



清华大学
Tsinghua University

An Integrated Medical CPS for Early Detection of Paroxysmal Sympathetic Hyperactivity

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1. What is PSH?

- a syndrome manifested with: *simultaneously* increased heart rate, respiratory rate, blood pressure, body temperature and **many other clinical features**, such as severe sweating, posturing, etc.



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2. Why we study PSH?

- meeting with Dr. He
- Facts from medical publications in USA
 - Primarily caused by traumatic brain injury(TBI)
 - 33% of severe TBI have been reported with PSH
 - Costs millions of dollars every year, 90% of all TBI cost
 - ***Delayed recognition*** results 45% with severe disability, 30% with persistent vegetative state and 18% with death
(7% good recovery)



Challenges

1. ***No universally accepted clinical diagnostic criteria*** exist because of the limited evidence of pathophysiology

Body Temperature 38 ? 38.5
How many clinical features?
What are they?
...



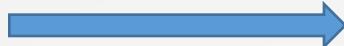
Many physicians learn a little background on it.



Challenges

1. **No universally accepted clinical diagnostic criteria** exist because of the limited evidence of pathophysiology
2. PSH is a syndrome with **complex manifestations** to which a lot of conditions have similar appearances.

Body Temperature 38 °C
Heart Rate 120 beats/min
...



**Many physicians misdiagnose
PSH**



Challenges

1. *No universally accepted clinical diagnostic criteria* exist because of the limited evidence of pathophysiology
2. PSH is a syndrome with *complex manifestations* to which a lot of conditions have similar appearances.
3. The paroxysmal clinical feature requires symptoms *to be recurrent and episodic* to make a diagnosis.

Medical staff have already overloaded!



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Therefore, all these limitations hamper the awareness of a diagnosis and it is not easy for medical staff to make an early detection of PSH.



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1. A formal model to describe diverse clinical criteria sets uniformly.
-> **Challenge1 & 2**
2. An early detector in terms of the formal models and medical CPS with medical device adapters integrated to observe patient vital signs automatically and continuously.
-> **Challenge2 & 3**
 2. PSH is a syndrome with **complex manifestations** to which a lot of conditions have similar appearances.
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Formal models

1. Clinical criteria

- a strong agreement on *simultaneous and paroxysmal feature*
- *Episode duration and frequency*
- *Clinical feature composition and severity*

simultaneous occurrence of **5 or more** of the following features:

- (1) tachycardia (heart rate > 120beats/min),
- (2) tachypnea (respiratory rate > 30 breaths/min),
- (3) hyperthermia (temperature > 38.5 °C),
- (4) hypertension (blood pressure > 160 mmHg),
- (5) increased muscle tone,
- (6) decerebrate or decorticate posturing, and
- (7) excessive sweating

at least 1 daily paroxysm that occurs for at least 3 days.



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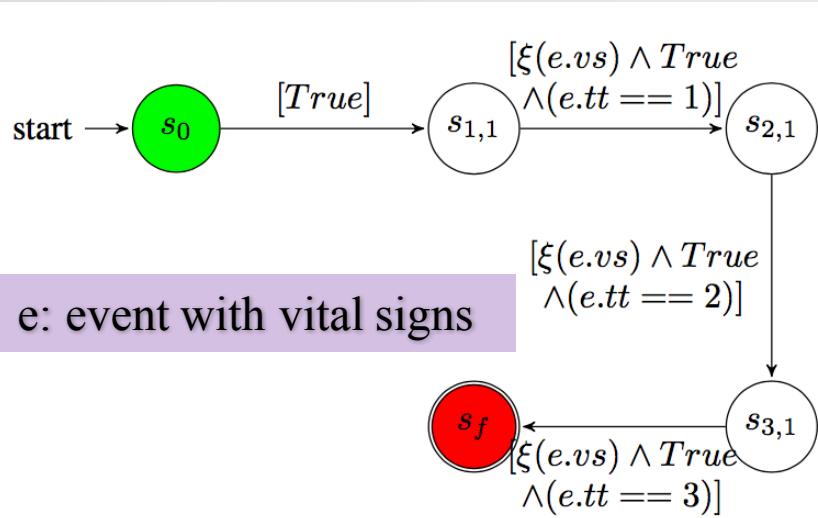
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- **Model combination. We can utilize multiple clinical criteria sets with a weight vector.**

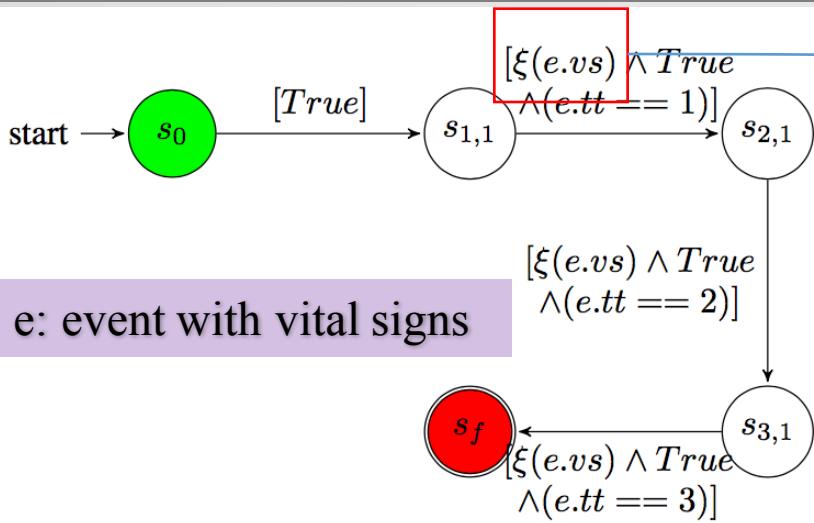


$$g_{(s_{i,j}, s_{m,n})}(e) = C.\xi(e.vs) \wedge fre_{(s_{i,j}, s_{m,n})}(e) \wedge dur_{(s_{i,j}, s_{m,n})}(e)$$

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Occurrence: 5 or more of the features

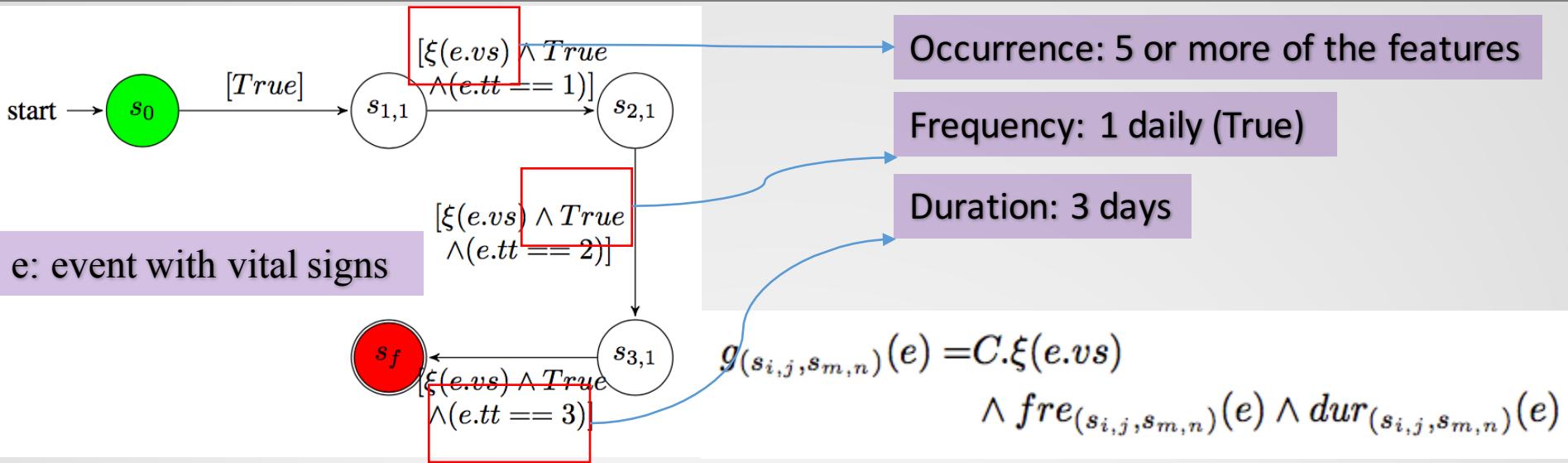
e: event with vital signs

$$g_{(s_{i,j}, s_{m,n})}(e) = C.\xi(e.vs) \wedge fre_{(s_{i,j}, s_{m,n})}(e) \wedge dur_{(s_{i,j}, s_{m,n})}(e)$$

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Medical CPS – Components and Interactions

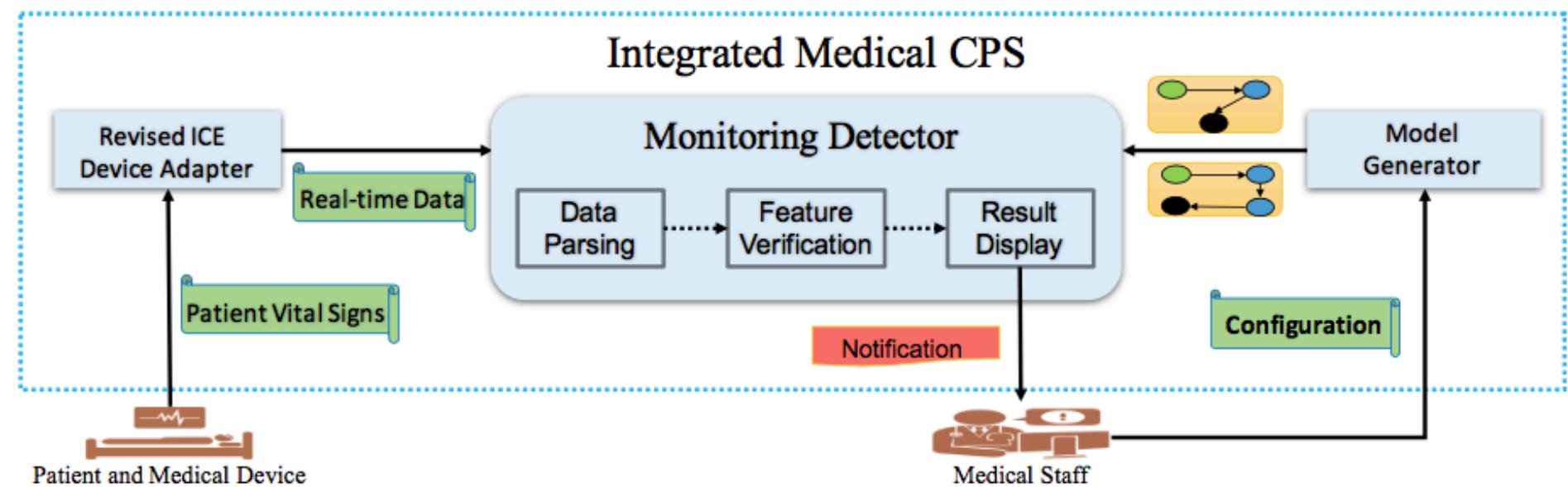


Fig. 1: Components and interactions of our integrated Medical CPS for early detection of PSH



Medical CPS – Implementation and Deployment in Lab





Evaluation

1. Experimental Setup

- two of the most widely used criteria sets -> any of them
- 97 PSH cases and 10 non-PSH from medical publications
- we invite volunteers with medical experience to manually check patient data every hour -> there is no runnable tool

2. Results



TABLE I: Detection results on cases from medical publications

Publication	Cases			PSHMonitor				Manually			
	PSH	N-PSH	Total	TP	TN	FP	FN	TP	TN	FP	FN
Lee [18]	2	0	2	2	0	0	0	1	0	0	1
Hughes [14]	44	0	44	44	0	0	0	37	0	0	7
Baguley [3]	15	0	15	14	0	0	1	13	0	0	2
Blackman [5]	20	0	20	20	0	0	0	16	0	0	4
Deepika [9]	4	0	4	3	0	0	1	1	0	0	3
Lv [19]	6	0	6	6	0	0	0	4	0	0	2
Baguley [2]	6	0	6	4	0	0	2	4	0	0	2
Umbriaco [24]	0	5	5	0	4	1	0	0	4	1	0
Martin [20]	0	5	5	0	3	2	0	0	4	1	0
Summary	97	10	107	93	7	3	4	76	8	2	21

PSH is for patient confirmed as PSH and N-PSH is used for other cases like *Sepsis* and *Malignant hyperthermia*. TP is true positive for PSH cases detected as PSH. TN is true negative for N-PSH cases detected as N-PSH. FP is N-PSH cases misdiagnosed as PSH and FN is PSH cases underdiagnosed .



Evaluation

	PSH Monitor	Manually
Precision	$\frac{93}{93+3}$ (96.88%)	$\frac{76}{76+2}$ (97.44%)

$$P = TP / (TP + FP)$$

For correctness , the same.

Namely, we will not burden medical staff with too much false alarms than the current approach.



Evaluation

	PSH Monitor	Manually
Precision	$\frac{93}{93+3}$ (96.88%)	$\frac{76}{76+2}$ (97.44%)
Recall	$\frac{93}{97}$ (95.88%)	$\frac{76}{97}$ (78.35%)

$$R = TP / (TP + FN)$$

For detection ability, better.

In medical domain, with a reasonable false alarm rate, a higher recall indicates a better solution



Evaluation

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Precision	$\frac{93}{93+3}$ (96.88%)	$\frac{76}{76+2}$ (97.44%)
Recall	$\frac{93}{97}$ (95.88%)	$\frac{76}{97}$ (95.88%)
Efficiency	cases	17 more (17.53%) -
	time	+4.5 hours

For efficiency, in the same duration, we can detect more and earlier.



Evaluation

PSH Monitor

Manually

Volunteers missed N-PSH cases.

False alarm	Mis-	3	2
	Under-	4	21



Lessons

- **Medical CPS is desired.**
 - Medical devices have been equipped in hospitals
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- False alarms are hard.
 - Invite physicians to define the thresholds.
- **Simplicity is better.**
 - Computer technologies are totally unknown domain to medical staff.
 - An extensible structure is demanded to cope with the volatile clinical requirements such as the evolution in definitions of diseases.



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 - Medical devices have been equipped in hospitals
 - They need more “intelligent tools”
- False alarms are hard.
 - Invite physicians to define the thresholds.
- Simplicity is better.
 - Computer technologies are totally unknown domain to medical staff.
 - An extensible structure is demanded to cope with the volatile clinical requirements such as the evolution in definitions of diseases.
- Data is precious.
 - Medical CPS will be helpful.



Conclusion

We presented an integrated Medical Cyber-Physical System for early detection of paroxysmal sympathetic hyperactivity.

- A formal diagnostic criteria model
- A detector employed the formal models
- A medical CPS with the detector and medical devices integrated
- Evaluation on cases from medical publications



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Thanks & Questions.