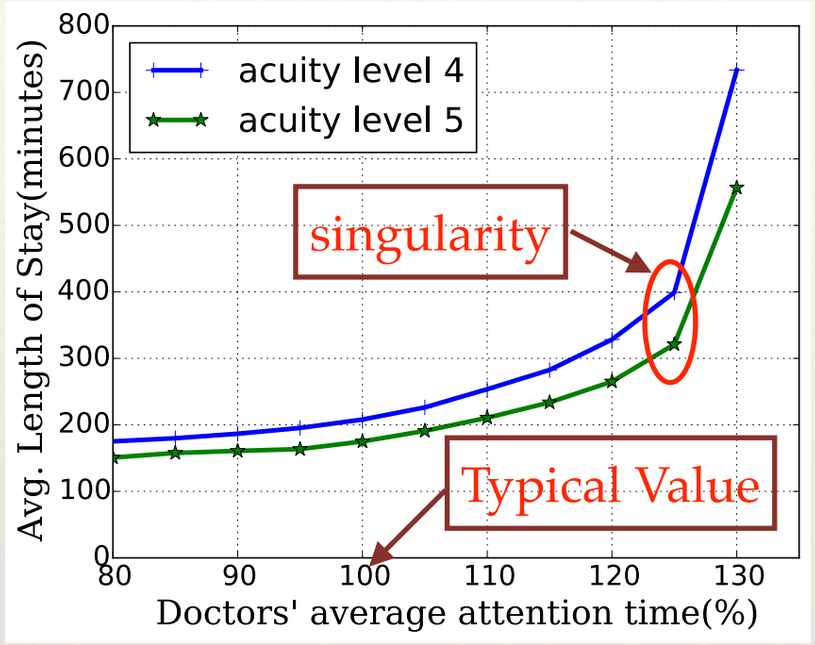
note: the scale of vertical coordinates are different.



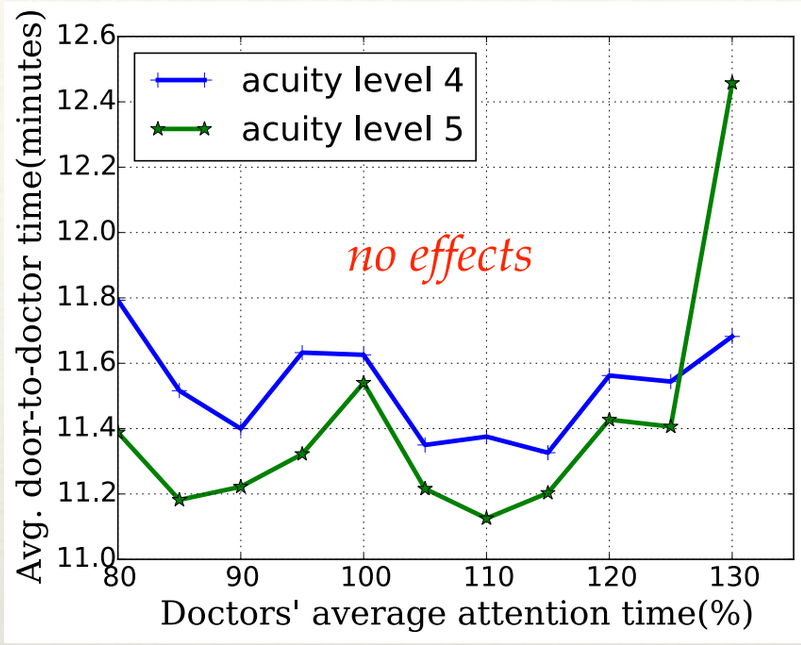
Demo No. 2

Explore the effects of doctors' behavior on the system-level behavior.
and
Explain why (identify the root cause).

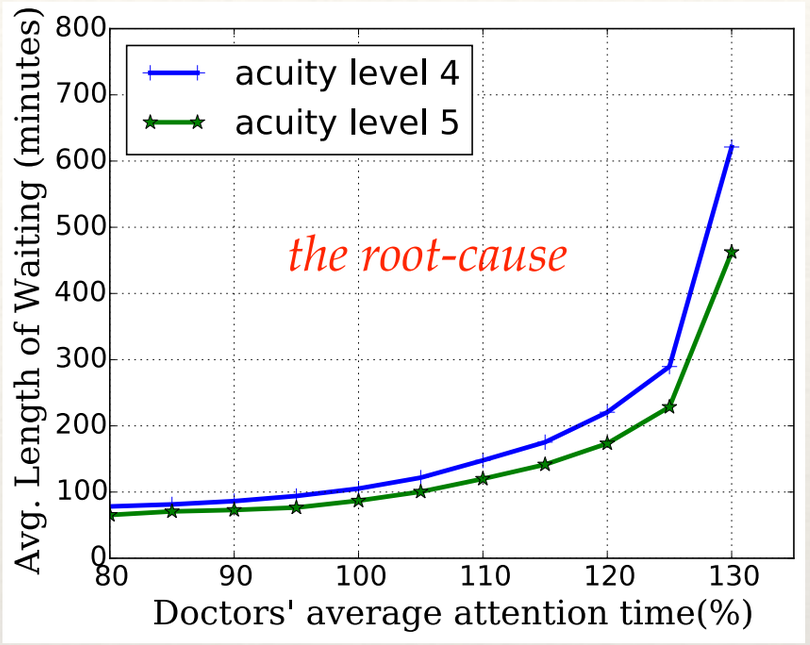
The effect of length of doctors' (area B) attention time on macro-level LoS, and the root cause identification.



(a) length of stay

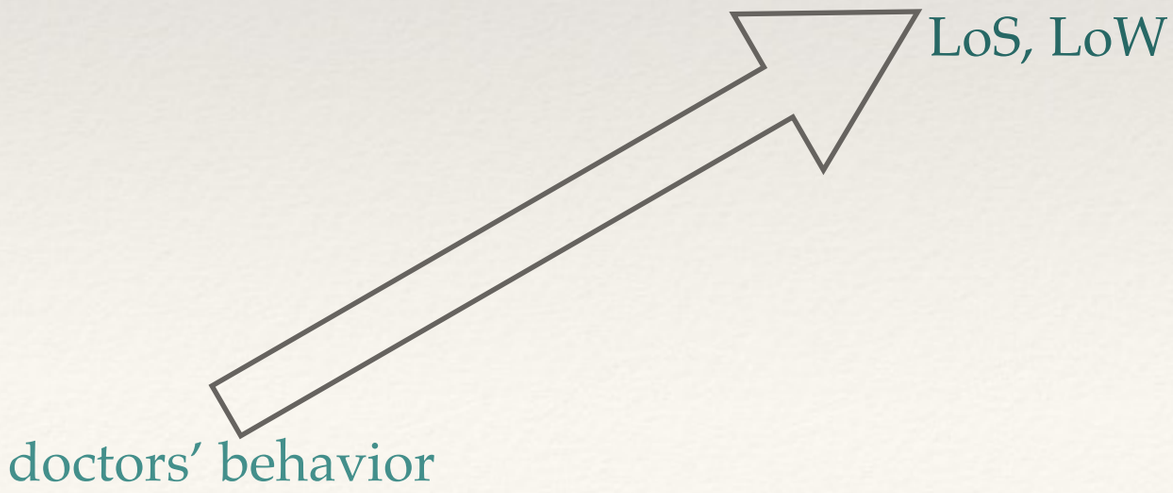


(b) door-to-doctor time



(c) length of waiting time

note: the vertical coordinate scale of (b) is quite different as (a) and (c)



Conclusion

- This article presents an approach to discover knowledge of emergency department through simulating individual behavior of its components.
- It provides a way to see the forest through the trees and, insight is often more important than sheer numbers.
- The model is customizable from individual level, the atomic data about agent interaction and environment state record are provided by customizable “sensor”.

Future work

- Develop an automatic calibration/tuning tool along with the model for users to calibrate and validate the model parameters for their EDs without the involvement of model developer.

Connections

=> **Poster** (Agent Based Poster Madness M1, 5:15pm-5:45pm, **Monday**, **Salon A**)

ABMS Simulator of Propagation of Nosocomial Infection in Emergency Department
*(Note: Principal way of MRSA transmission is the frequent **interaction** between patients and healthcare staff.)*

=> **Poster** (New Simulation Applications Poster Madness M4, 5:15pm-5:45pm, **Monday**, **Catalina**)

Evaluation of Performance and Response Capacity in Emergency Departments

Thanks for Your Attention!

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