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DECU: ICU Patient Motion Summarization

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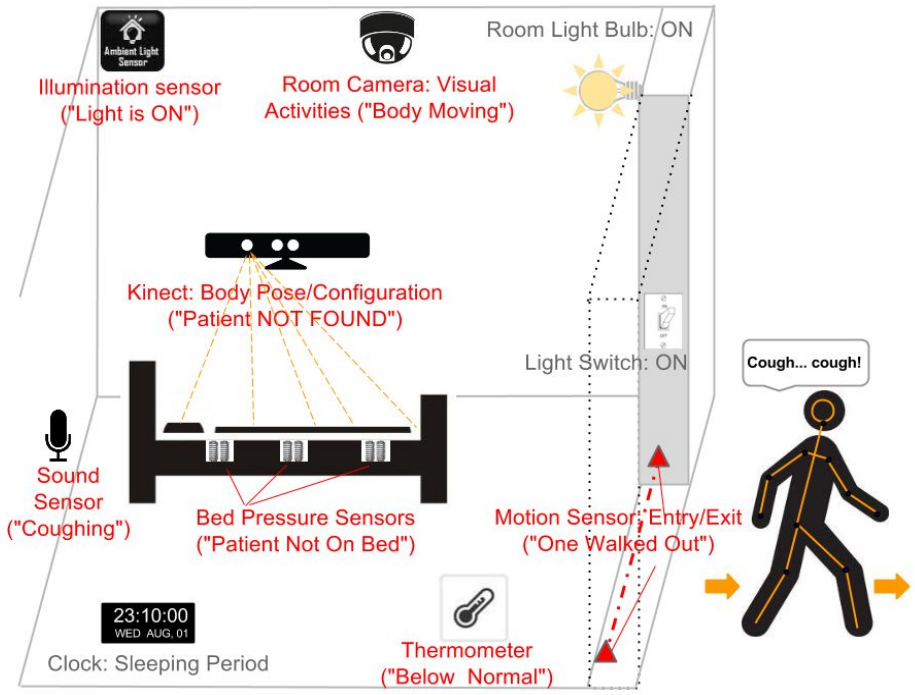
Outline: Deep Eye-CU (DECU)

- Healthcare Motivation: ICU Focus, Need, & Impact
  - Pathologies and Existing Solutions
  - Desired Solutions
- Problem
  - Definition and Objective
  - Evaluation of Popular and Existing Techniques
- MEYE Network and Healthcare Data Challenges
  - Mock-Up & Real ICU
  - Evaluation of Popular Techniques
- DECU Framework
  - Review of Hidden Markov Models -- Limitations
  - Hidden Semi-Markov Models -- Properties
- Results in Mock-Up and Real ICU rooms

Motivation - ICU Need

"Monitoring Intensive Care Units can save up to $15 Billion by saving up to $20,000 in each of the 750,000 ICU beds"

Harvard Medical Report. Published Aug 4th 2016.



Questions:

- Why the ICU?
  - Control and dissemination
- What are the problems?
  - Pathologies
- How to help? Solutions?
  - Unobtrusive and non-intrusive

Impact - Why the ICU?

Intensive Care Unit (ICU) Statistics

- 5 million people per year are admitted to the ICU.
- 46% are over the age of 65.
- Annual national ICU cost is $130 billion and rising $5 billion/yr.
- Average duration of stay in the ICU is 9.3 days.
- Mortality rate is 10-30% and increases by 7% per day.
- Year 2020 estimates:
  - ICU elderly population will increase to 69%.
  - Caregiver workforce will shrink by 35%.

** Src: Online - US Department of Health and Human Services. Feb 2016*

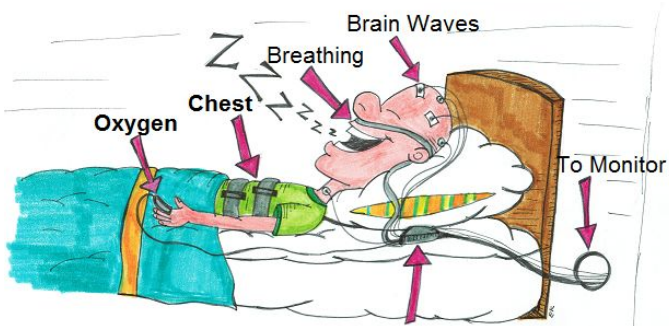
Motion Patterns Correlate with Patient Health

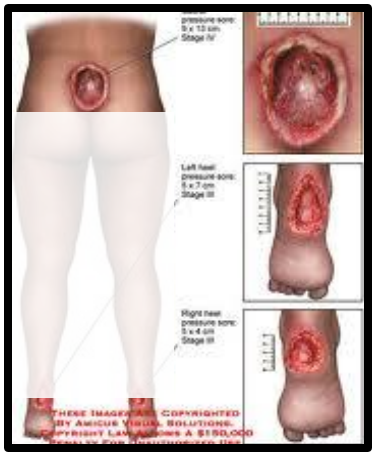
Sleep Deprivation* - Sleep Hygiene

- ➔ "Bad night" → ICU stay + 10%
- ➔ Sleep Poses → Quality of Sleep
- ➔ Obtrusive Measurements + Surveys
- ➔ No Prevention

Decubitus Ulcerations (DU)** - Bed Sores

- ➔ 2.5M cases (80% occur in ICU)
- ➔ Pose + Time + Bony areas = DU
- ➔ Braden scale (subjective & observational)
- ➔ Rounds & Patient Rotation (2hr, <20%)





*Sleep in the Critically Ill Patient, Weinhouse and Schwab. Sleep 2006
Factors affecting sleep in the ICU. Bihari et al. JCSM 2012

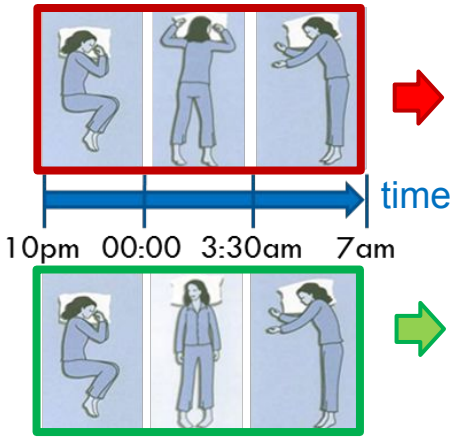
**Preventing Pressure Ulcers in Hospitals. Soban et al. Jrnl on Quality & Patient Safety 2011
Online Medical-Dictionary: pressure ulcer, retrieved Feb 2016

Desired: Pose Patterns → Patient Health

Automated Analysis of Sleep Hygiene and DU Incidence/Prevention

- Non-intrusive **automated** patient monitoring and data collection
- Incidence & risk evaluation from **evidence** (measurements vs observations)
- **Individualize** therapies using quantifiable data

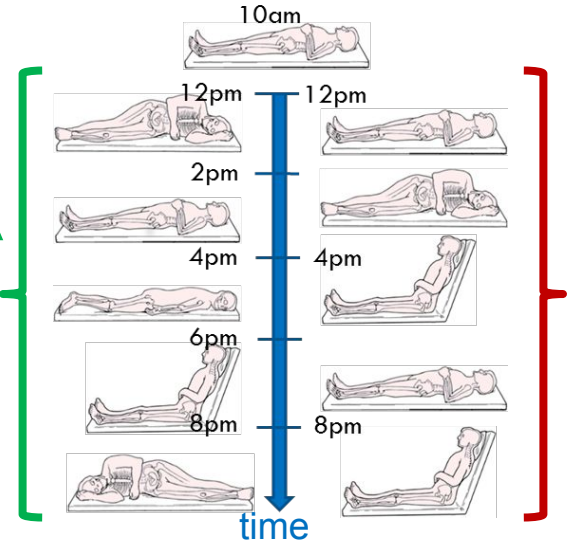
SLEEP DISORDER ANALYSIS



Sequence X
(MD: Bad Sleep)

Sequence Y
(MD: Good Sleep)

DECUBITUS ULCERATION ANALYSIS



Sequence A
DU risk: **0**
(lowest)

Sequence B
DU risk: **10**
(highest)

Problem Definition - High Level

- **Goal**: analyze patterns of poses/pseudo poses (Y) over time
- **Observations**: multimodal multiview videos (X)

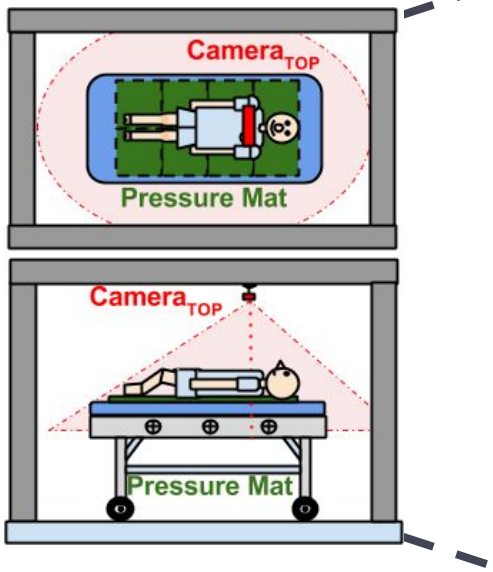
- Sleep Disorders: rapidly going from pose i to pose j
  - fine: tossing/turning transition direction, range & rate
  - coarse: sequences that correspond to good sleep

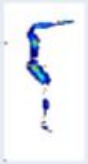
- DUs: Sequence of poses over long periods of time
  - fine: involuntary and voluntary poses (irritations/pain)
  - coarse: sequences that prevent/cause DUs

- Differences: their resolution, duration, and inclusion of rotation direction and range

Data: Mock-up ICU Bright and Clear Scenario

PHYSICAL SETUP



NAME	Soldier	Log	Yearner	Fetal	Freefaller	Starfish
POSE						
RGB (R)						
Depth (D)						
4-Pressure						

Performance of Popular Techniques

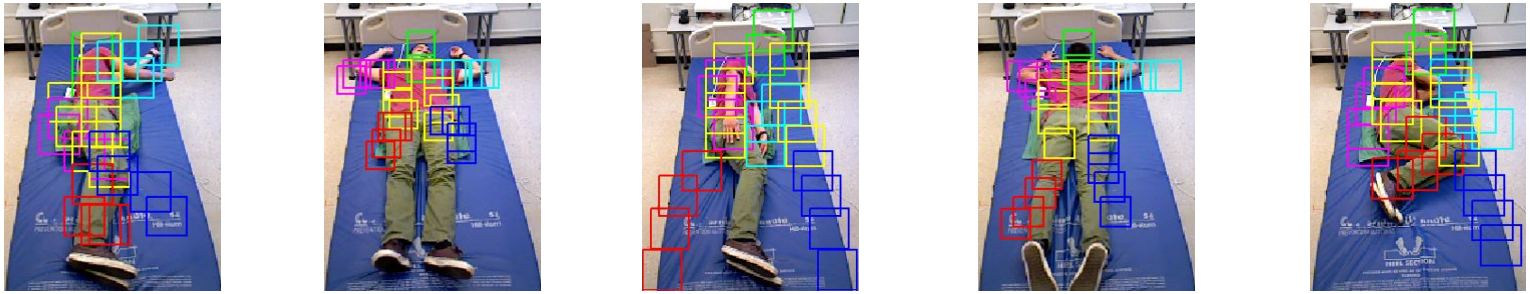
ASSUMPTIONS

- View Point and Depth Contrast
- "Good" Illumination
- No Occlusions

FAILURE CAUSES

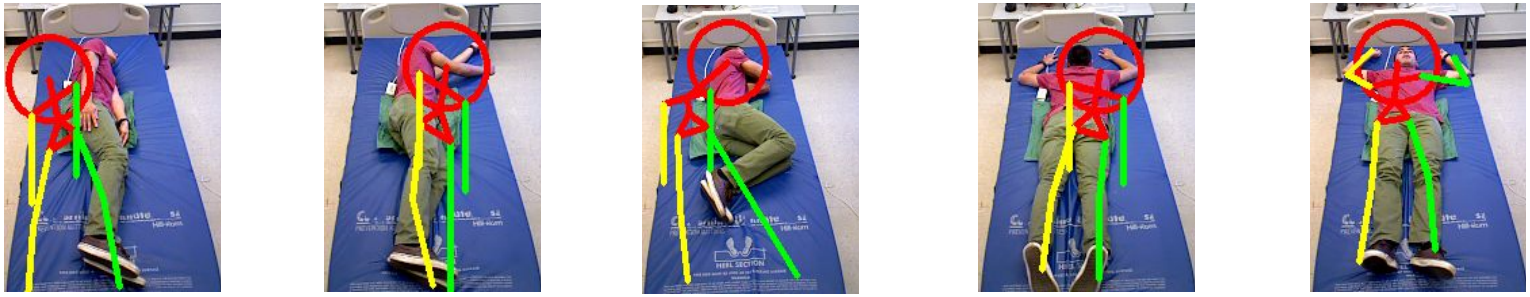
- Clutter
- Minor self-occlusions
- Depth Contrast

1. Deformable Part Models [3]



RGB

2. Kinect API [4]

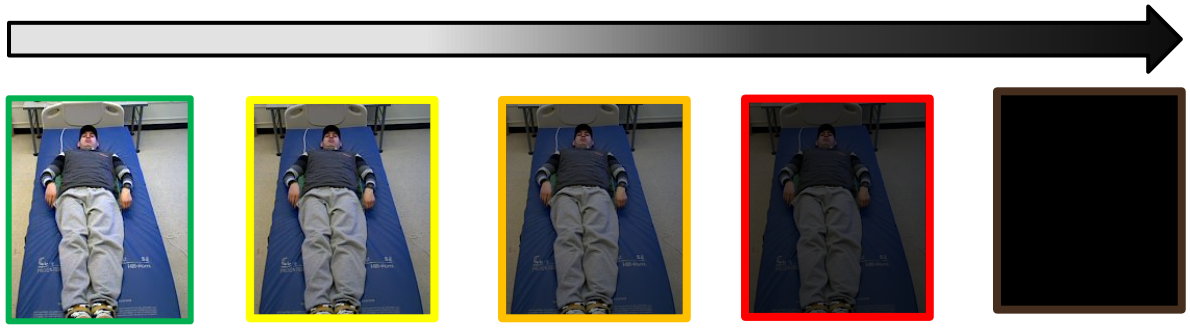


Depth

Additional Challenges of ICU Scenes

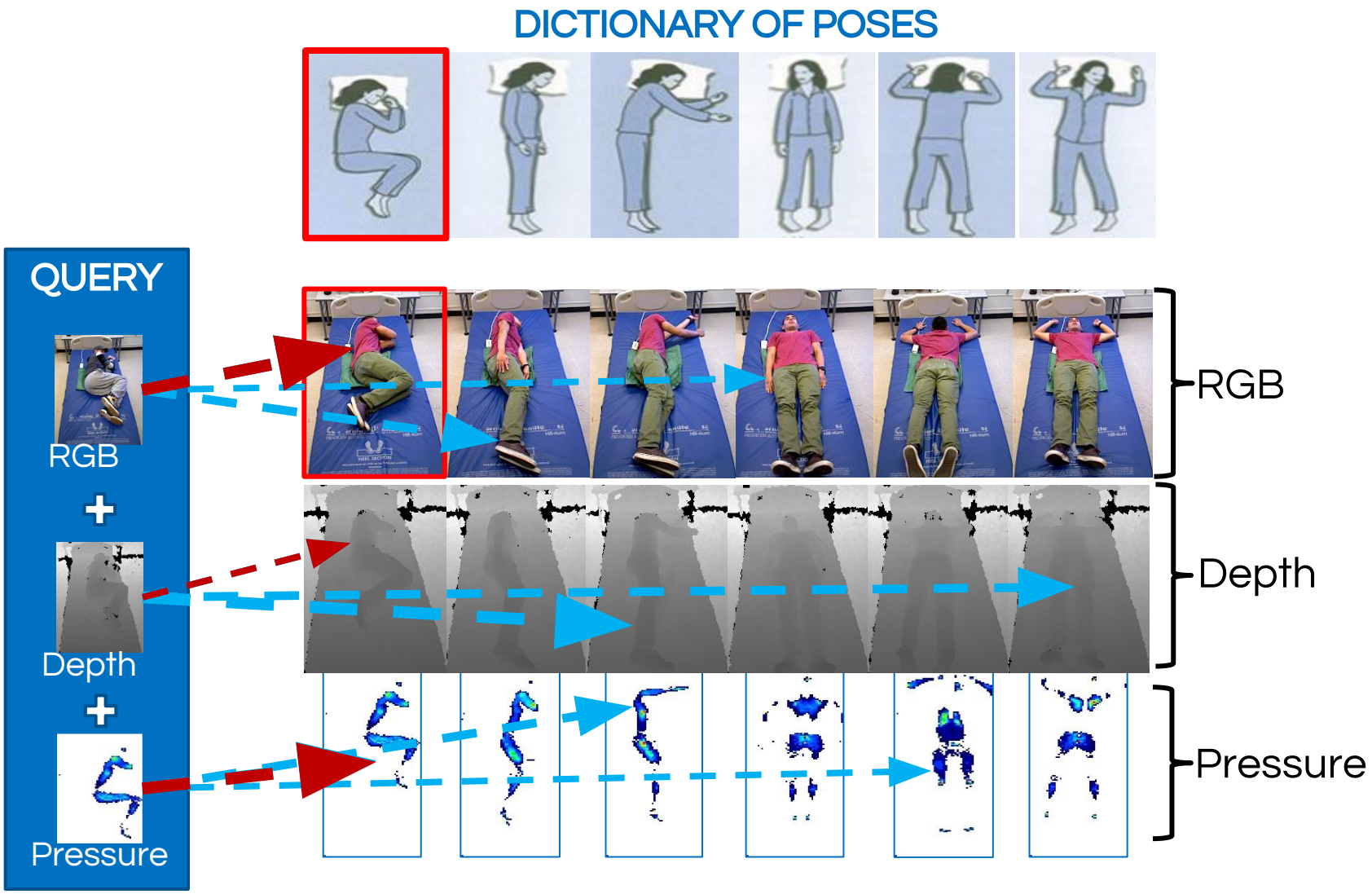
The ICU is a **natural** scenario (unstructured)

Illumination variations

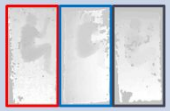
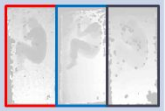
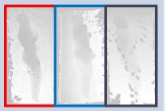
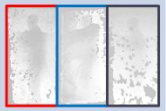
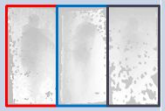
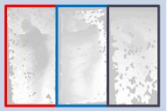
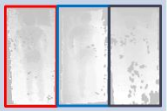
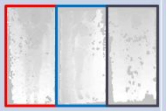
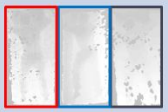
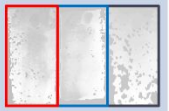


Occlusions (blankets)

Multimodal Data Classification [6] & [7]



Multimodal **Multiview** Classification [8]

Symbol	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
POSE	Fetal L	Fetal R	Log L	Log R	Yearner L	Yearner R	Soldier D	Soldier U	Faller D	Faller U
RGB (*R*): Views: *t s h*										
Depth (*D*) Views: *t s h*										
Pressure (*P*)										
Light	Bright	Medium	Dark	Bright	Medium	Dark	Bright	Medium	Dark	Bright
Occlusion	Clear	Clear	Clear	Blanket	Blanket	Blanket	Pillow	Pillow	Pillow	Blanket Pillow

$$\underset{\mathbf{w}}{\text{minimize}} \frac{1}{2}\|\mathbf{Aw}-\mathbf{b}\|_2^2$$
$$\text{subject to} \quad \mathbf{1}^T\mathbf{w}=1$$
$$0 \le w_m \le 1, m=1,..,M$$

Objective: find the optimal **W** (multimodal multiview weights)

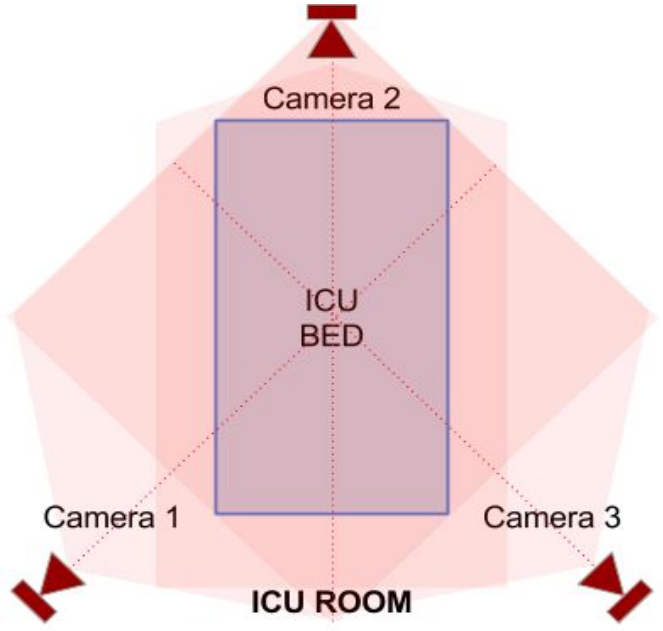
Limitations to Real-World Applications

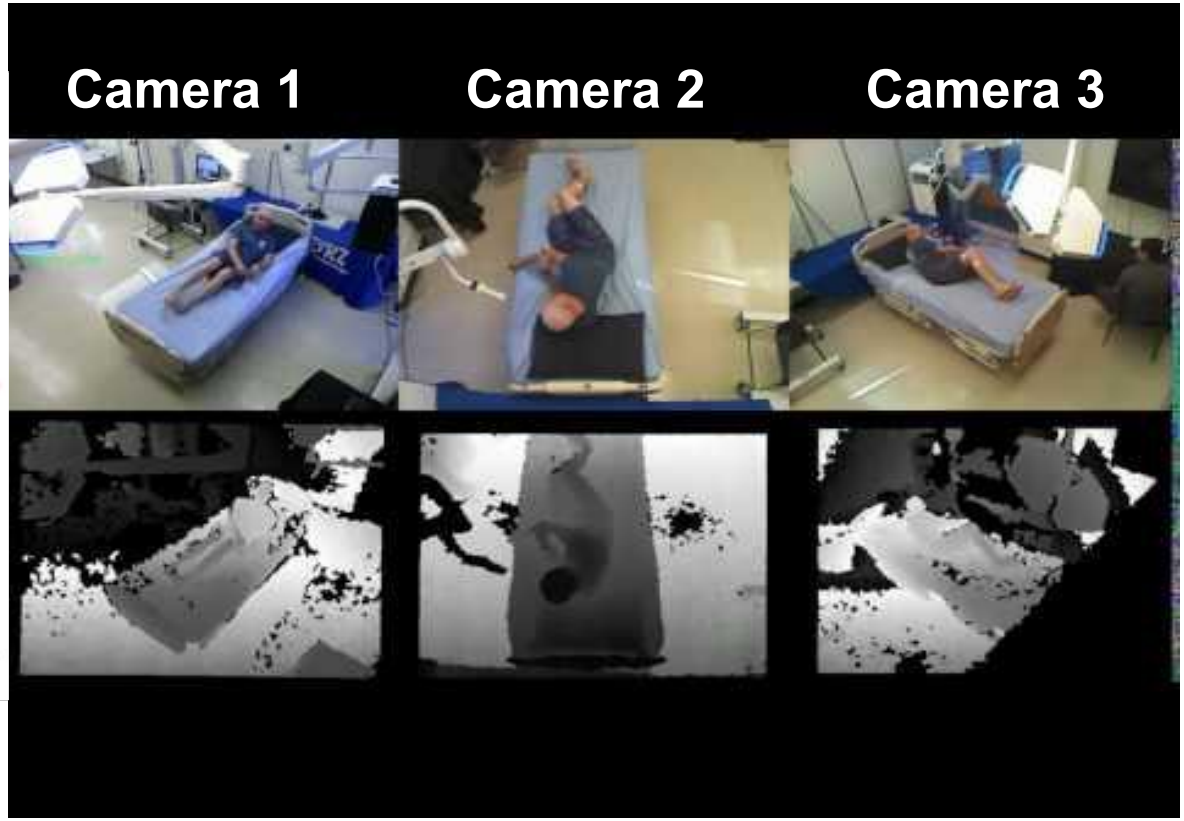
- Simulated scenarios
  - DECU → Mock-Up and Real ICUs
- Well-defined poses that are visually "distinct"
  - ICU patients do not move much
  - DECU → Poses, Aspiration, and Pseudo Poses
- Motion range and rate are not considered
  - DECU → Time-Series Analysis & Models State Durations

DECU: Multimodal Multiview ICU Network

Dry Lab: Mock-up ICU

Multimodal Multiview - Pose Transition





Approach: Time-Series

How likely are we to see the **sequence of poses or pseudo poses** (states)

$$Y = \{y_1, \ldots, y_T\}$$

From only observing **multimodal multiview video features** (over time)

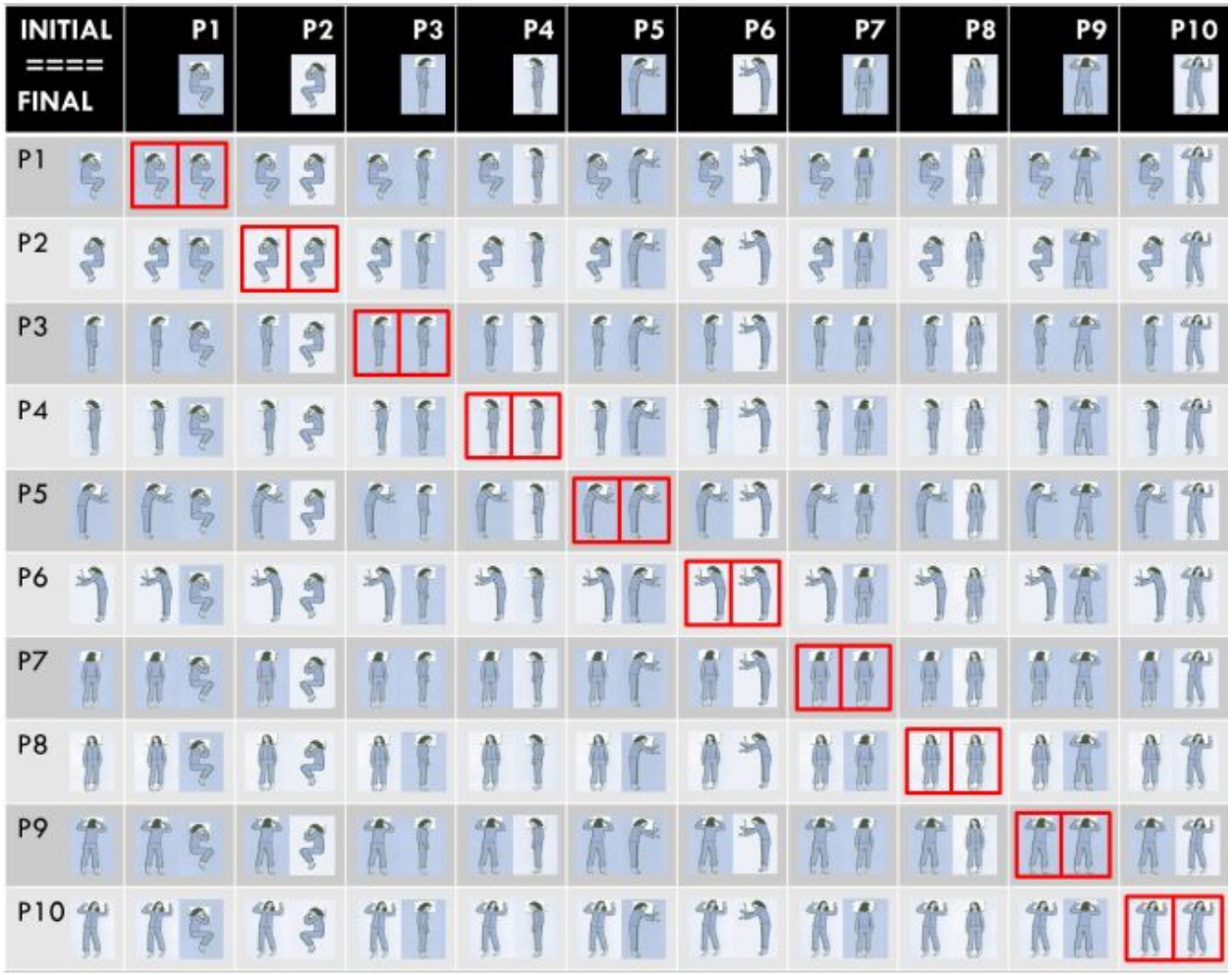
$$X = \{x_1, \ldots, x_T\}.$$

The k-th observation from view v from RGB(R) and Depth (D)

$$x_k = x^{(v)}_{k,m} = \{\mathcal{R}_k, \mathcal{D}_k\}$$

Compute $P(Y_{1:T}, X_{1:T})$ overtime for t in 1:T

Mock-Up Set Of Poses - Subset For Real ICU



100 pose pairs

×

2 rotation directions

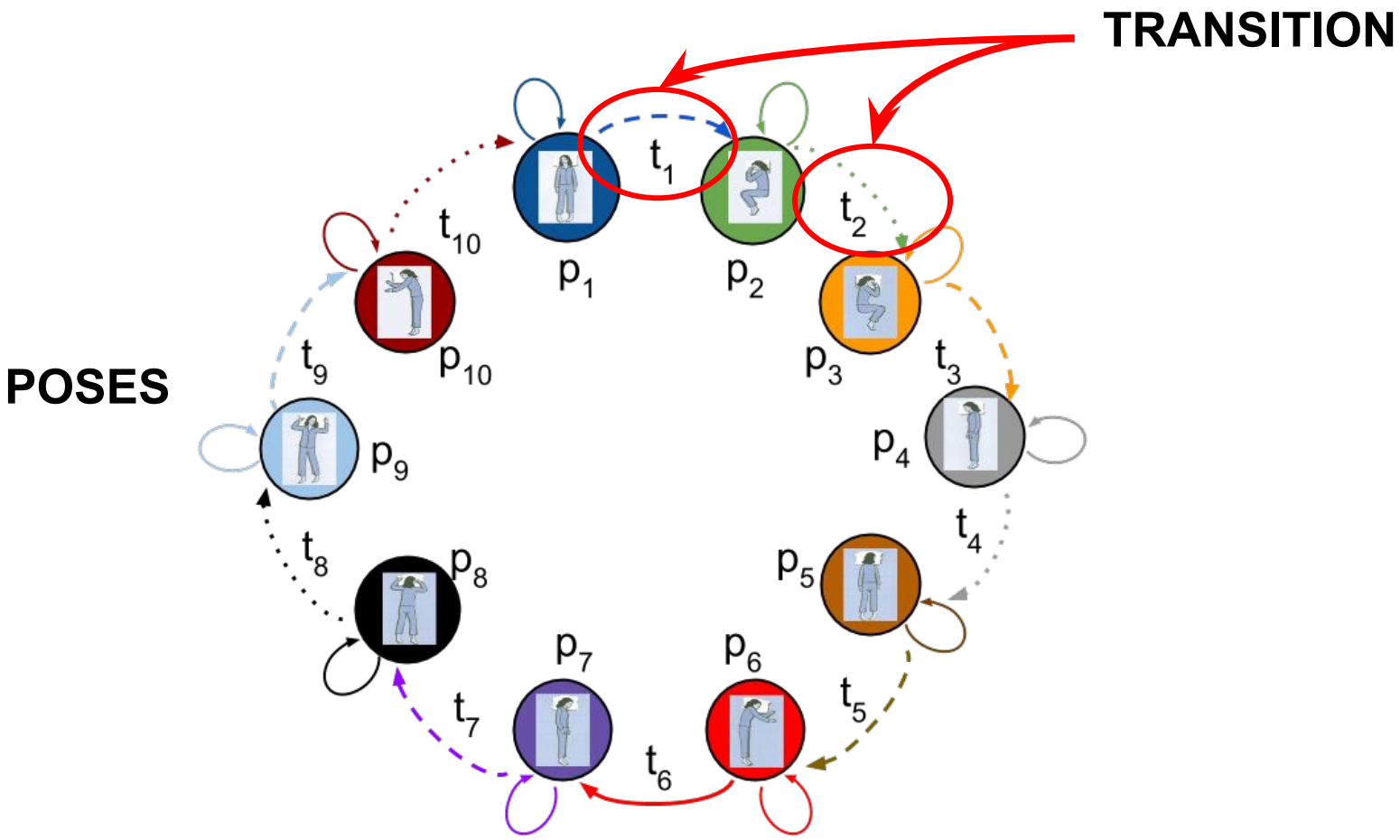
=

200 transitions

10 volunteers (~2hrs ea)

2 patients (48hr ea)

Time: Pose Sequence vs Pose Transitions



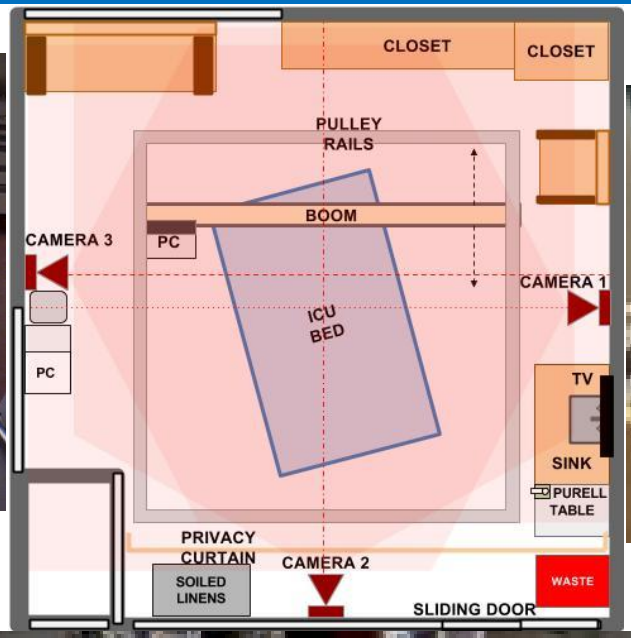
RGB Multiview - Scene Variations

Modality: RGB
View: 1
Scene: Dark and Occluded (DO)
Resolution: 640 x 480

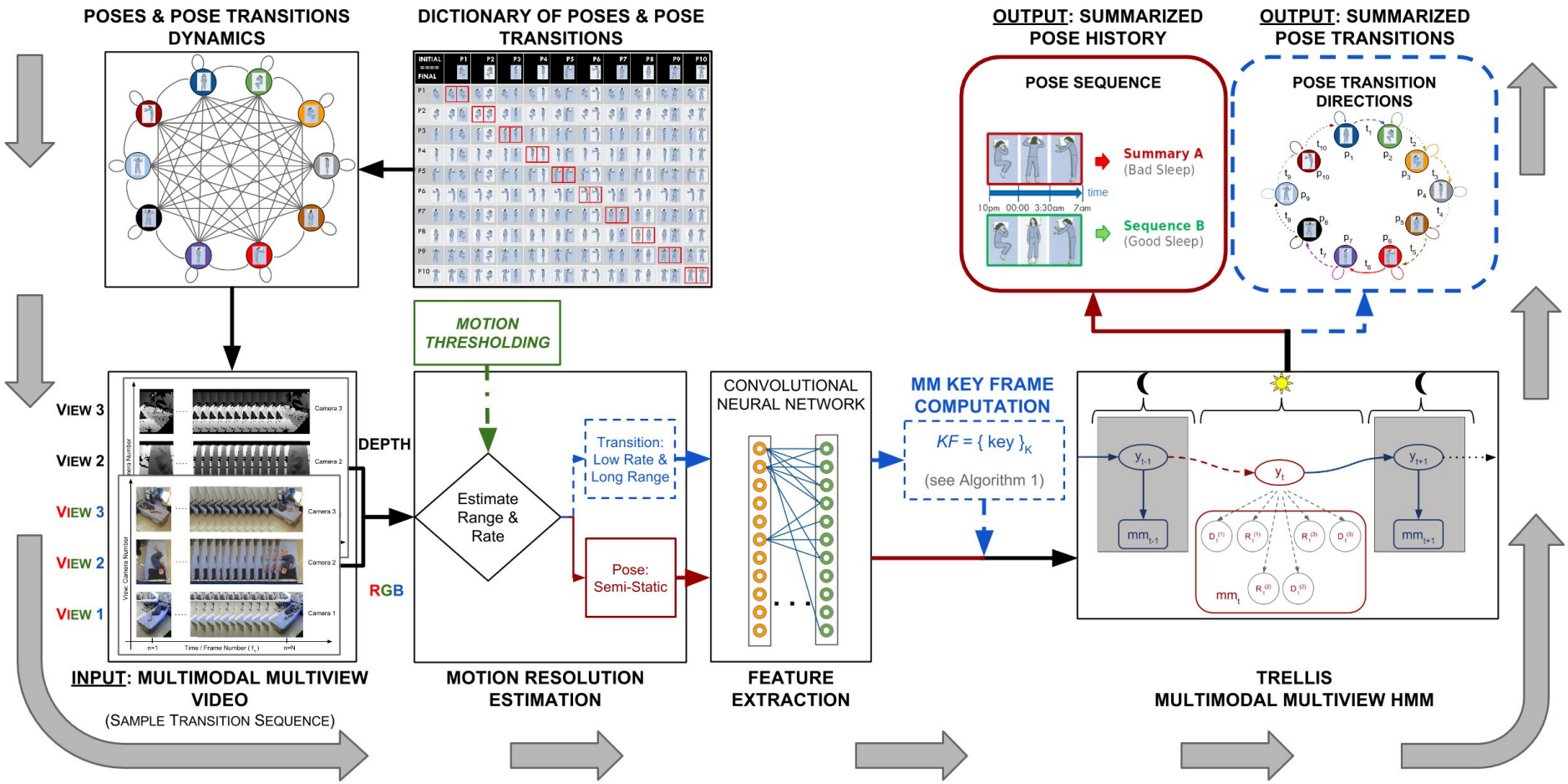
Modality: RGB
View: 2
Scene: Bright and Clear (BC)
Resolution: 640 x 480

Real ICU And Its Challenges - Sample Video

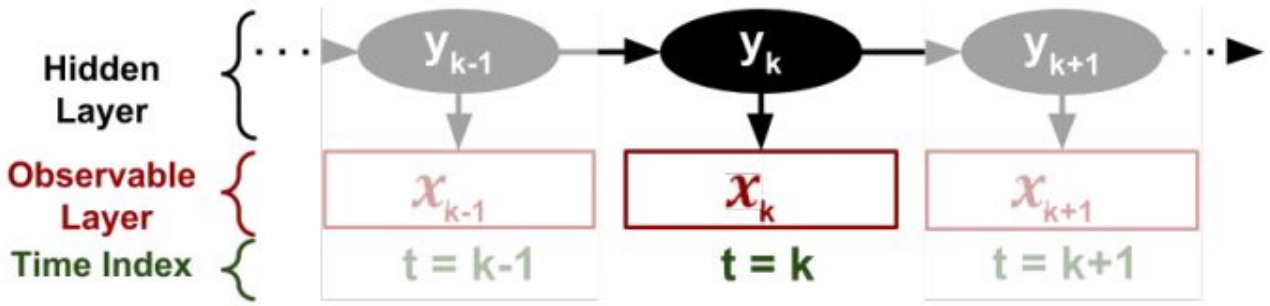
RGB-D Multiview - Real ICU



DECU Framework



Review: Hidden Markov Model (HMM)



$$x_k = x_{k,m}^{(v)} = \{R_k, D_k, ...M_k\}$$ } Observable

$$y_k \ (\text{state}_k \text{ or } \text{pose}_k)$$ } Hidden

k is the time index

Review: HMM -- Modelling State Durations

$$P(Y_{1:T}, X_{1:T}) = P(y_1) \prod_{t=1}^{T} P(x_t|y_t) \prod_{t=2}^{T} P(y_t|y_{t-1})$$

$x_k = x_{k,m}^{(v)} = \{R_k, D_k, \ldots M_k\}$ } Observable

y_k (state_k or pose_k) } Hidden

COMPLEXITY:
$O(QT^2)$

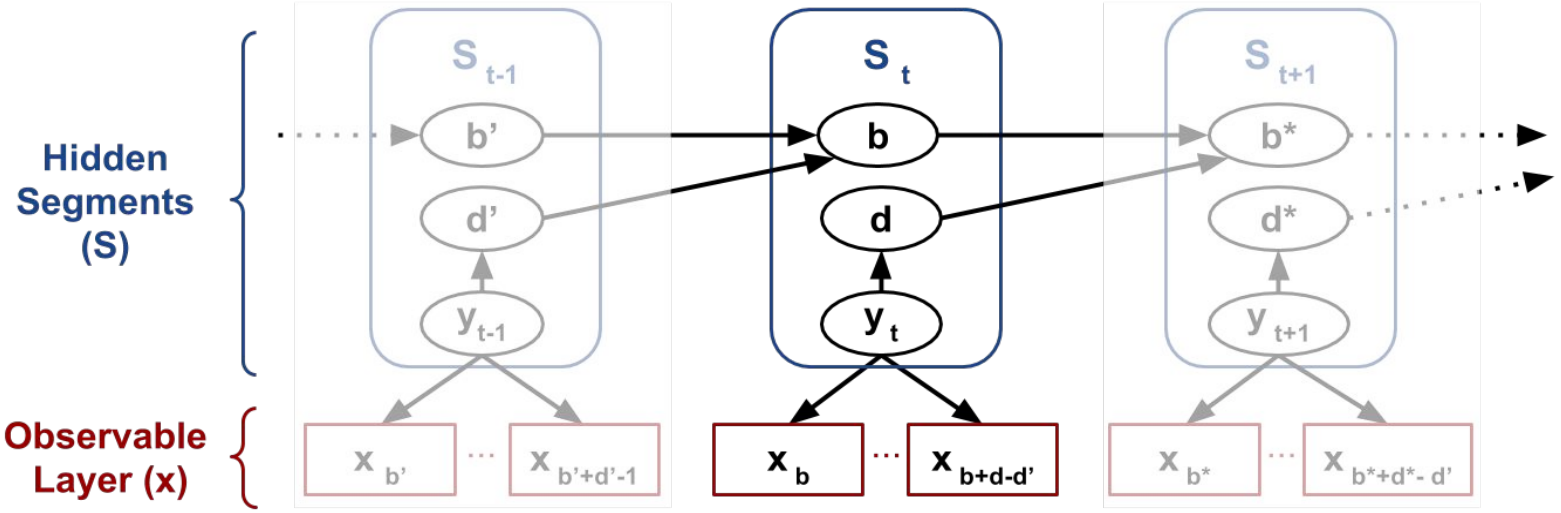
$P_i(d) = (a_{ii})^{d-1}(1-a_{ii})$ } Probability of state i with duration d

Inability to differentiate a poses from a pseudo or transition poses for which the only difference is their relative duration.

Hidden Semi-Markov Model (HSMM)

- Consider the sequence
  - $Y_{1:8} = \{1, 1, 1, 2, 2, 1, 2, 2\}$
- Encode its state duration using “segments”
  - $S_{1:4} = \{(1,3,1), (4,2,2) (6, 1, 1), (7,2,2)\}$
- Generalizing
  - $S_{1:U} = \{(b_1,d_1,y_1), ..., (b_U,d_U,y_U)\}$
- Properties:
  - t =1:T w/o overlap
  - $b_1=1$
  - $\Sigma d_u = T$, u=1:U
  - $b_{j+1} = b_j + d_j$, j>1

HSMM - Trellis



Where:

b's are the segment beginnings

d's are the segment durations

S_{t-1} is the segment starting at b' and ending at b'+d'-1

y_{t-1} is the pose or pseudo-pose

HSMM -- Modelling State Durations

$$P(S_{1:U}, X_{1:T}) = P(Y_{1:U}, b_{1:U}, d_{1:U}, X_{1:T})$$

Joint via Segments

$$= P(y_1)P(b_1)P(d_1|y_1) \prod_{t=b_1}^{b_1+d_1+1} P(x_t|y_1) \times$$

Initial Probability

$$\prod_{u=2}^{U} P(y_u|y_{u-1})P(b_u|b_{u-1}, d_{u-1}) \times$$

Transition Probability

$$P(d_u|y_u) \prod_{t=b_u}^{b_1+d_1+1} P(x_t|y_u)$$

Emission Probability

HSMM -- Modelling State Durations

$$P(b_u = m | b_{u-1} = n, d_{u-1} = l) = \delta(m, n + l)$$

Compute subsequent points

$$P(d_u = l | y_u = i) = P_i(l), \text{ with } P_i(l) = \mathcal{N}(\mu, \sigma)$$

Segment duration probability

Where:

m, n, l are dummy variables

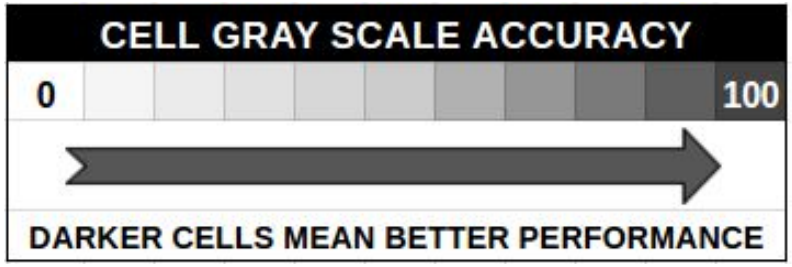
δ is the dirac delta function

$\mathcal{N}$ is the normal distribution

COMPLEXITY:

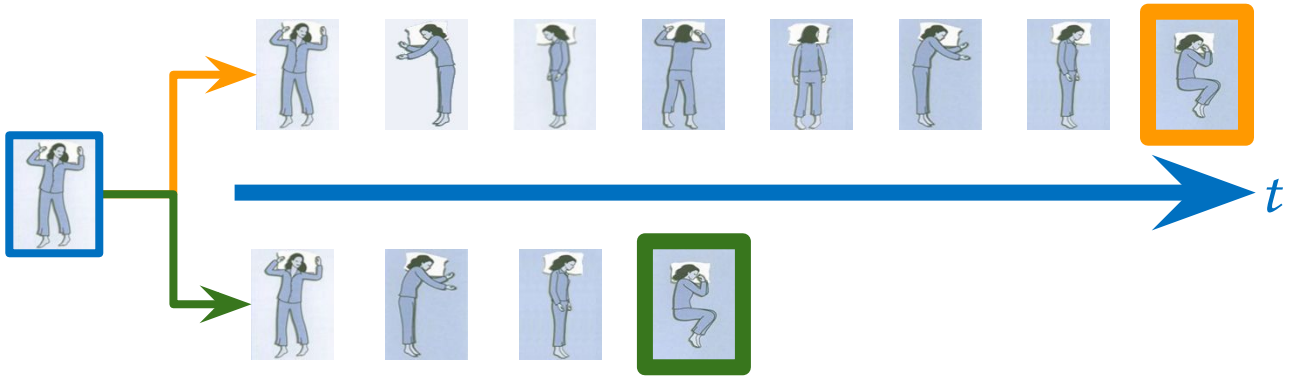
$O(QT^2D)$

Results: Scale and Legend



LEGEND			
COLOR	Black	Green	Orange
ROTATION ANGLE	0	0<, <180	>= 180

Orange (turning left): 180º <= large rotation



Green (turning right): 0º < small rotation < 180º

Results Summarization: Mock-Up ICU

Detecting Transitions along with the Direction of Rotation

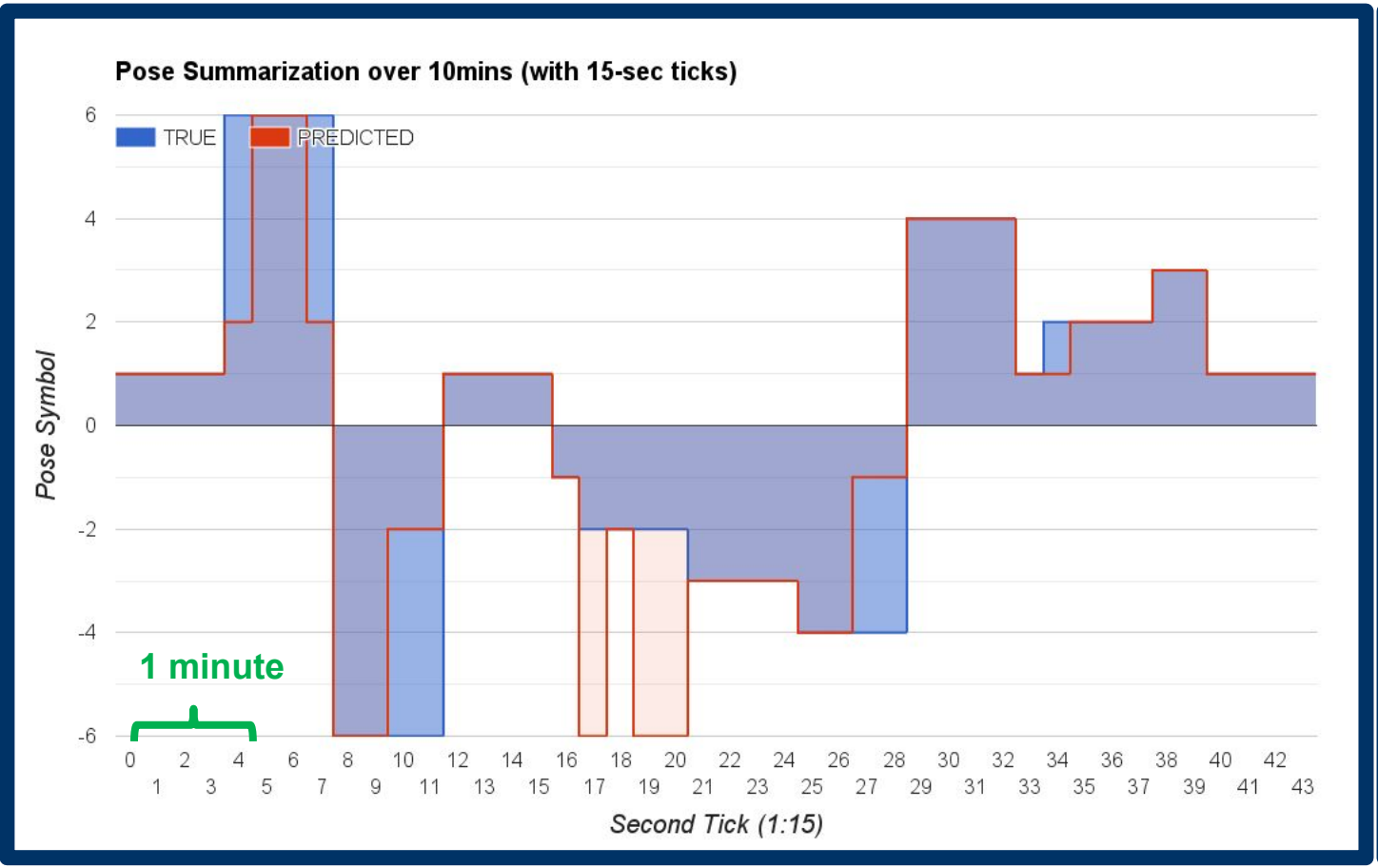
		MOCKUP ICU SINGLEVIEW																			
		FINAL POSE: Po																			
		solU	solU	solD	solD	logR	logR	logL	logL	yeaR	yeaR	yeaL	yeaL	fetR	fetR	fetL	fetL	falU	falU	falD	falD
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
INITIAL POSE: Pi	solU	48	43	43	56	47	53	68	54	64	60	55	57	22	71	41	64	15	38	51	47
	solD	55	48	37	58	50	65	45	36	68	42	46	36	35	63	60	53	33	41	66	64
	logR	34	55	54	48	48	30	35	69	44	54	55	48	48	52	54	59	27	48	52	52
	logL	49	43	54	55	33	43	26	58	69	62	24	42	61	75	54	41	61	31	40	57
	yeaR	31	47	46	48	22	52	21	54	36	53	63	58	55	40	41	63	68	63	33	56
	yeaL	48	49	42	66	48	47	49	65	34	30	48	56	53	45	69	58	46	54	62	65
	fetR	52	48	39	63	68	54	41	53	44	36	51	55	51	58	64	47	57	68	48	44
	fetL	41	37	52	54	67	61	38	41	58	55	64	47	34	37	55	55	63	66	55	57
	falU	40	51	36	67	48	56	62	73	52	47	42	33	41	49	49	65	32	35	51	38
	falD	49	61	41	48	56	49	33	72	48	25	59	24	50	63	46	58	45	24	62	46

Results Summarization: Mock-Up ICU

Detecting Transitions along with the Direction of Rotation

		MOCKUP ICU MULTIVIEW																			
		FINAL POSE: Po																			
		solU	solU	solD	solD	logR	logR	logL	logL	yeaR	yeaR	yeaL	yeaL	fetR	fetR	fetL	fetL	falU	falU	falD	falD
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
INITIAL POSE: Pi	solU	76	73	70	70	74	60	55	71	71	57	52	71	67	58	67	71	62	66	73	71
	solD	71	71	74	73	67	60	66	71	65	69	73	63	62	73	71	58	61	63	74	74
	logR	66	72	71	65	65	67	72	70	71	69	73	71	68	69	71	76	63	71	78	61
	logL	66	60	71	62	70	70	63	65	66	63	71	69	73	73	69	67	70	66	77	62
	yeaR	68	74	73	65	69	69	68	67	70	70	70	71	62	67	68	60	65	70	73	72
	yeaL	75	66	69	63	71	70	66	67	71	67	71	71	60	62	73	65	75	69	65	69
	fetR	70	75	76	65	65	64	68	70	76	73	69	73	75	75	65	66	73	76	71	58
	fetL	68	64	66	71	63	74	65	68	74	72	71	73	61	74	72	72	76	59	62	73
	falU	67	68	76	74	75	59	65	70	73	64	59	70	68	63	66	72	73	74	79	76
	falD	76	78	68	65	63	76	80	59	75	72	58	61	67	70	63	72	67	65	79	79

Results Summarization: Mock-Up ICU



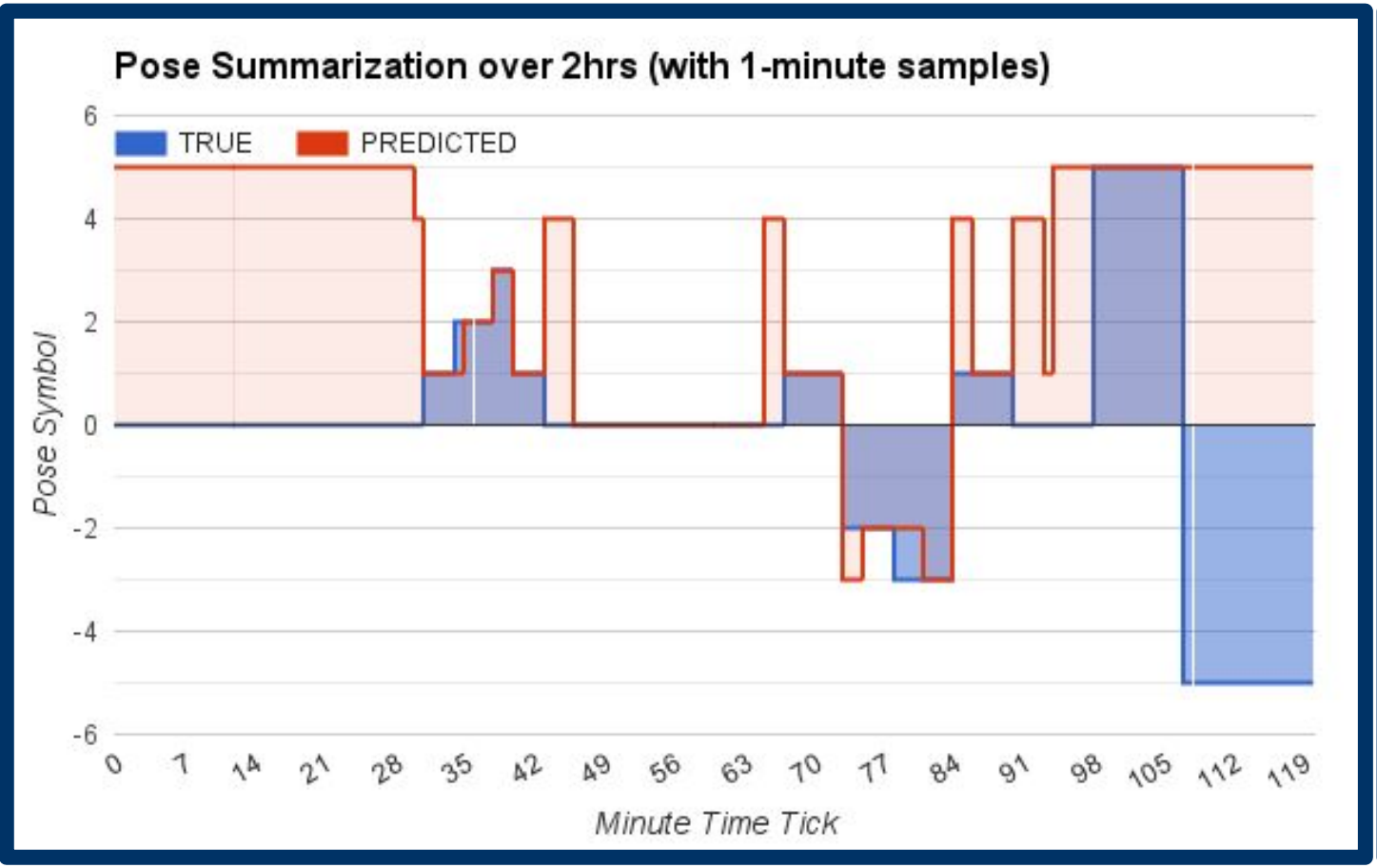
SYMBOL	POSE
+ 1: Up - 1: Down	
+ 2: Right - 2: Left	
+ 3: Right - 3: Left	
+4: Up - 4: Down	
+6: Right - 6: Left	

Results Summarization: Real ICU

Detecting Transitions along with the Direction of Rotation -- Reduced Set

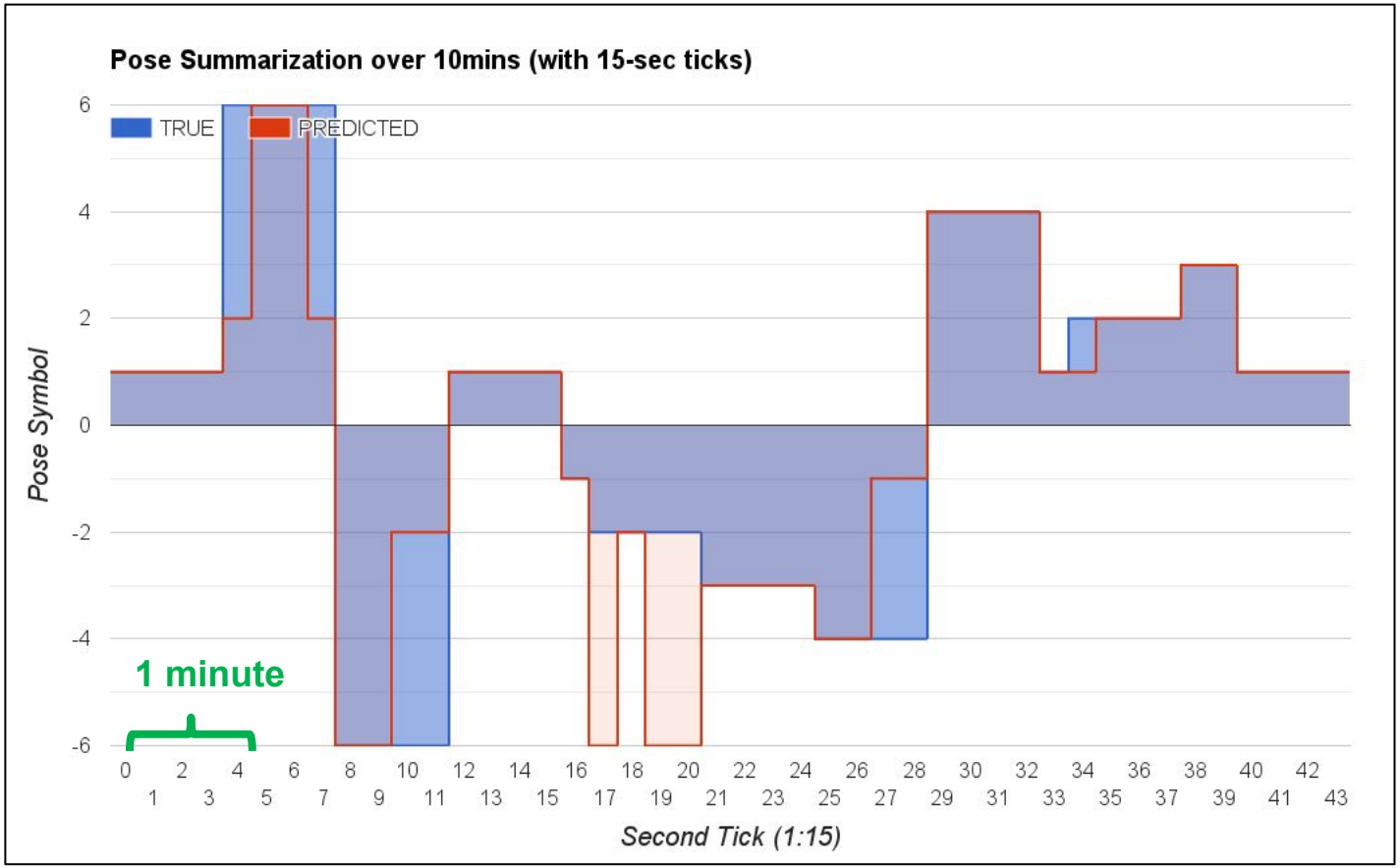
		REAL ICU MULTIVIEW															
		FINAL POSE: Po															
		solU	solU	logR	logR	logL	logL	yeaR	yeaR	yeaL	yeaL	fetR	fetR	fetL	fetL	falU	falU
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
INITIAL POSE: Pi	solU	N/A		73	68	N/A		70	65	N/A		71	80	N/A		57	
	logR	79	N/A			80	N/A	63		N/A	84	62		84	N/A	76	N/A
	logL	N/A	73	N/A	83	N/A		76	68		N/A	86	61		N/A	79	
	yeaR	81	N/A	60		81	N/A			83	N/A	58		81	N/A	78	N/A
	yeaL	N/A	79	N/A	83	60		N/A	80	N/A		75	64		N/A	82	
	fetR	83	N/A	58		81	N/A	67		82	N/A			78	N/A	86	N/A
	fetL	N/A	77	N/A	87	69		N/A	85	63		N/A	87	N/A		72	
	falU	60		N/A	72	78	N/A		77	72	N/A		76	79	N/A		

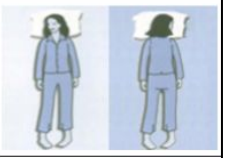
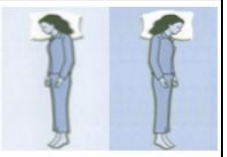
Results Summarization: Real ICU



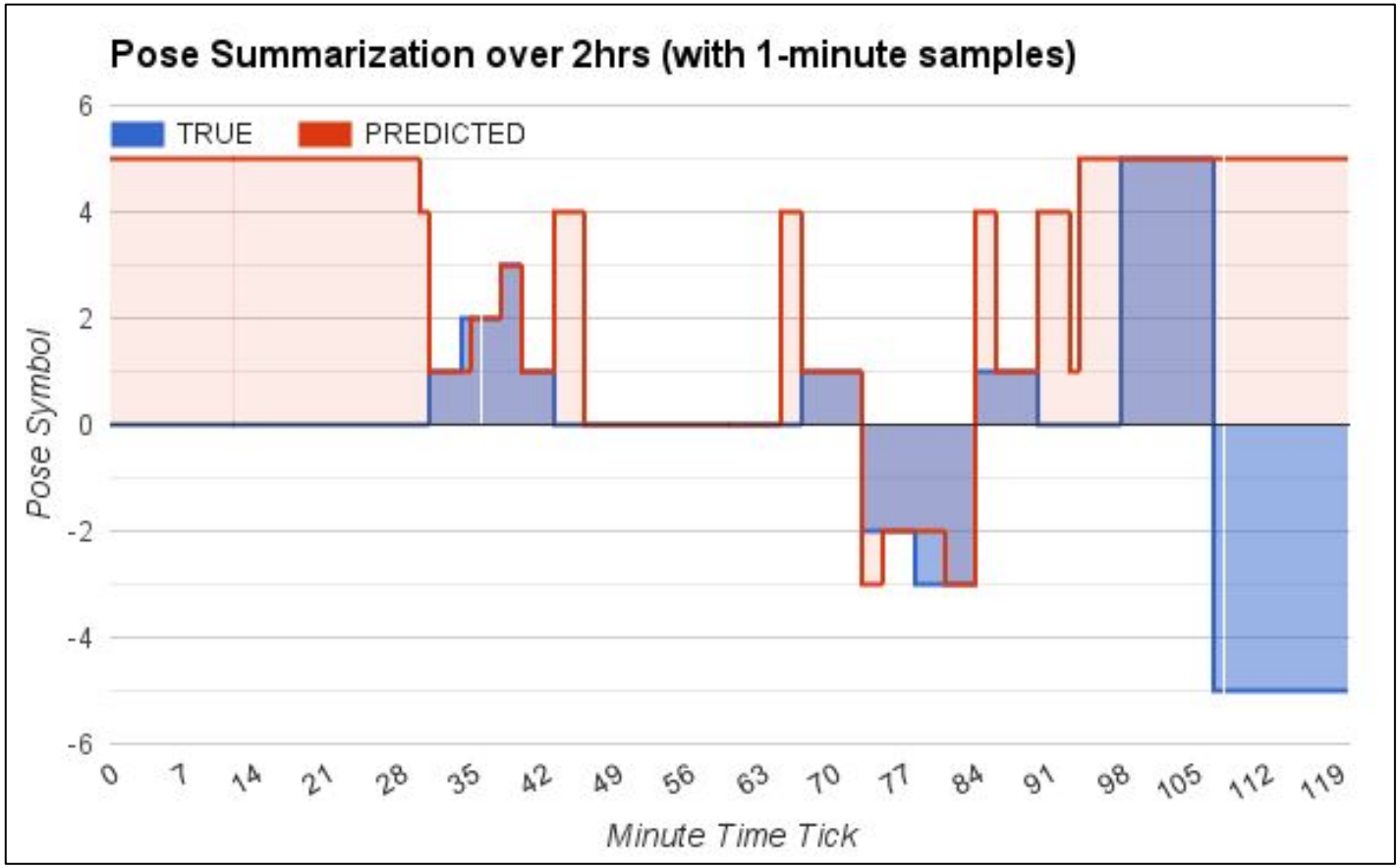
SYMBOL	POSE
0	
1	
+ 2: Right - 2: Left	
+ 3: Right - 3: Left	
4	
+5: Other - 5: None	

Results Summarization: Mock-Up ICU



SYMBOL	POSE
+ 1: Up - 1: Down	
+ 2: Right - 2: Left	
+ 3: Right - 3: Left	
+4: Up - 4: Down	
+6: Right - 6: Left	

Results Summarization: Real ICU



SYMBOL	POSE
0	
1	
+ 2: Right - 2: Left	
+ 3: Right - 3: Left	
4	
+5: Other - 5: None	

Conclusion

- Evaluation of **existing** methods and unimodal approaches
  - Yang et al. and Shotton et al. – not suitable
  - Huang et al. – suitable for **ideal** static scenario that allow mats **ONLY**!
  - Torres et al. (ICVS 2015) – expensive and requires a pressure mat
  - Torres et al. (WACV 2016) – multiview multimodal for pose classification (simulated)
  - ALL THE ABOVE METHODS IGNORE TIME INFORMATION AND SUB-POSES
- **DECU** is **promising**
  - Able to monitor patients with constrained motion (subset of poses poses)
  - Monitoring method that can be adjusted to the task (motion resolution)
  - Robustness to illumination, sensor failures, and occlusions (multiview)
  - Simple and can run on arm processor (~10-15fps)
- May enable **automated** temporal **analysis** of ICU patients
  - Sleep Hygiene
  - Pressure Ulcers

THANK YOU!

Q & A

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