Medical Internet of Things:
from bedside to big data

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Overview

- Problem
- Integrated Clinical Environment (ICE)
- How is DDS Connext Used
- Medical Internet of Things Platform
- Medical IOT → Big Data → Data Driven Healthcare
- The Future

User Requests

"We need complete, accurate and contextually aware data"

"Health data must be contextually aware"

"We need to change what is expected of technology in healthcare"

"Why can't this be automatically put in the medical record?"

"Why can't I manage my devices remotely?"

"Why can't I pause an infusion pump when the person is overdosing?"

"Can I know in real-time how many ventilators I have?"

"I need to keep a patient alive for 5 days without a doctor present with what I carry in my backpack"

"how do I take my 30 years of experience and use it to help a new physician provide high quality healthcare?"

"I want to monitor every patient at every bed in every country I have a hospital"

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Problems

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- Architecture
- Data
- Process

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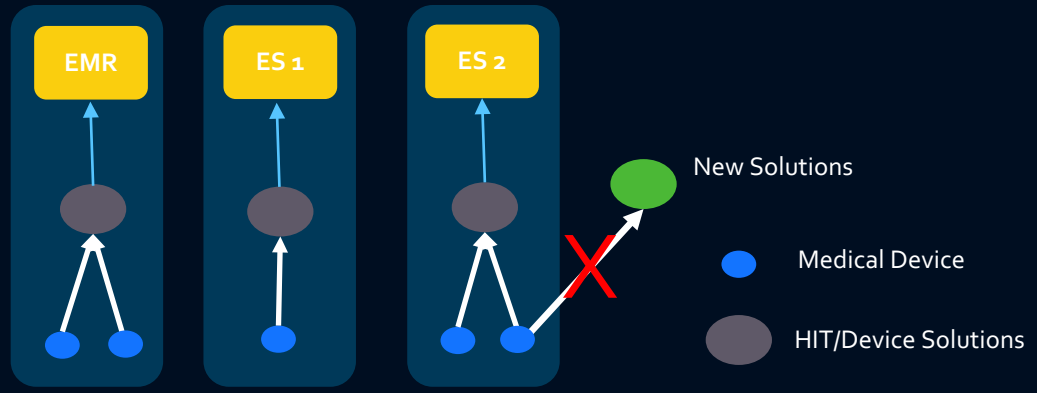
Architecture



- Device, point solutions and EHR are proprietary and vertically integrated.
- Integration is expensive, complicated & incomplete
- No way of bringing the data back to innovate

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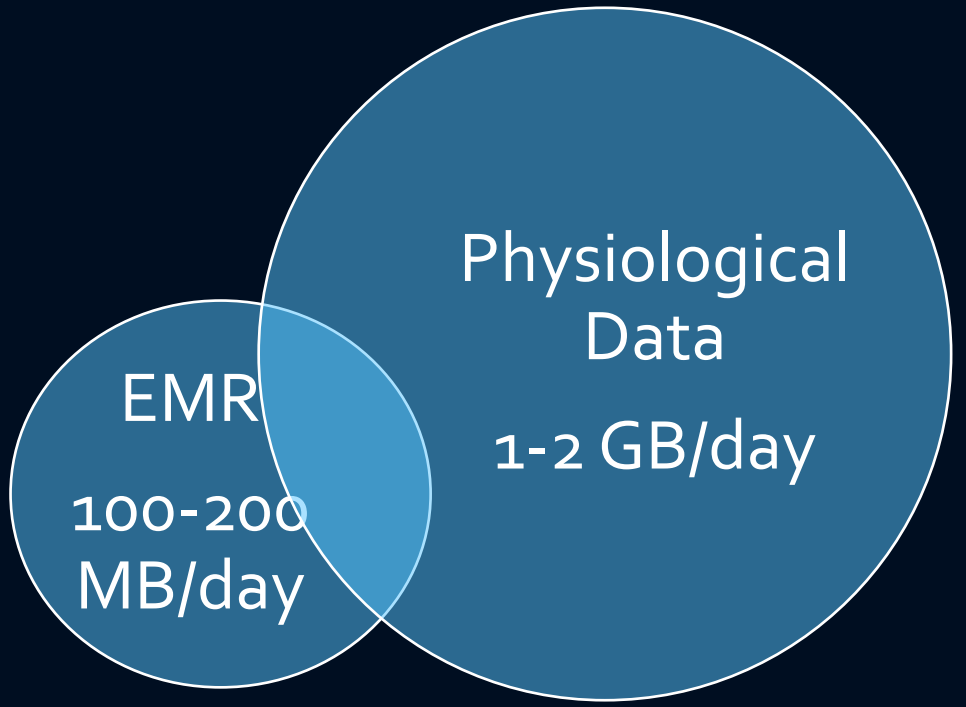
Data

- EMR data is infrequent
- Poor data quality
- Proprietary vertically integrated data creates analytics and clinical solution challenges
- Lacks consistent time stamps
- Lacks contextually complete data



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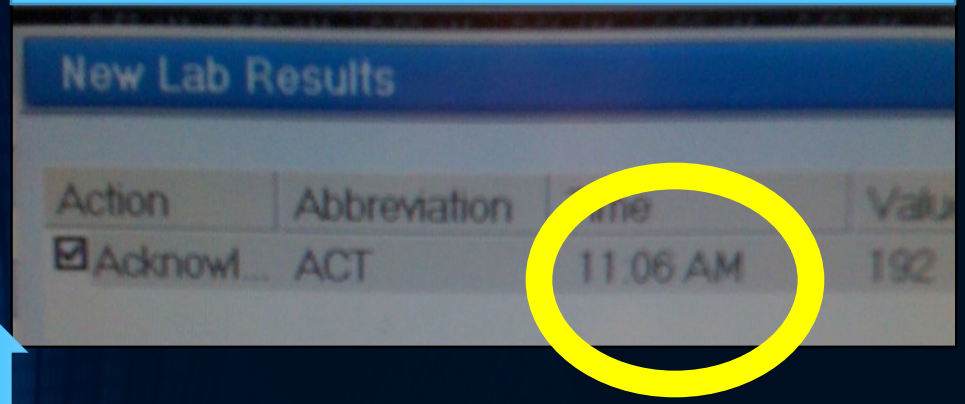
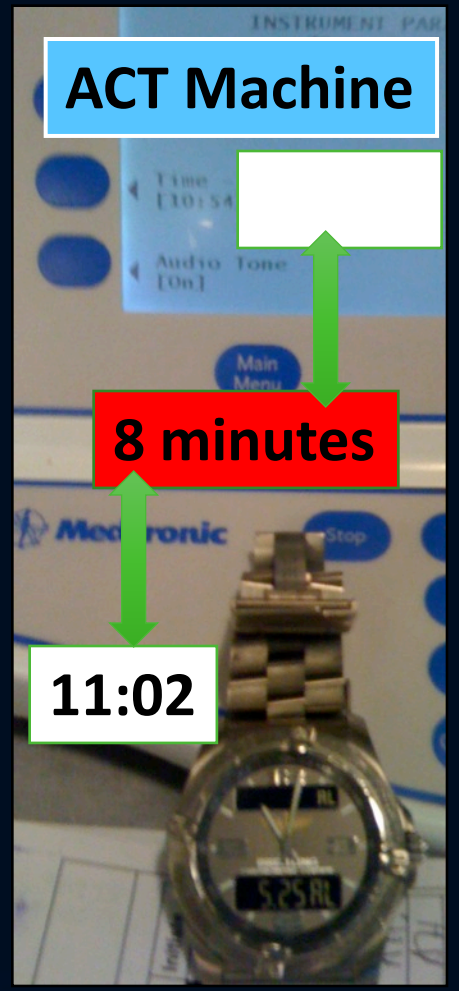
EMR time-stamp error

EMR screen



ACT – appeared to have been checked 22 minutes after heparin administration (was actually 30 min). Could → stroke.
Cause – ACT device time incorrect
(Note - device does not use NTP)



ACT Machine

Data protocol converter

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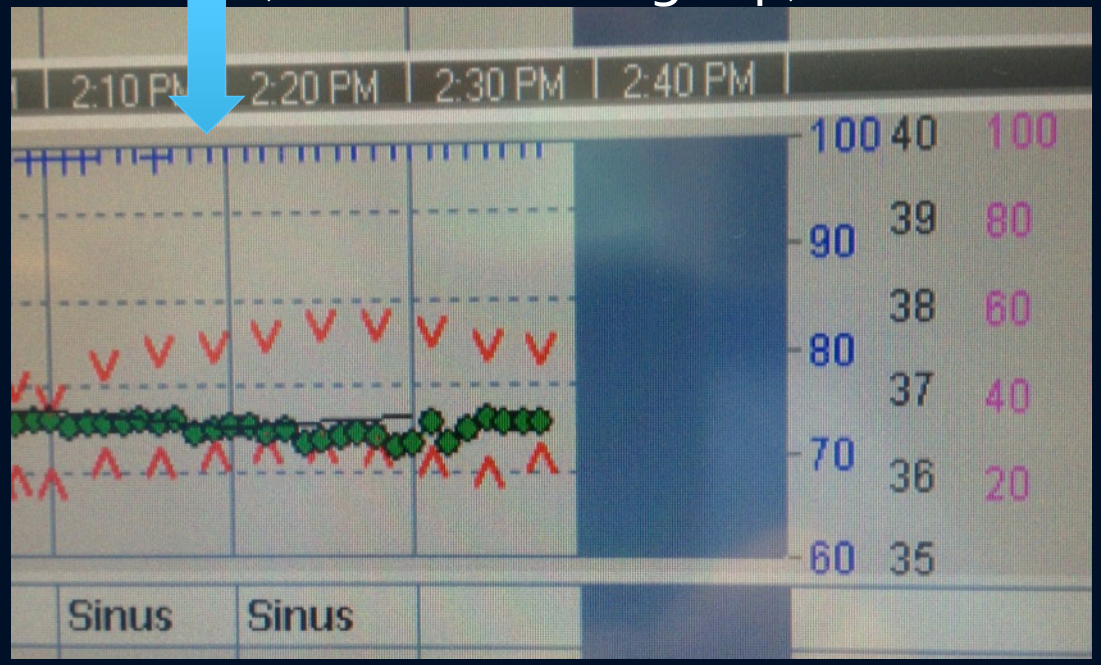
Patient Monitor Recorded Low SpO_2 Alarm Event "84%"

- 84% oxygen saturation detected by bedside physiological monitor
- Not recorded in permanent record

No evidence of low SpO_2 in EHR (blue ticks along top)



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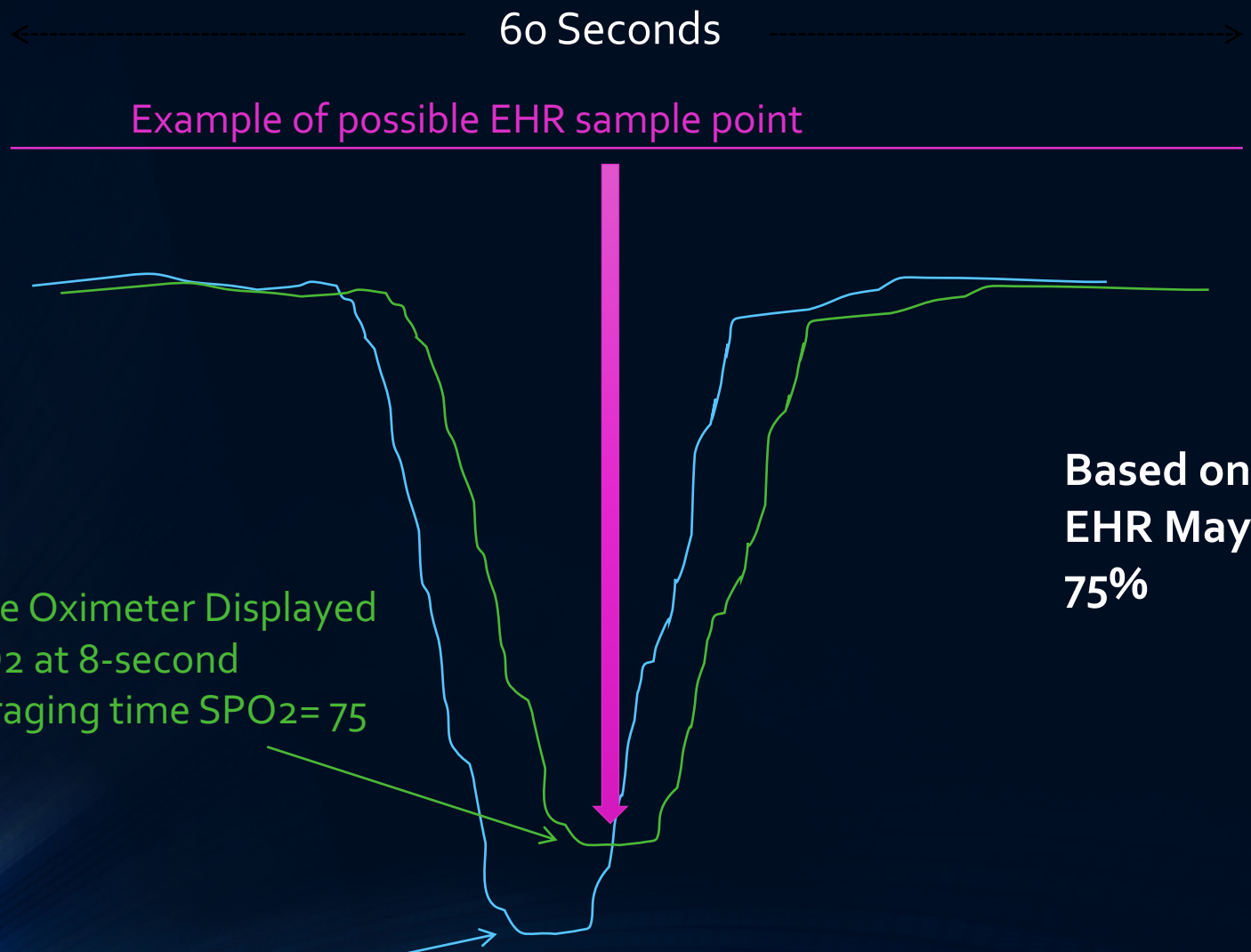
EHR data – 1 point collected



Based on this example, EHR May record SpO2 as: 75%

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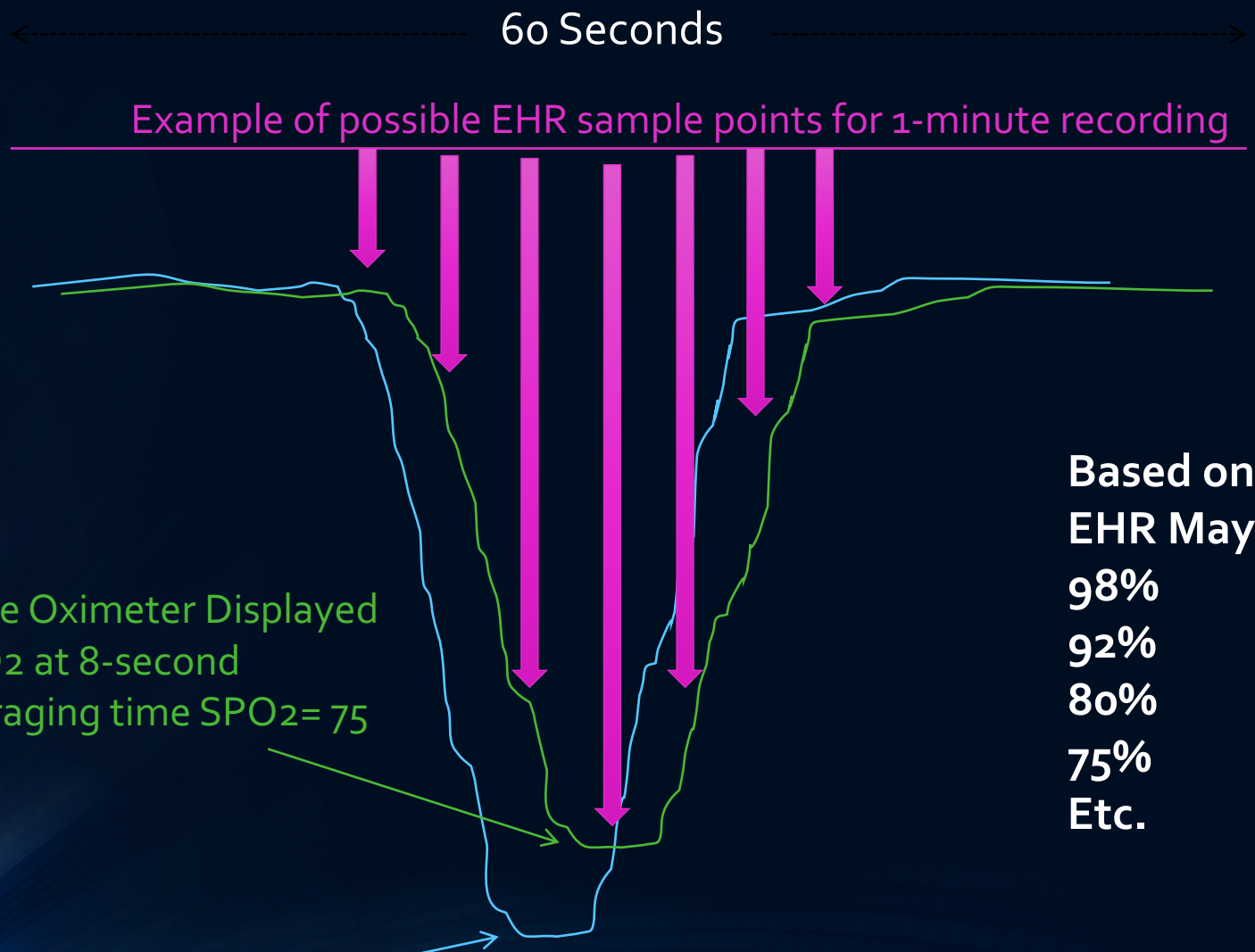
Sources of variation in EHR documentation d/t Data Sampling



Based on this example, EHR May record SpO2 as:
98%
92%
80%
75%
Etc.

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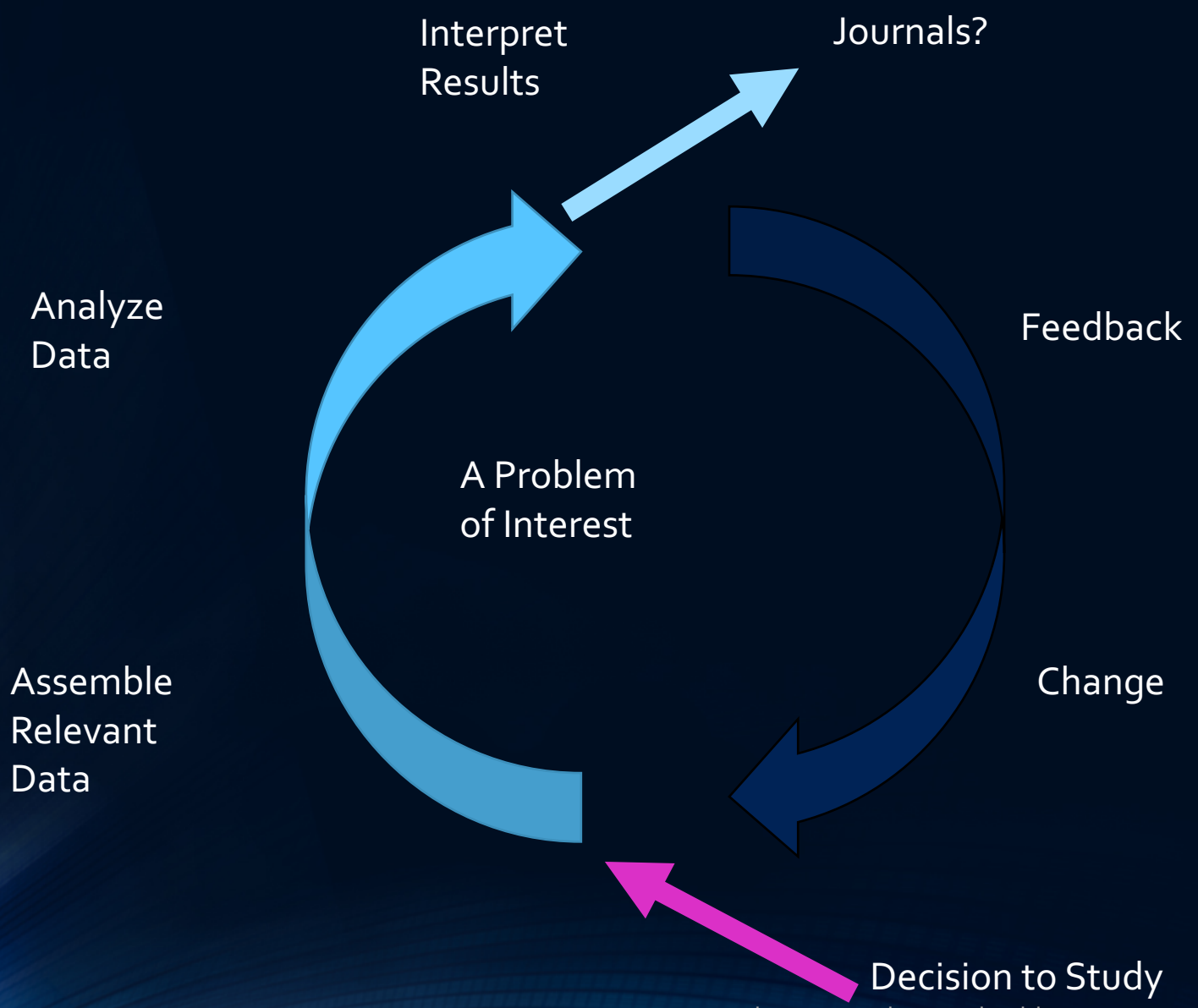
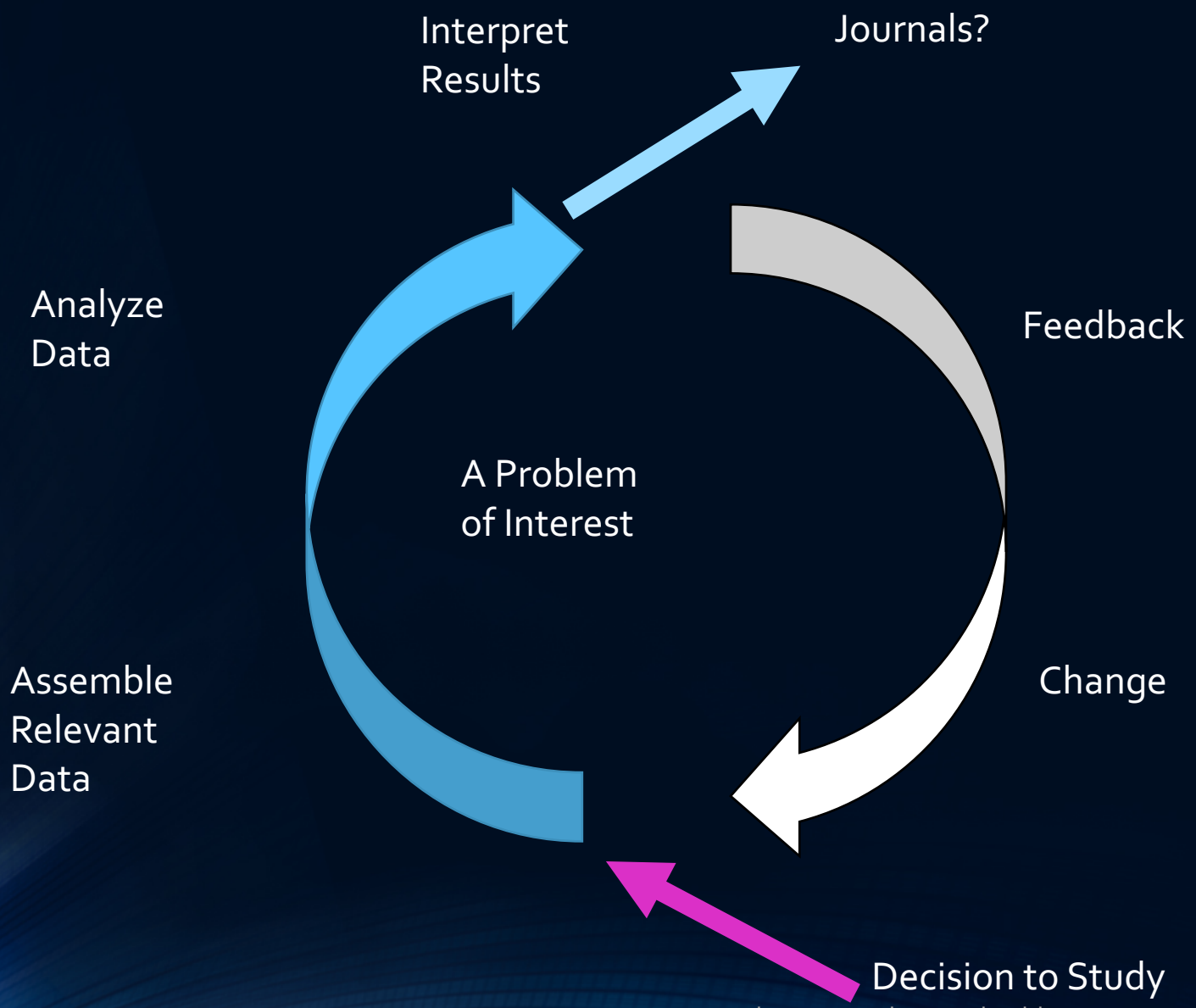
Process



http://www.learninghealthcareproject.org/section/background/learning-healthcare-system

Process



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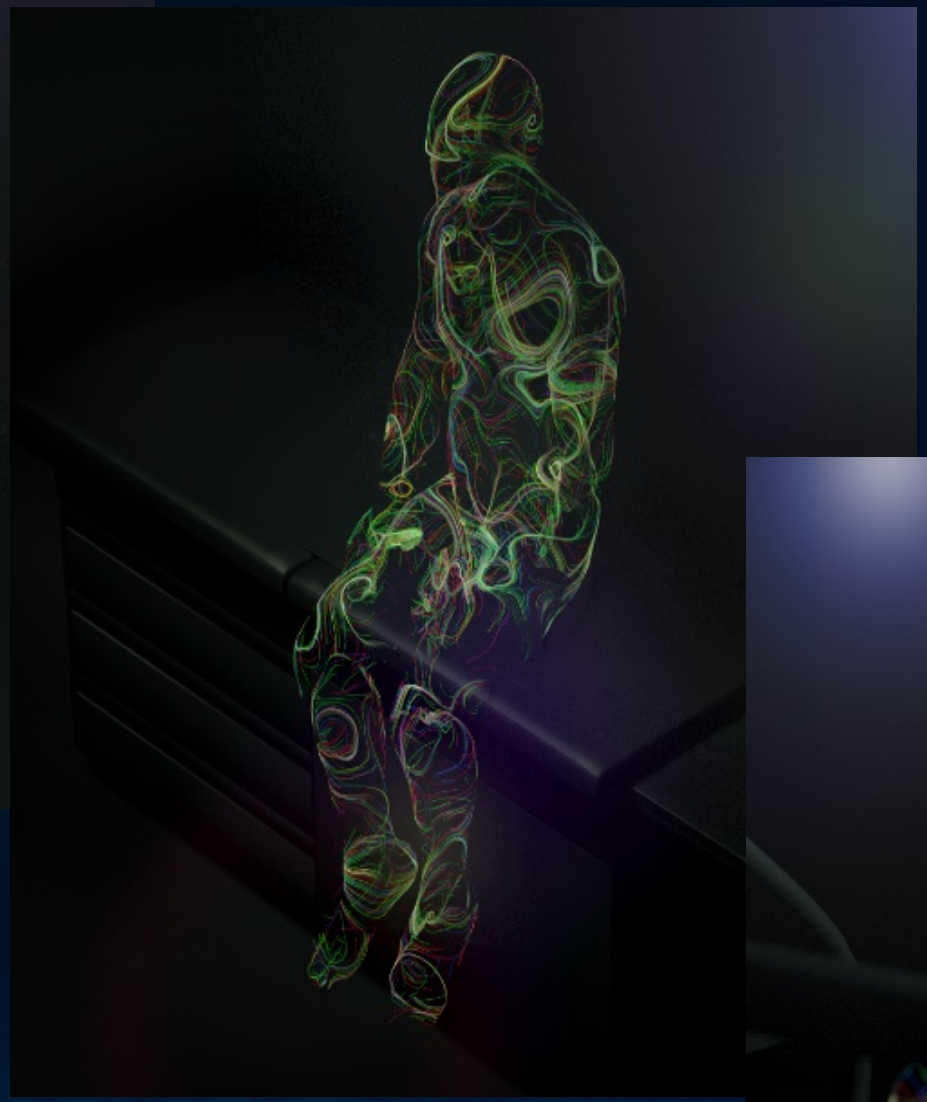
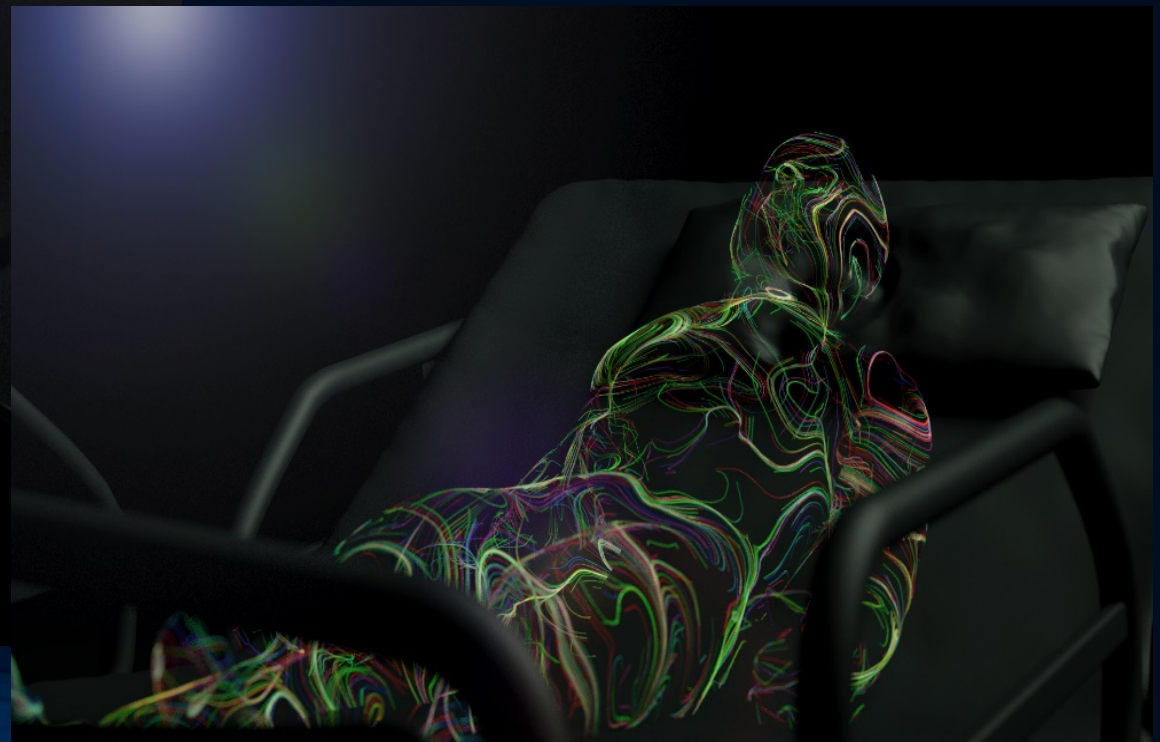
Patient Centered





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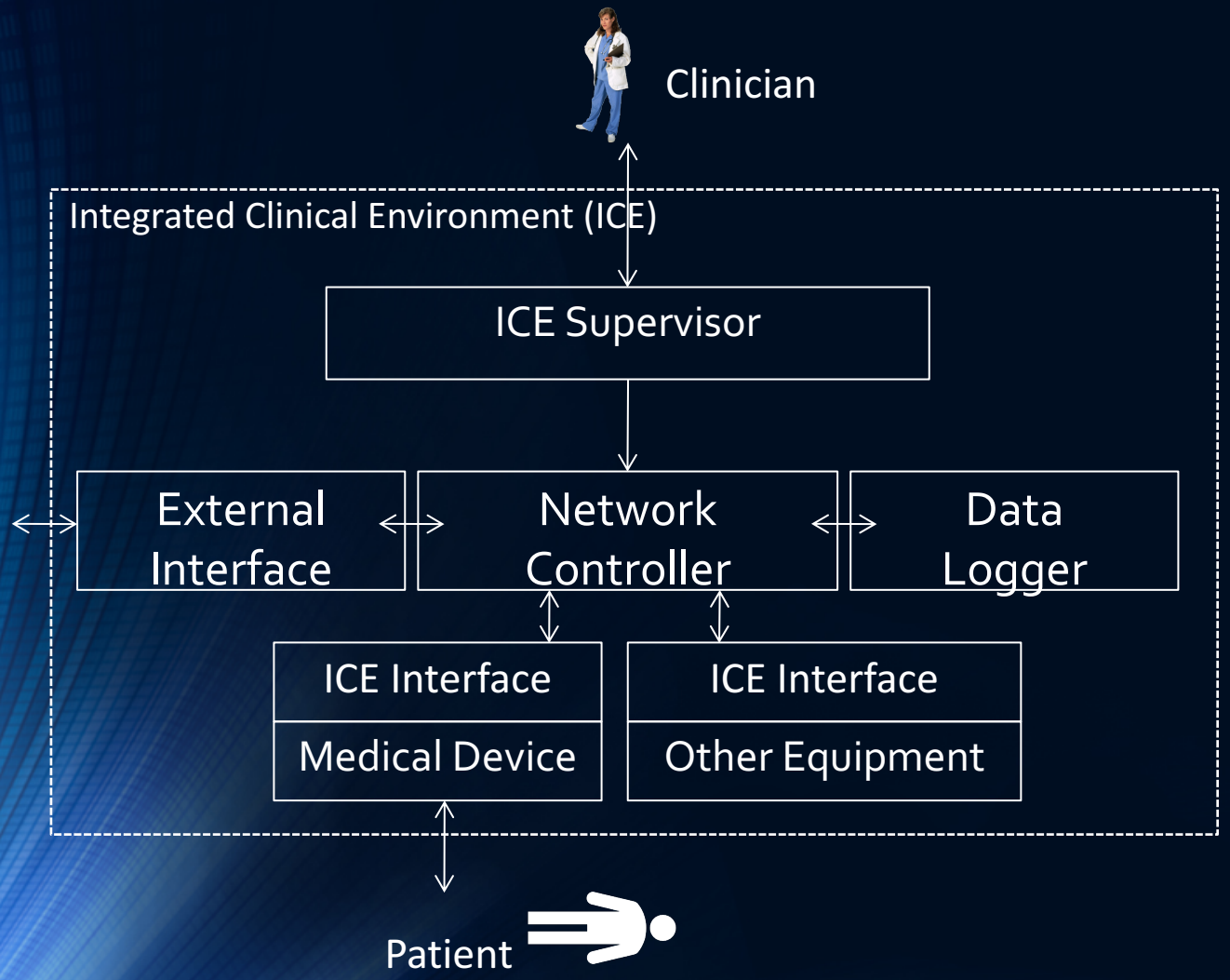
Integrated Clinical Environment (ICE)



- Work began in 2004
- ASTM F2761 standard
- New Data Logger Standard AAMI active
- 1 patient per ICE
- **FUNCTIONAL** architecture
- Currently new $14M in DoD, DHS funding supporting further development. In excess of $30M in R&D in total.

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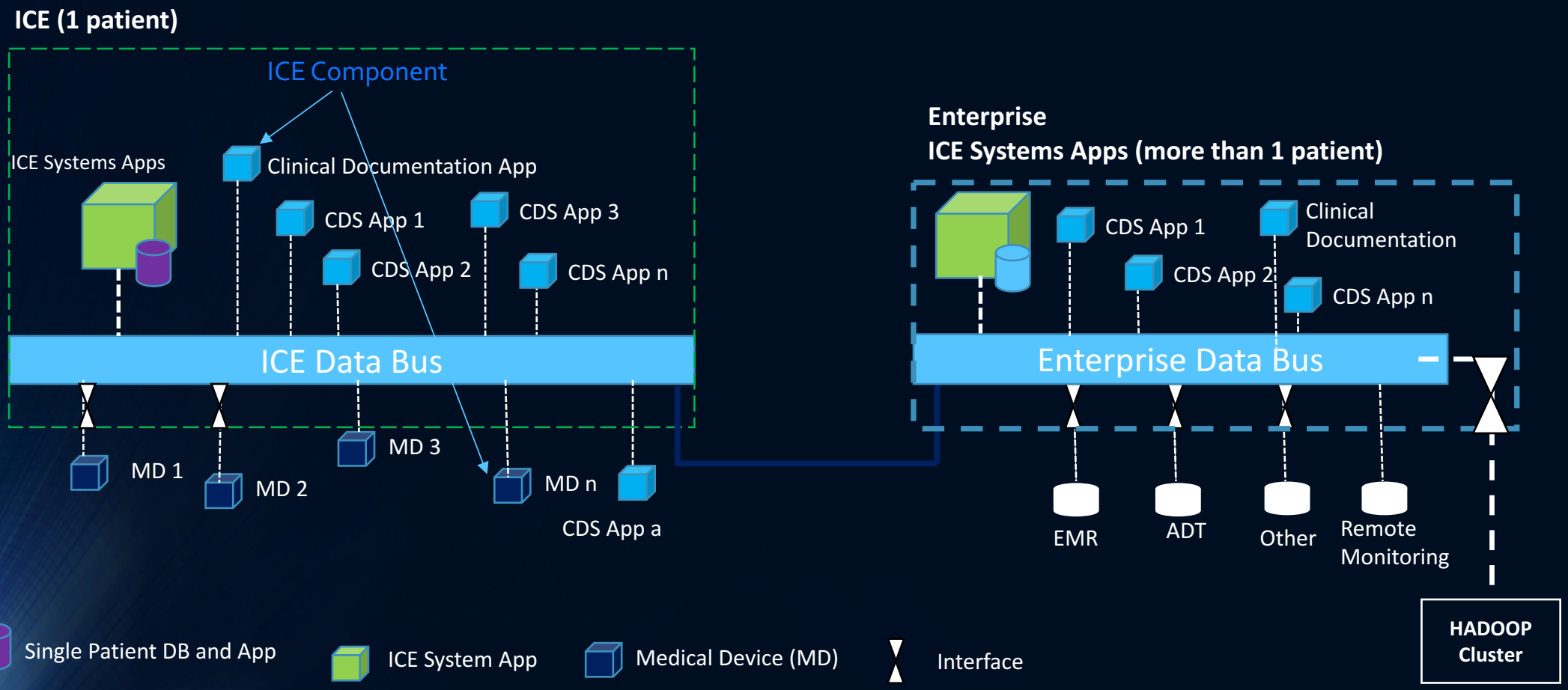
Medical IoT Platform

- Based on Integrated Clinical Environment (1 ICE = 1 Patient)
- Distributed
- Open
- Standards based data model
- Cybersecurity and risk management is included

DocBox's Platform



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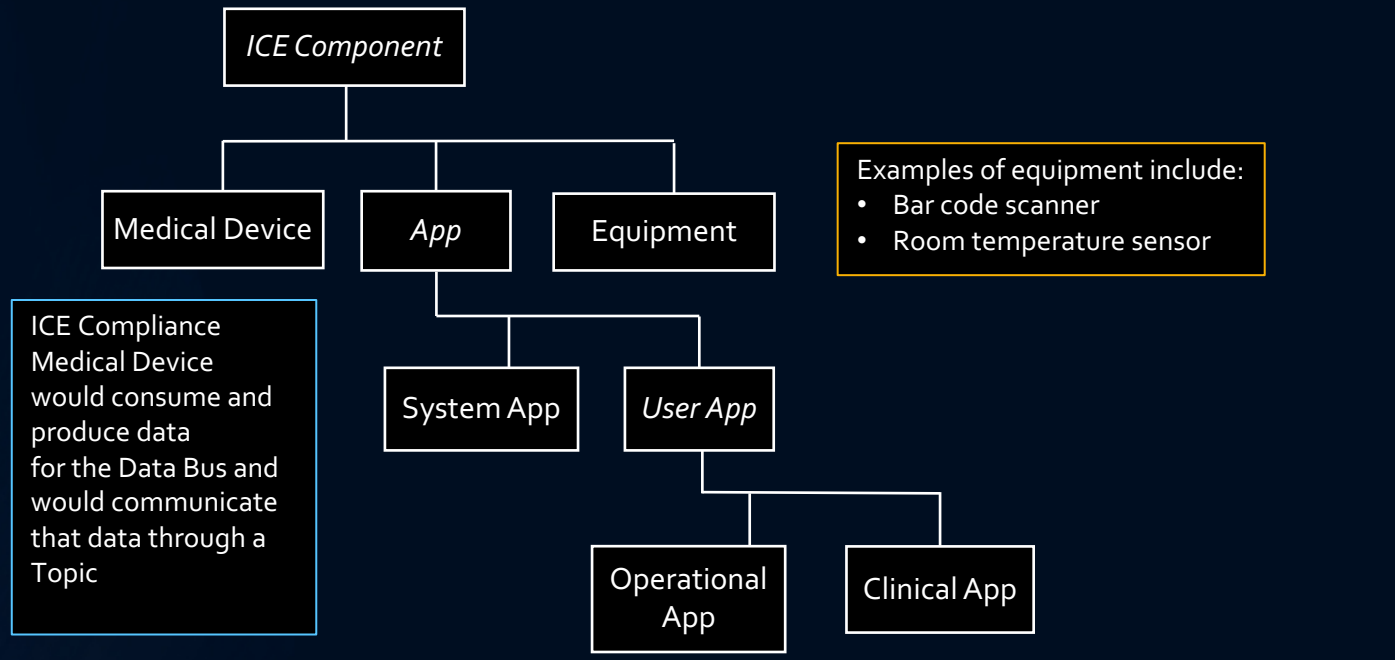
ICE Component

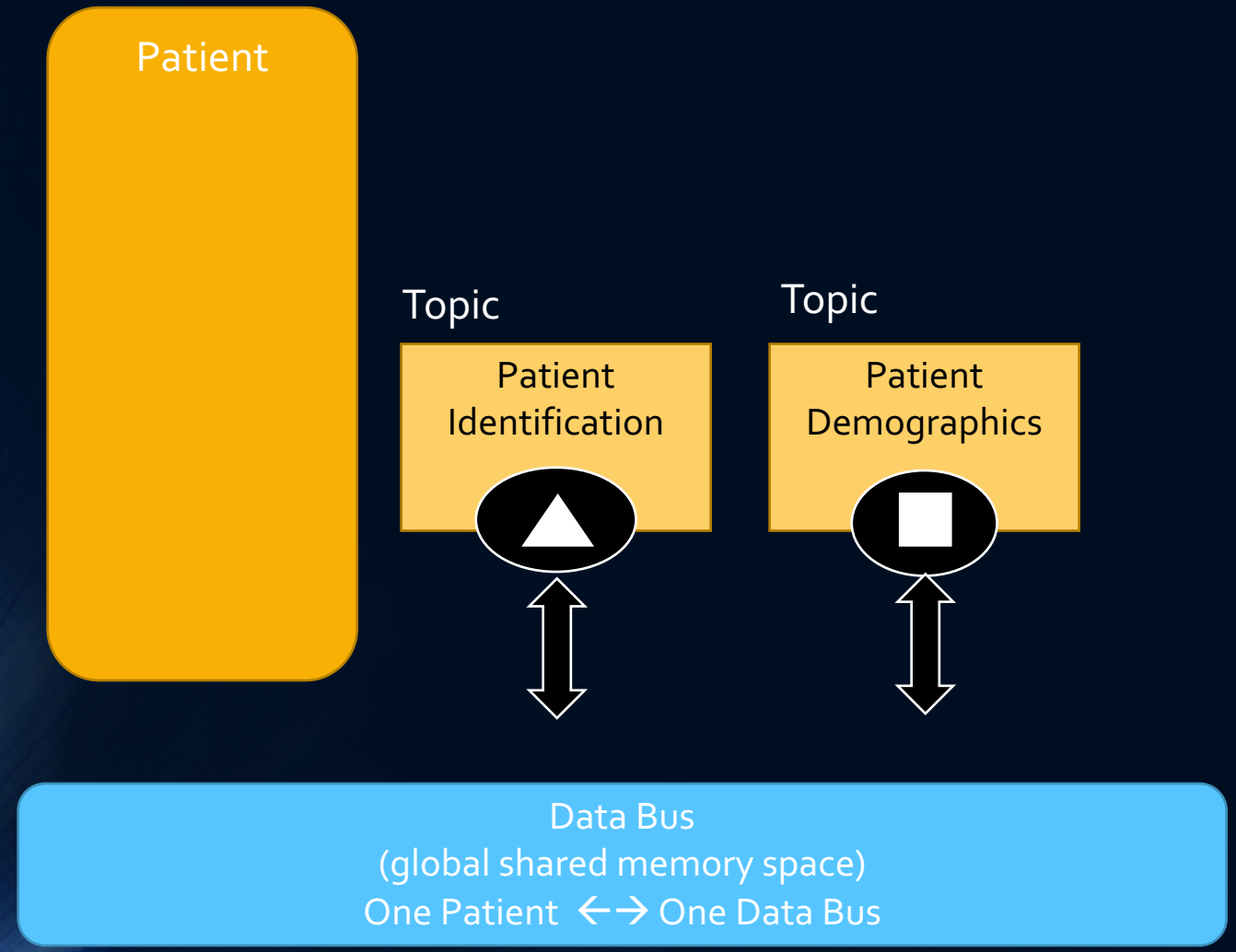


RTI Connext DDS Data Bus
(global shared memory space)
One Patient ←→ One Data Bus

Data Model

- Utilizes IEEE 11073-10201, FHIR for data structures
- Utilizes IEEE 11073-10101, LOINC, SNOMED CT for nomenclature
- Patient centric and Data Centric
- Interface Definition Language (IDL) is created from Data Model
- Data Model is setup by Object Type and Nomenclature becomes key

Patient Component of Data Model



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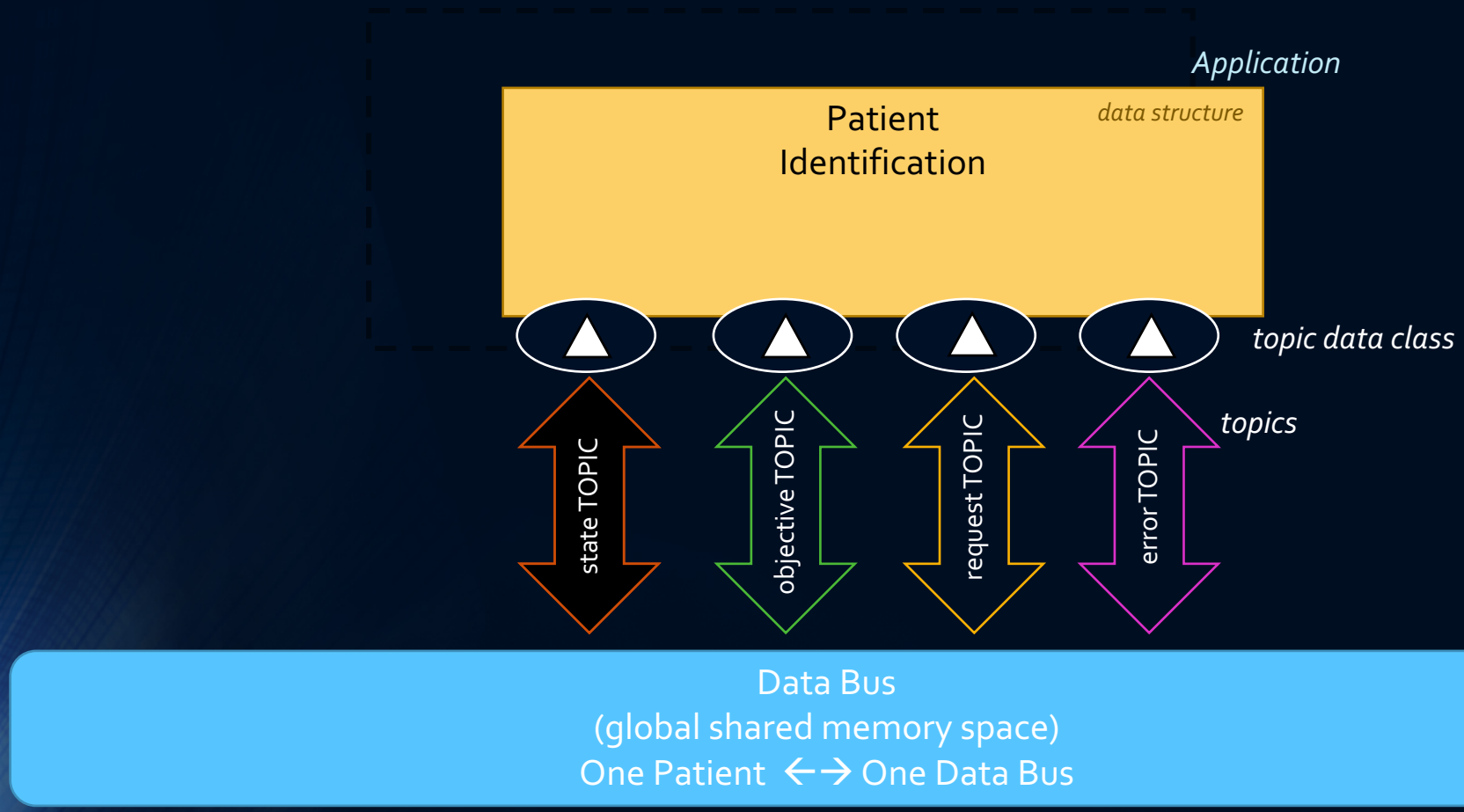
Objective State Pattern

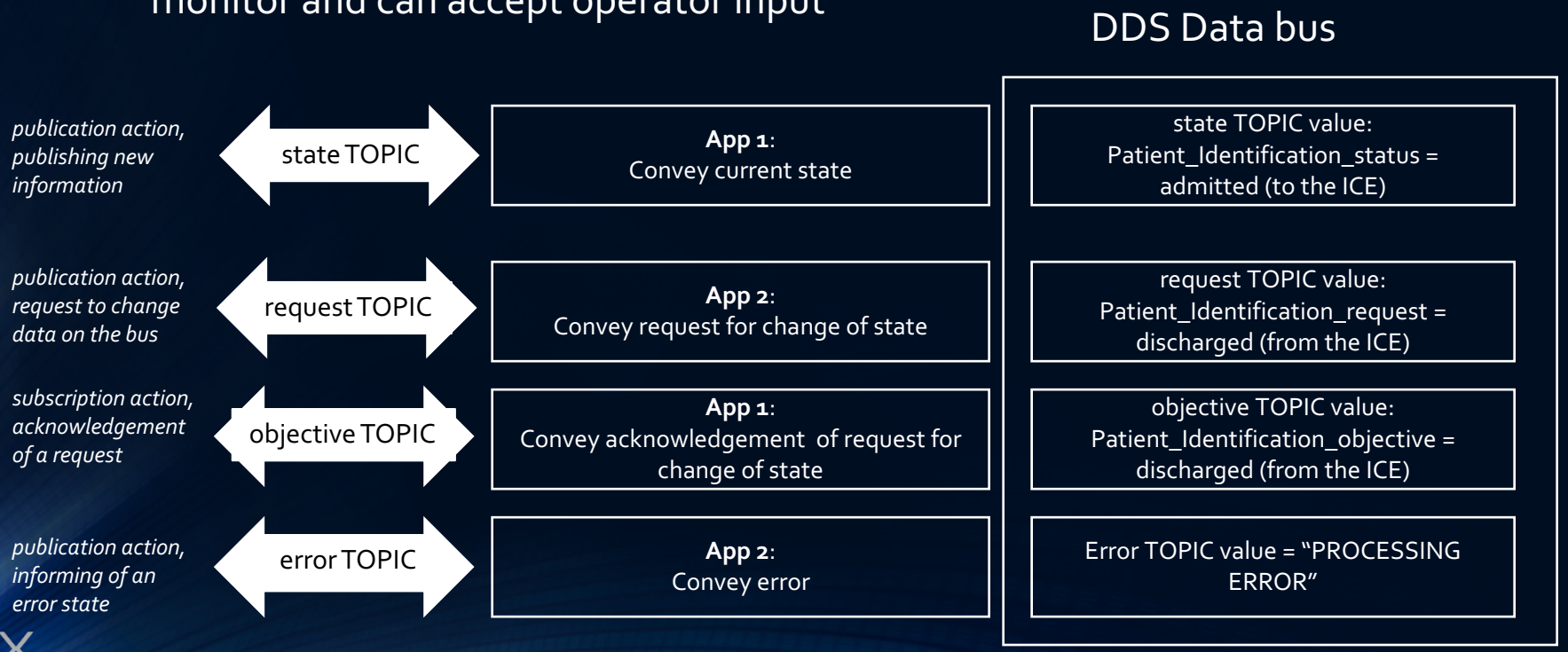


Communication Pattern (Objective State Pattern)

There are 4 specific TOPIC types that are strongly coupled with the data structure for which they support. These 4 types are state, request, objective, and error TOPICs.

Let's consider the following example:

- App 1 is the Patient Manager app (System App)
- App 2 is a Clinical App (e.g. Flow Sheet) that displays patient information on the monitor and can accept operator input



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ICE Component Software Development Kit (SDK)

- Applications, Devices and Equipment will be able to connect, and V&V to the platform
- Regulatory Benefits , V&V is part of connectivity of FDA Master File (in process Q2 2018)
- Cybersecurity aspects will meet DoD RMF cybersecurity certification (in process Q2 2018)
- Funded by USAMRMC CMMRP W81XWH-17-C-0013

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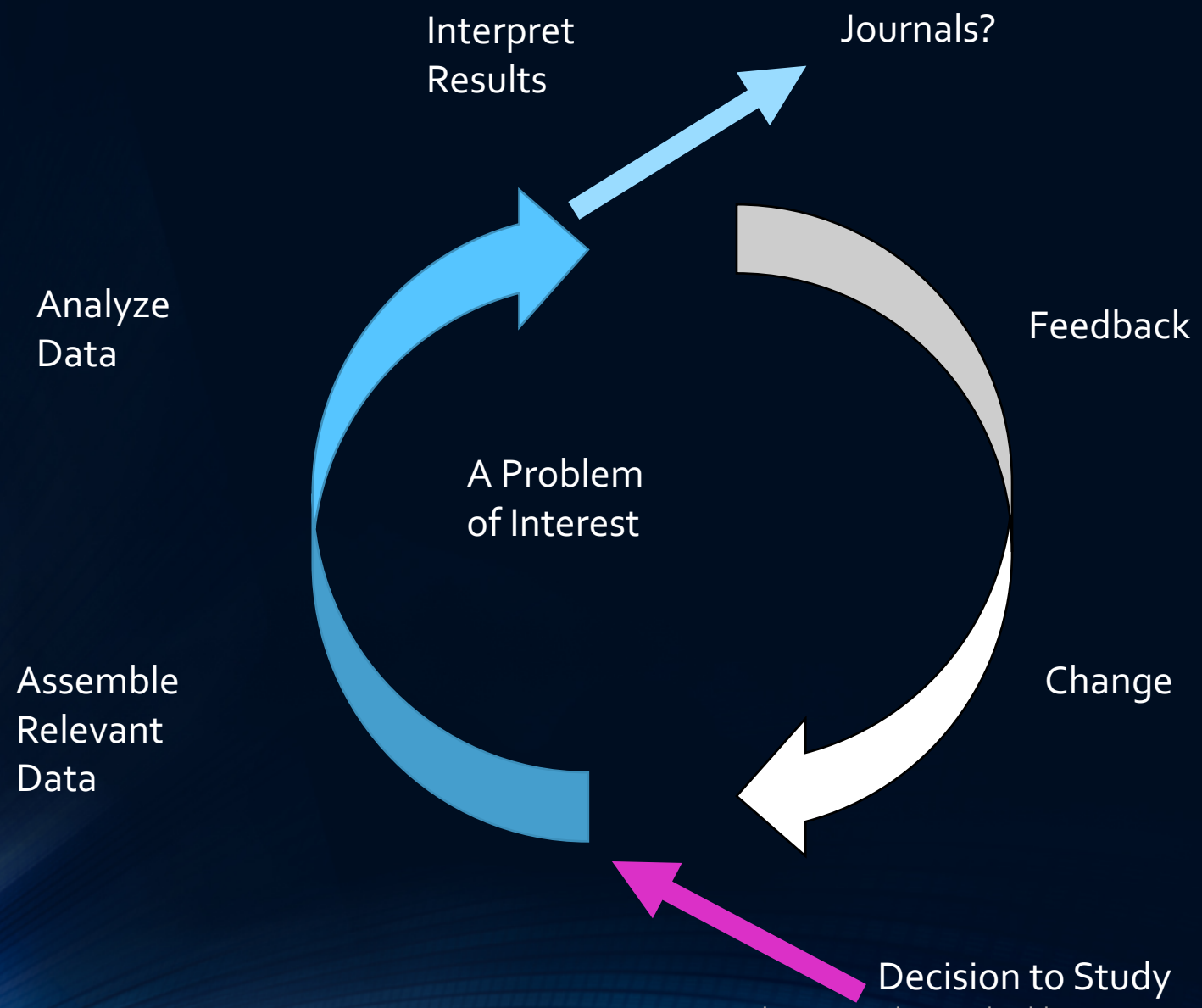
Closing the Loop

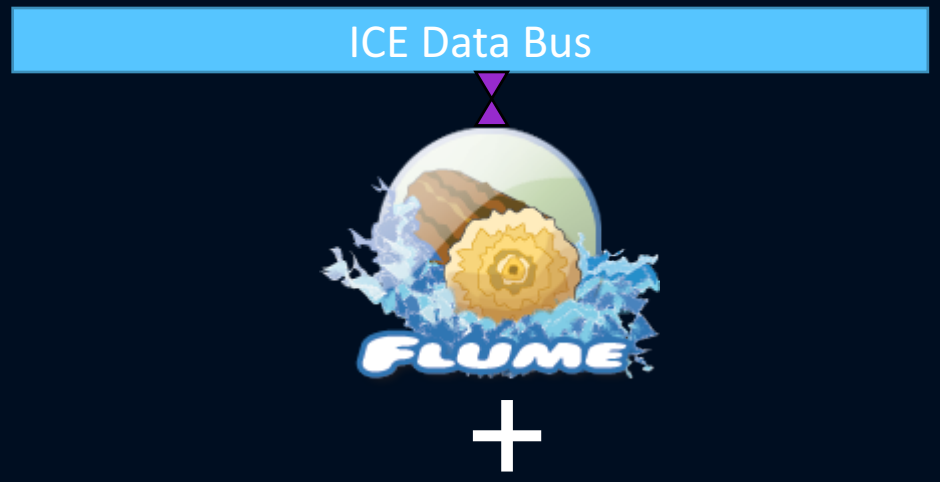


http://www.learninghealthcareproject.org/section/background/learning-healthcare-system

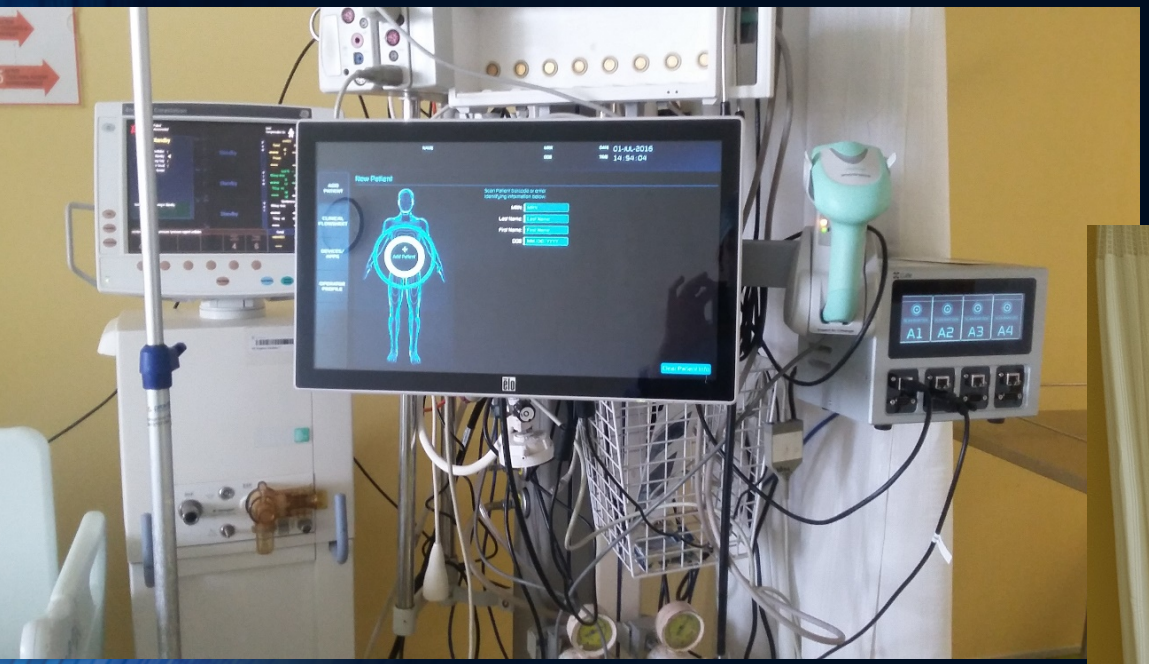
How Do You Close the Loop?

- Using an ICE architecture highly granular patient data can be collected
  - ~1.5 – 2 GB per day per critical care bed
- Data is collected from multiple devices in a vendor agnostic, data centric, structured data model
- Data can be used for real-time and historical analytics
- Data can be viewed from both a clinical and operational perspective

IoT to Big Data



Process - Clinical



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Bed Utilization Analysis

6 month analysis

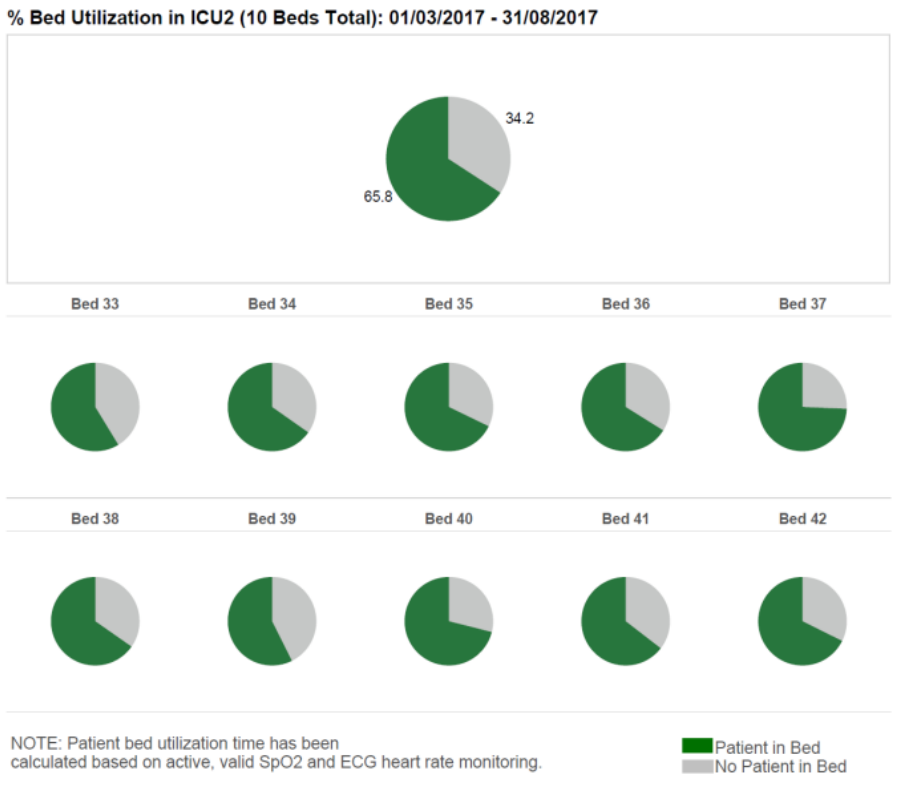
Total Patient Admission Events

Total # of Unique Admitted Patients	Average # of Unique Patients Admitted per Day
914	5.0

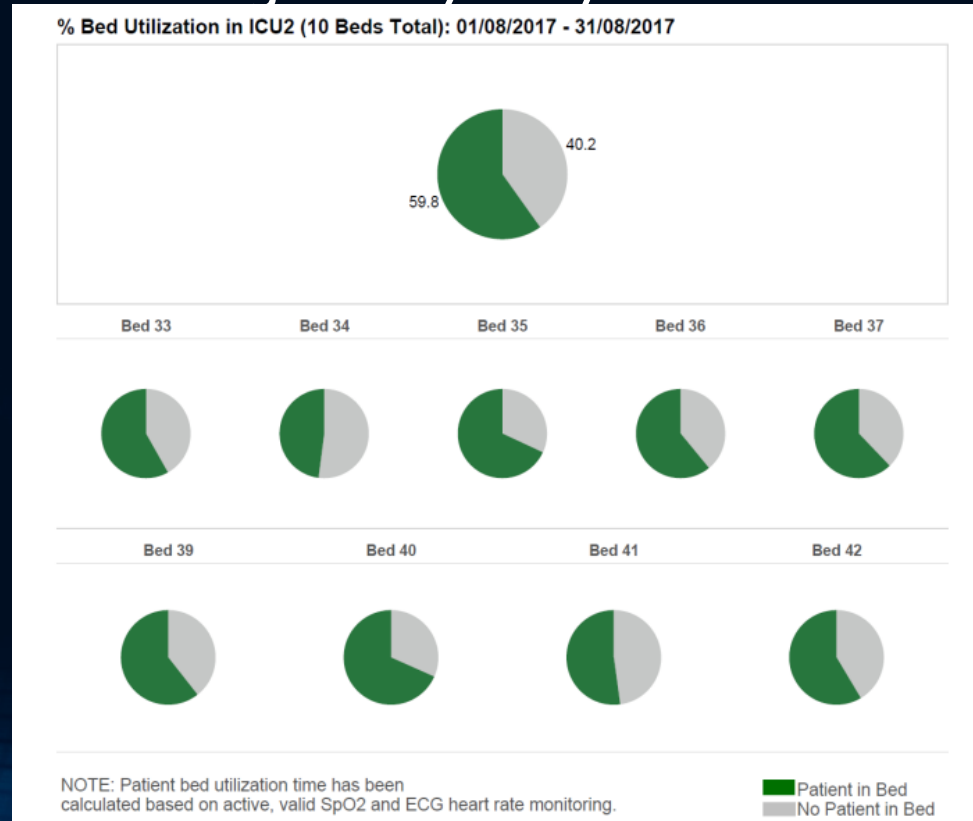
Patient Bed Utilization (hrs)

Total ICU2 Bed Utilization (hrs)	Total ICU2 Bed Utilization (days)	Avg ICU2 Bed Utilization per Bed per Day (hrs/day)
29,060.18	1,210.84	15.79

6 month analysis using platform data

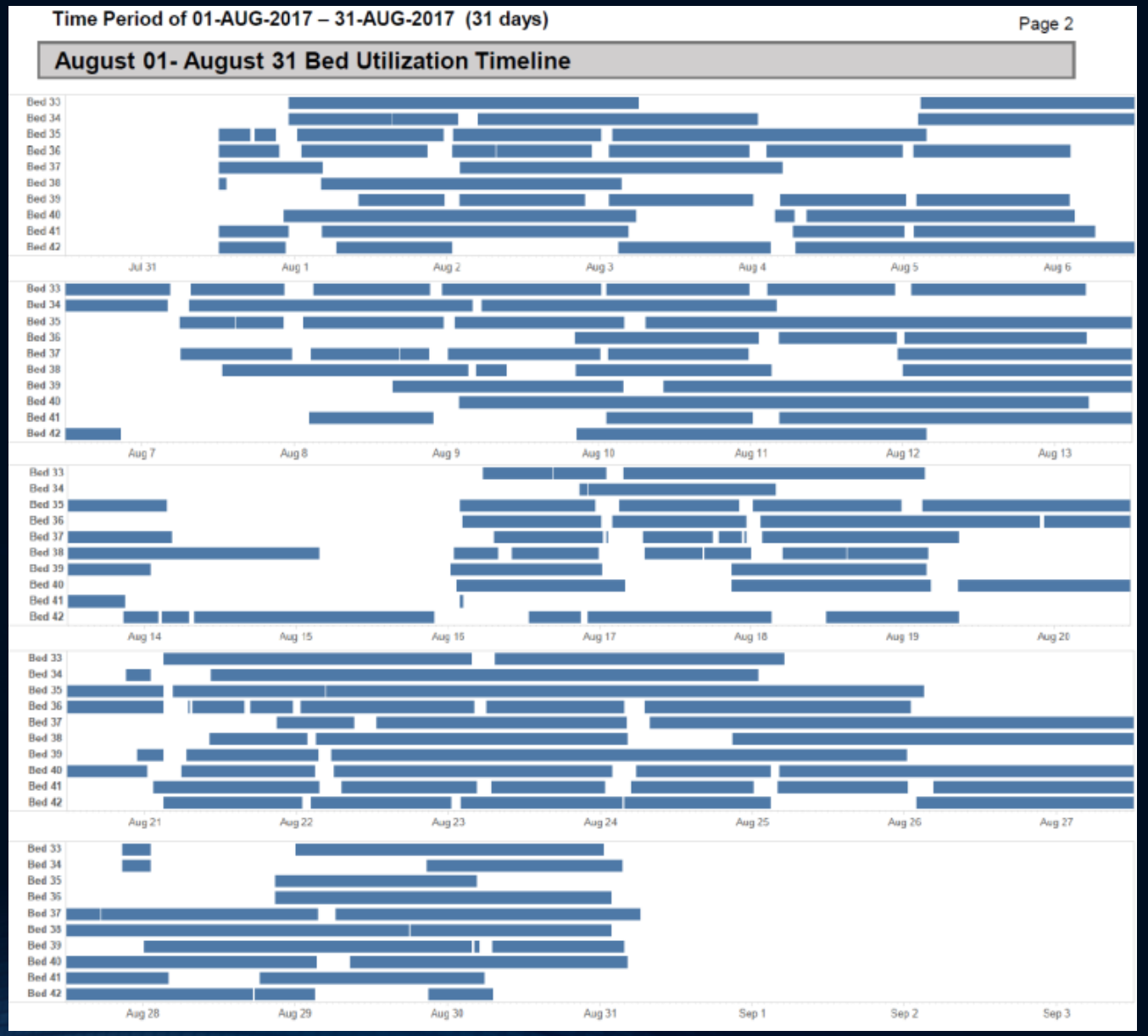


August 2017 analysis



Individual Bed Utilization by Day/Hour

- Blue - bed is occupied
- Can be provided in near real time (i.e. operations dashboard)
- Granularity to sub sec



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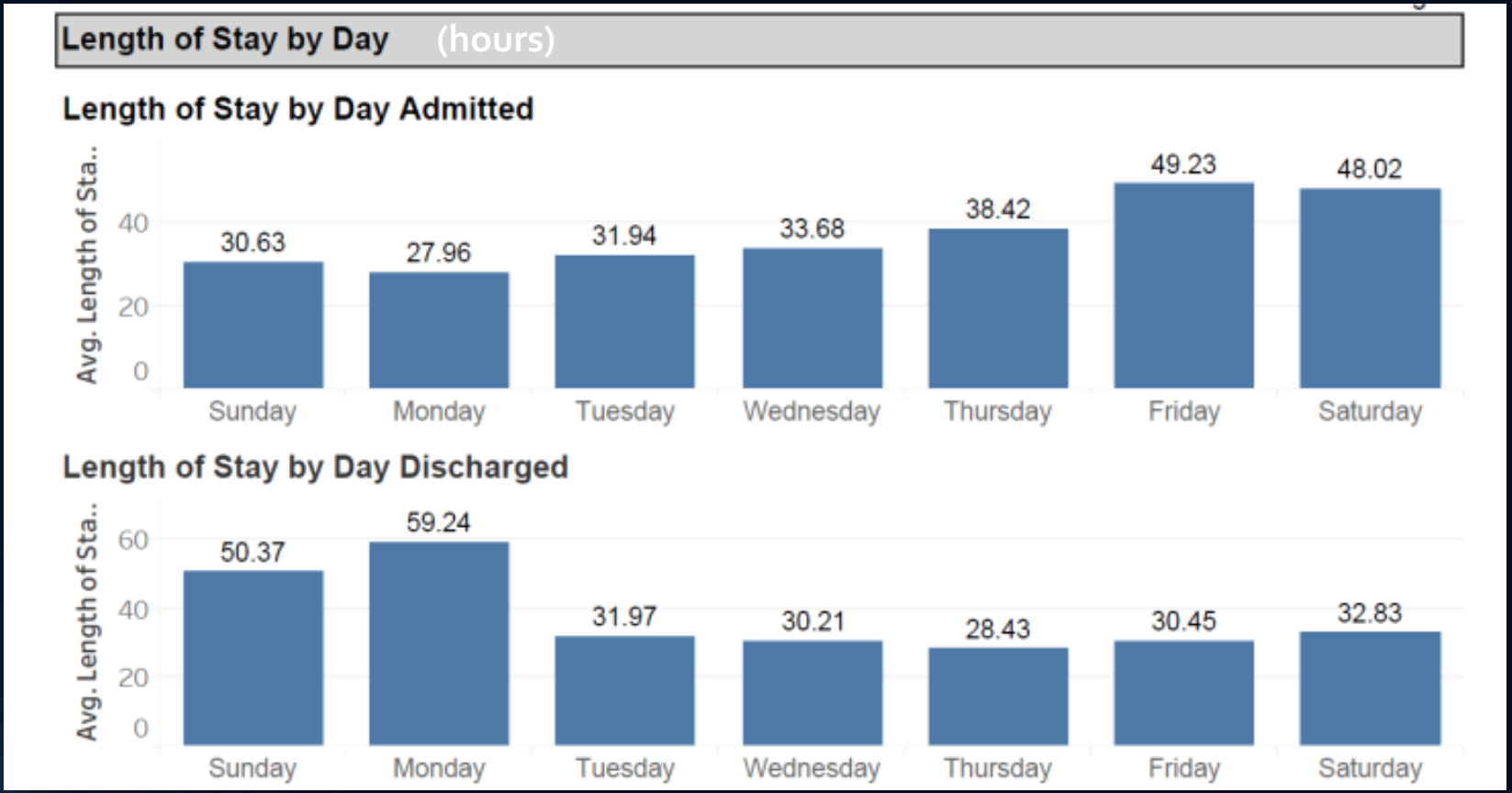
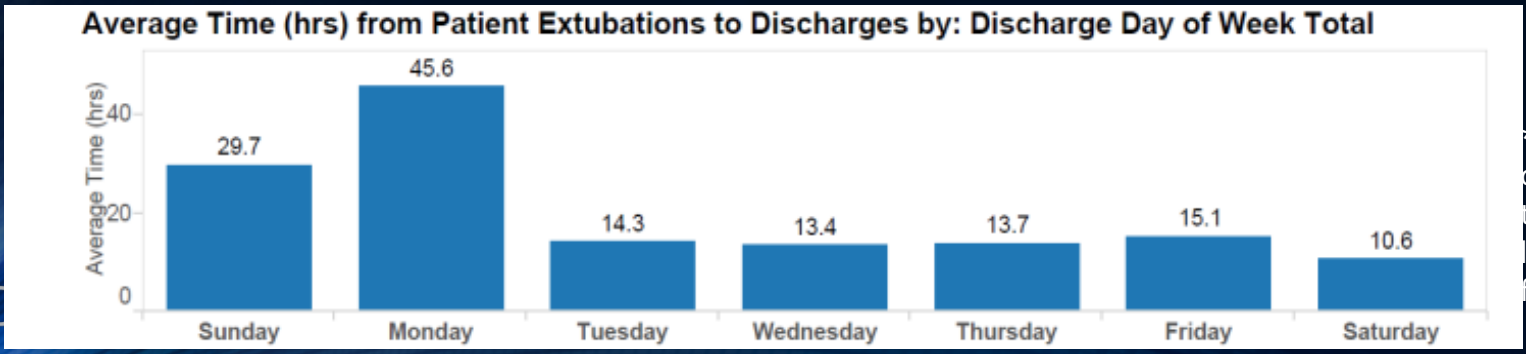
Length of Stay Analysis



Why are Sunday and Monday discharges so much longer?



*extubation is determined by when tidal volume is no longer available from ventilator

Research article

Open Access

Exploring if day and time of admission is associated with average length of stay among inpatients from a tertiary hospital in Singapore: an analytic study based on routine admission data

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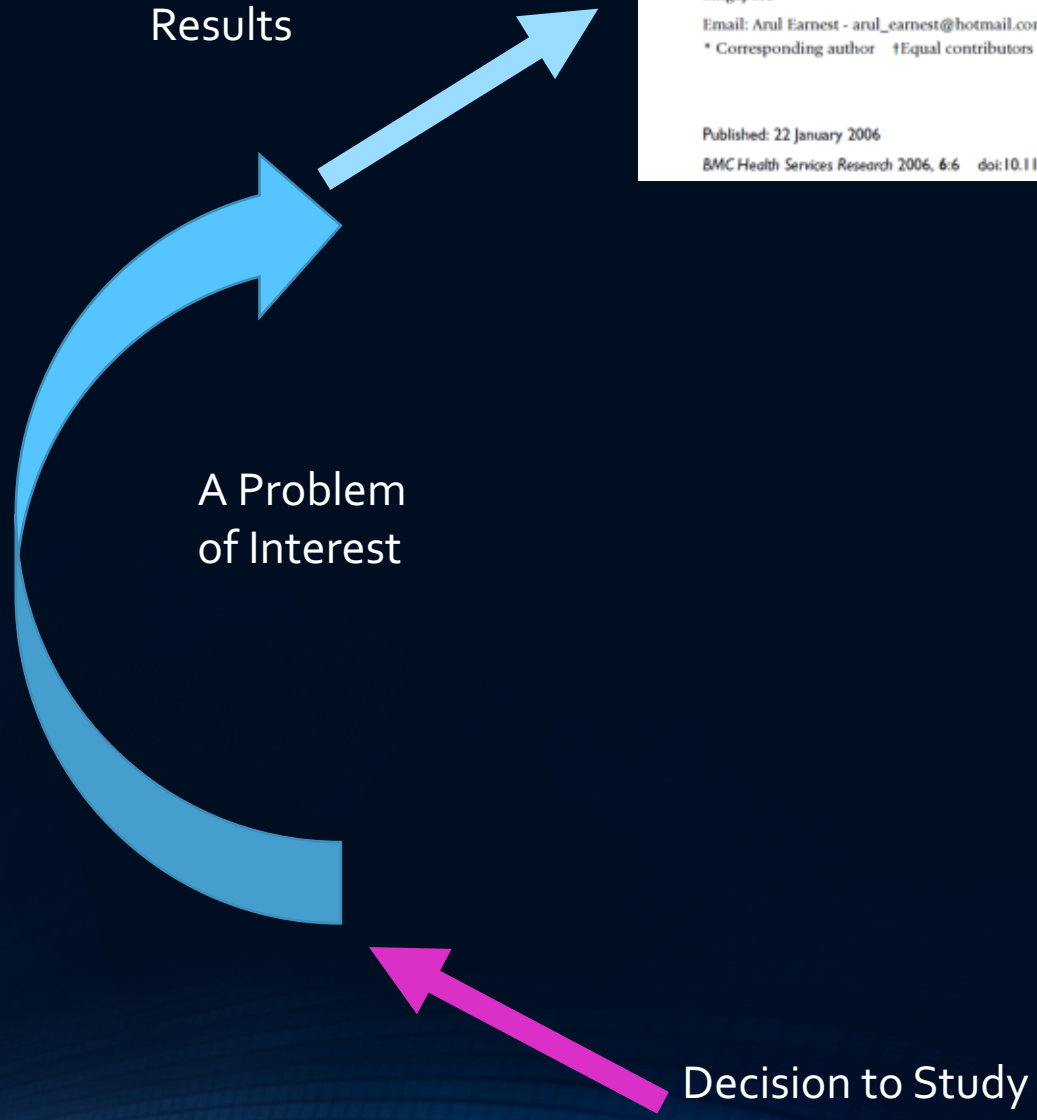
Accepted: 22 January 2006



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Average Procedure Time in ICU

Average Length of stay (hrs) for March-August 2017

Length of Stay by Procedure (hrs)

Length of Stay, St Dev, and Number of Patients	ASD	AVR	AVR + CABGx1	AVR + CABGx2	AVR + CABGx4	AVR + CRIF	AVR + DVR	AVR + MVR	Bentalls	CABGx1
	26.38	36.51	29.39	74.83	19.19	84.51	26.42	20.00	46.08	41.79
	22.594	22.543	15.597	22.778					18.817	18.063
	5	21	8	2	1	1	1	1	5	5

Length of Stay, St Dev, and Number of Patients	CABGx1 + MVR	CABGx2	CABGx2 + MVR	CABGx3	CABGx3 + MVR	CABGx4	CABGx5	DVR	Endarte..	LA Myxoma Excision
	63.58	37.96	44.45	46.37	44.80	51.73	20.69	62.08	19.48	50.46
	14.20	44.91	2.40	25.59		45.53		44.44		
	5	3	2	10	1	13	1	3	1	1

Length of Stay, St Dev, and Number of Patients	LA Myxoma Resection	MIDCABx1	MVR	MVR + LAA ligation	MVR + TVR	No Procedure Provided	OPCABGx1	OPCABGx1 + Endartere ctomy
	14.34	23.41	47.59	47.67	47.14	36.74	30.32	23.72
		6.65	38.95	65.21	19.37	26.88	23.86	
	1	2	13	2	6	416	22	1

Length of Stay, St Dev, and Number of Patients	OPCABGx2	OPCABGx2 + Endartere ctomy	OPCABGx2 +DJ stent	OPCABGx3	OPCABGx3 + Cholesyst ectomy	OPCABGx3 + diffuse Tvd	OPCABGx4	OPCABGx5
	33.38	19.32	25.43	34.45	13.71	19.30	34.33	31.34
	19.03	0.14		22.55			22.41	21.12
	32	2	1	124	1	1	76	6

Example of breakdown by procedure
(this can be used as a quality metric when enough patients are in base data set.

With a little more data, clinicians could easily see in real time that patient is not in line with care pathway

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Clinical Data View

DOCBOX

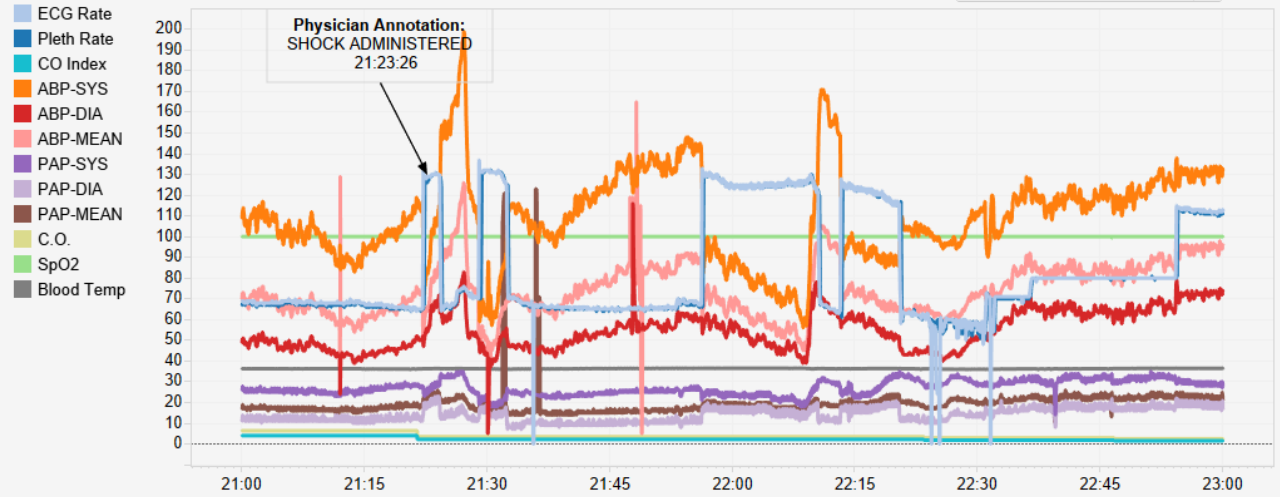
Date & Time August 24, 2016 9 PM — August 24, 2016 10 PM

Back to Patient Info | View Alarms

PATIENT MM1234567 Name: Smith, Joan
Sex: F Age: 74Y Location: ICU2 Bed 33

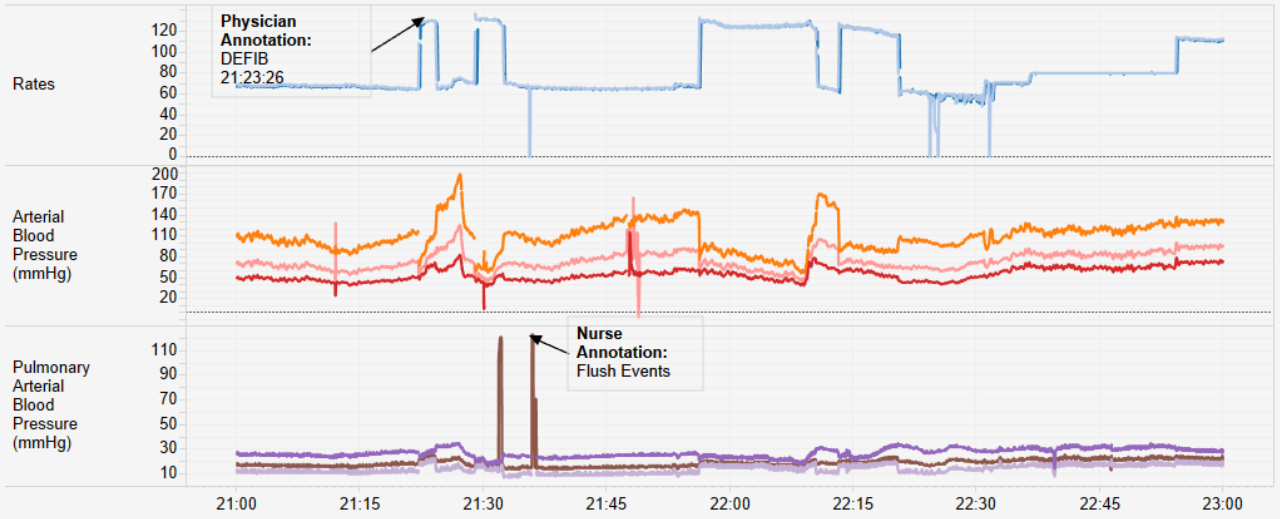
Clinical Trends Graph

Select values to view in Clinical Trends View: (All)



Detailed View

Select values to view in Detailed View: (Multiple values)



Ventilator Settings

Vent Mode: SIMV-VC

(All)

Mech RR	12.0				
Trigger Window	25.0				
End Flow	25.0				
Pressure Rise T..		100.0	100.0	100.0	100.0
Pmax	30.0	30.0	30.0	30.0	30.0
PSV Rise Time	50.0				
FiO2	50.0	50.0	50.0	50.0	50.0
Tube Size	7.5	7.5	7.5	7.5	7.5
Nebulizer Time	15.0	15.0	15.0	15.0	15.0
Pt Weight	70.0	70.0	70.0	70.0	70.0
Pt Height	170.0	170.0	170.0	170.0	170.0
ARC Level	35.0	35.0	35.0	35.0	35.0
RR		12.0	12.0	12.0	12.0
	21:00	21:15	21:30	21:45	22:00

Waveforms - *Select Values in Detailed View to View Relevant Waveforms*

DOCBOX

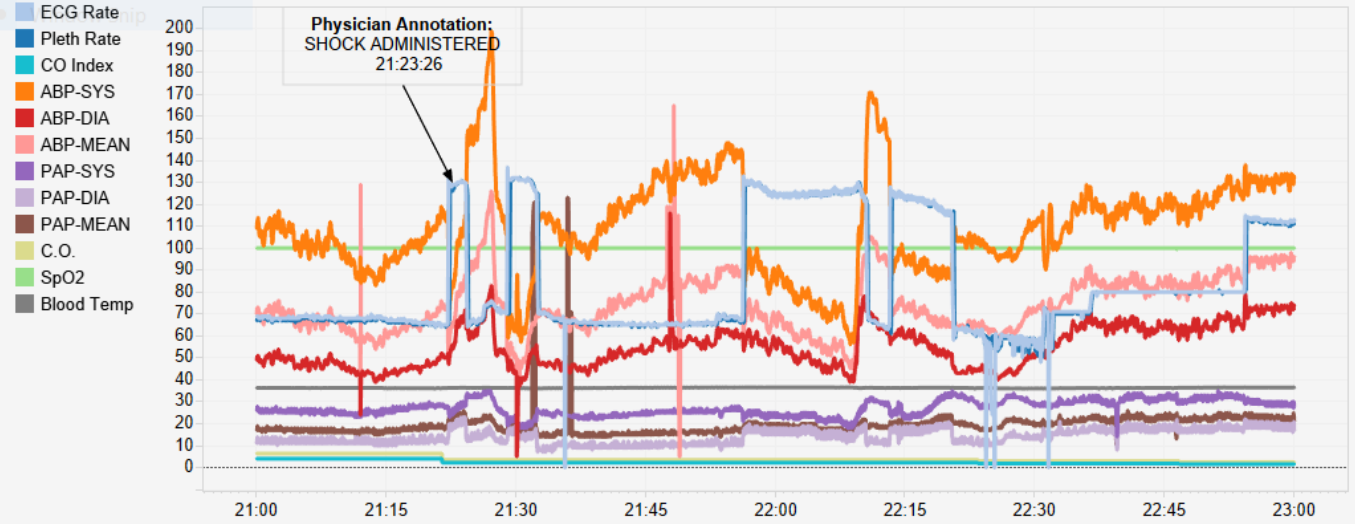
Date & Time August 24, 2016 9 PM — August 24, 2016 10 PM

Back to Patient Info | View Alarms

PATIENT MM1234567 Name: Smith, Joan
Sex: F Age: 74Y Location: ICU2 Bed 33

Clinical Trends Graph

Select values to view in Clinical Trends View: (All)



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Vent Mode: SIMV-VC

(All)

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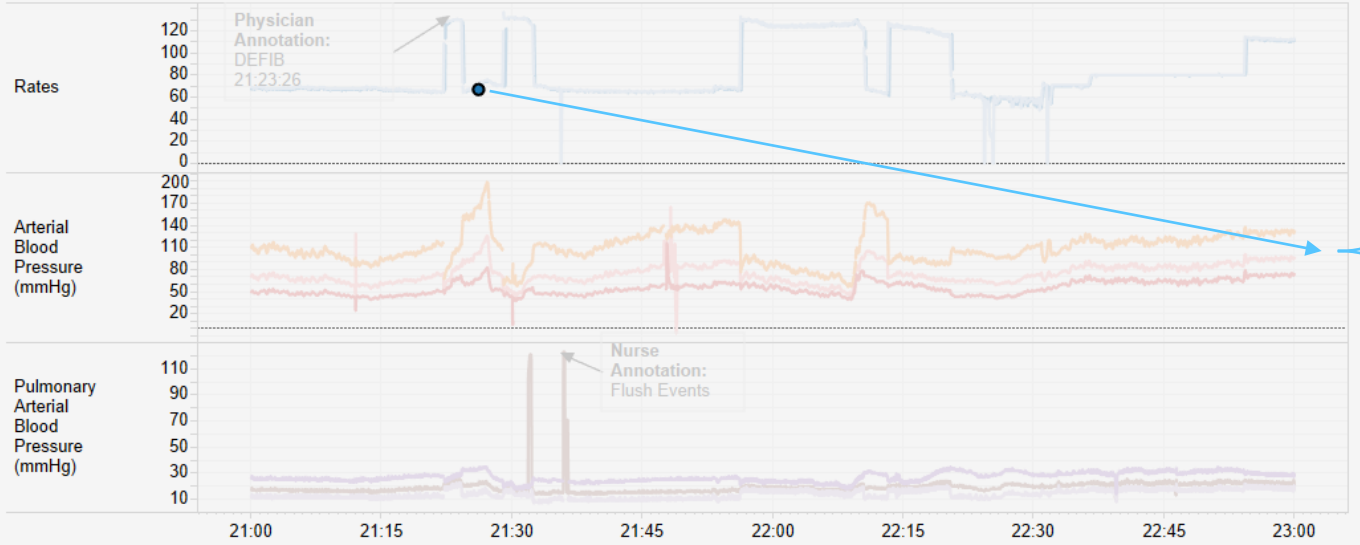
End Flow	25.0				
Pressure Rise T..		100.0	100.0	100.0	100.0
Pmax	30.0	30.0	30.0	30.0	30.0
PSV Rise Time	50.0				
FiO2	50.0	50.0	50.0	50.0	50.0
Tube Size	7.5	7.5	7.5	7.5	7.5
Nebulizer Time	15.0	15.0	15.0	15.0	15.0
Pt Weight	70.0	70.0	70.0	70.0	70.0
Pt Height	170.0	170.0	170.0	170.0	170.0
ARC Level	35.0	35.0	35.0	35.0	35.0
RR		12.0	12.0	12.0	12.0

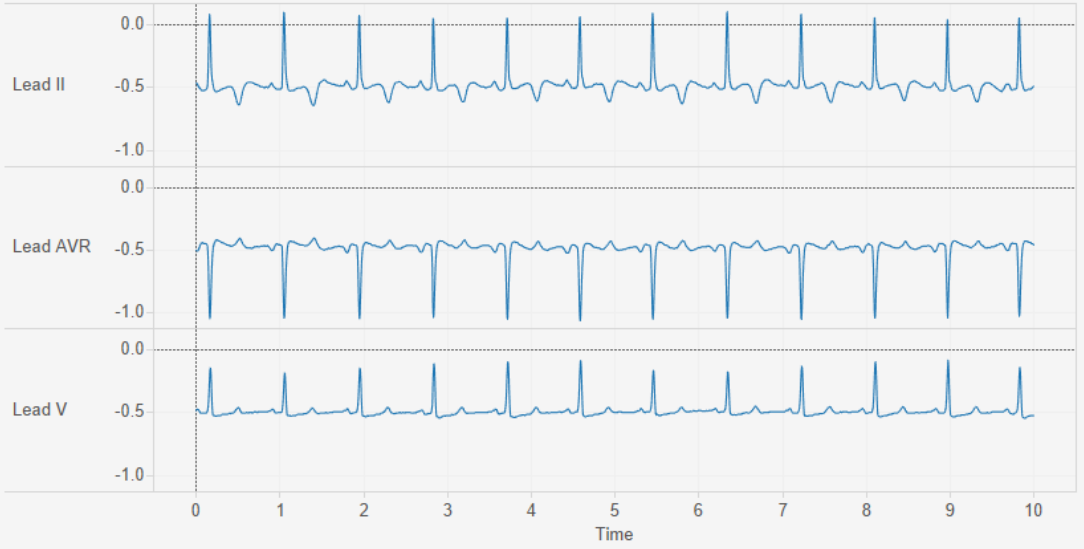
21:00 21:15 21:30 21:45 22:00 22:15 22:30 22:45 23:00

Detailed View

Select values to view in Detailed View: (Multiple values)



Waveforms - *Select Values in Detailed View to View Relevant Waveforms*



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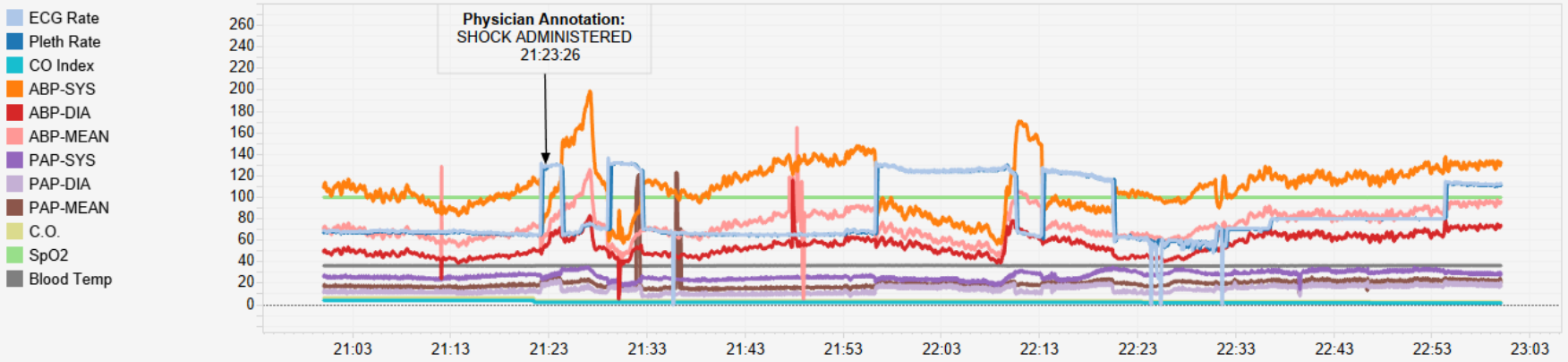
Date & Time August 24, 2016 9 PM — August 24, 2016 10 PM

View Trends & Waveforms | Back to Patient Info

PATIENT MM1234567 Name: Smith, Joan
Sex: F Age: 74Y Location: ICU2 Bed 33

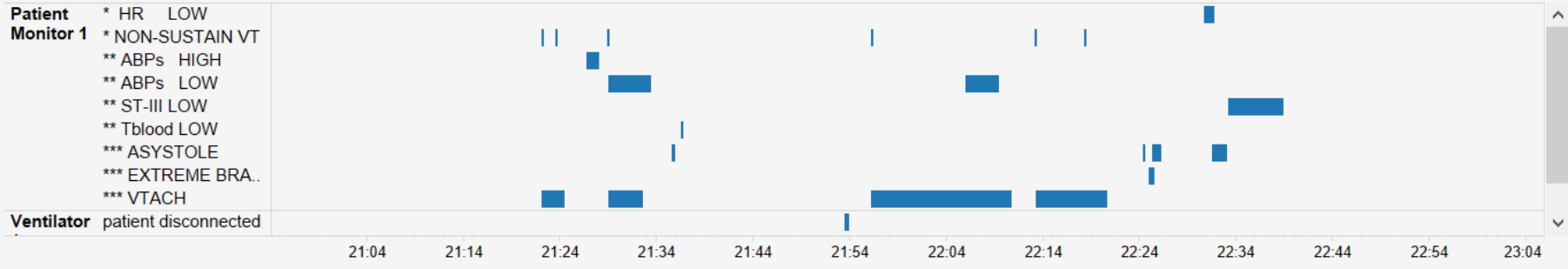
Clinical Trends Graph



Select values to view in Clinical Trends View: (All)

Physiological Alarms

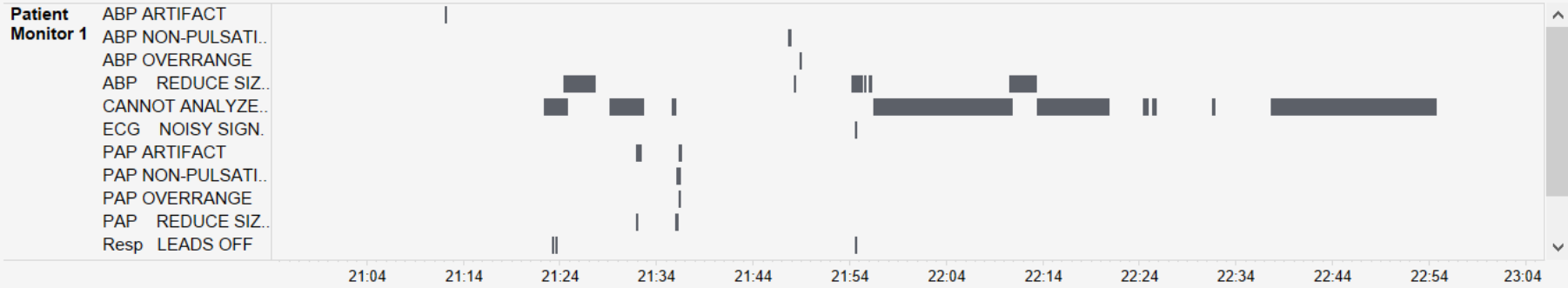
Select device to view alarms: (All)



Physiological Alarm Total Durations

Alarm Message	Device	Seconds	Hours
patient disconnected	Ventilator 1	2	0.001
plimit reached	Ventilator 1	4	0.001
* NON-SUSTAIN VT	Patient Monitor 1	7	0.002
** Tblood LOW	Patient Monitor 1	7	0.002
*** EXTREME BRADY	Patient Monitor 1	23	0.006
* HR LOW	Patient Monitor 1	50	0.014
** ABPs HIGH	Patient Monitor 1	66	0.018
*** ASYSTOLE	Patient Monitor 1	124	0.034
** ST-III LOW	Patient Monitor 1	321	0.089
** ABPs LOW	Patient Monitor 1	415	0.115

Technical Alarms

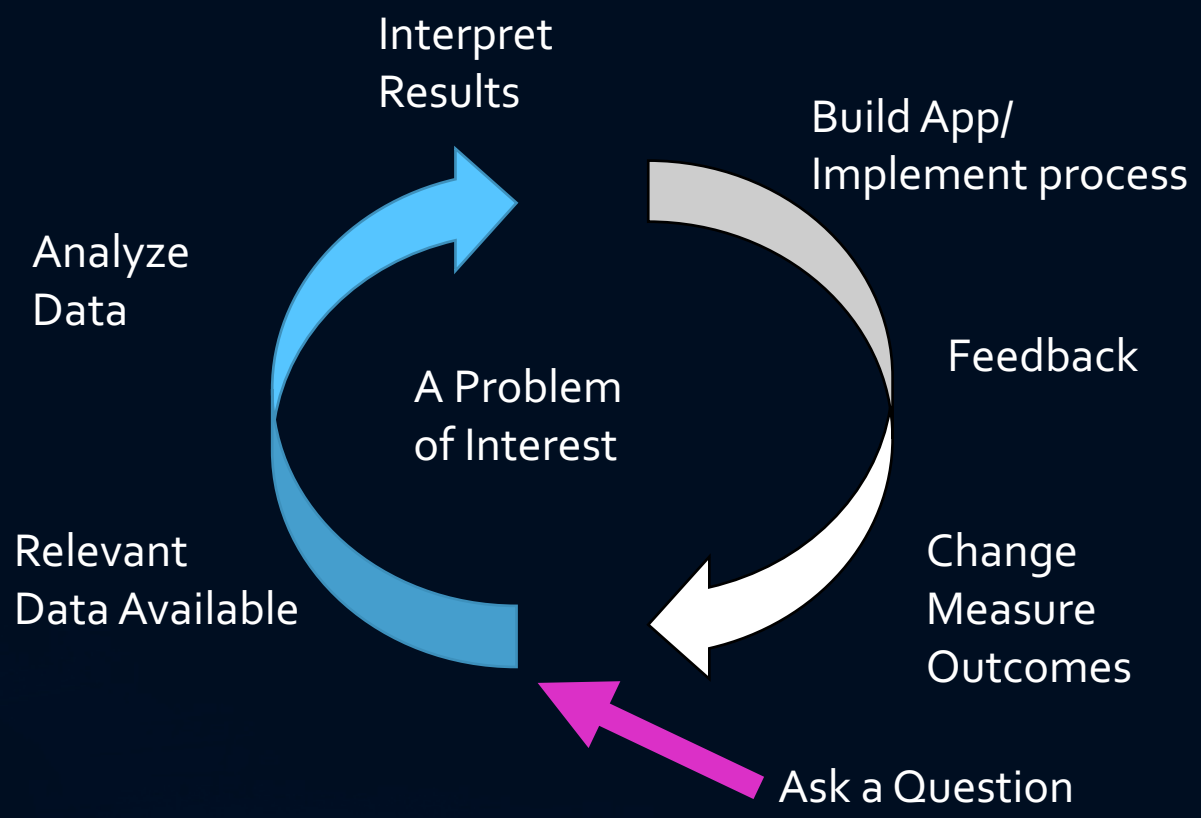


Technical Alarm Total Durations

Alarm Message	Device	Seconds	Hours
PAP OVERRANGE	Patient Monitor 1	1	0.000
ABP OVERRANGE	Patient Monitor 1	2	0.001
ECG NOISY SIGN.	Patient Monitor 1	2	0.001
SpO2 POOR SIGNAL	Patient Monitor 1	2	0.001
ABP ARTIFACT	Patient Monitor 1	5	0.001
Resp LEADS OFF	Patient Monitor 1	5	0.001
ABP NON-PULSATILE	Patient Monitor 1	6	0.002
PAP NON-PULSATILE	Patient Monitor 1	12	0.003
PAP REDUCE SIZE	Patient Monitor 1	14	0.004
PAP ARTIFACT	Patient Monitor 1	25	0.007
SpO2 LOW PERF	Patient Monitor 1	31	0.009

Closing the Loop

- New solutions can be deployed
- Data is collected continuously
- Improvements are continuous based on data
- Innovation is enabled
- Scale with new Apps on platform



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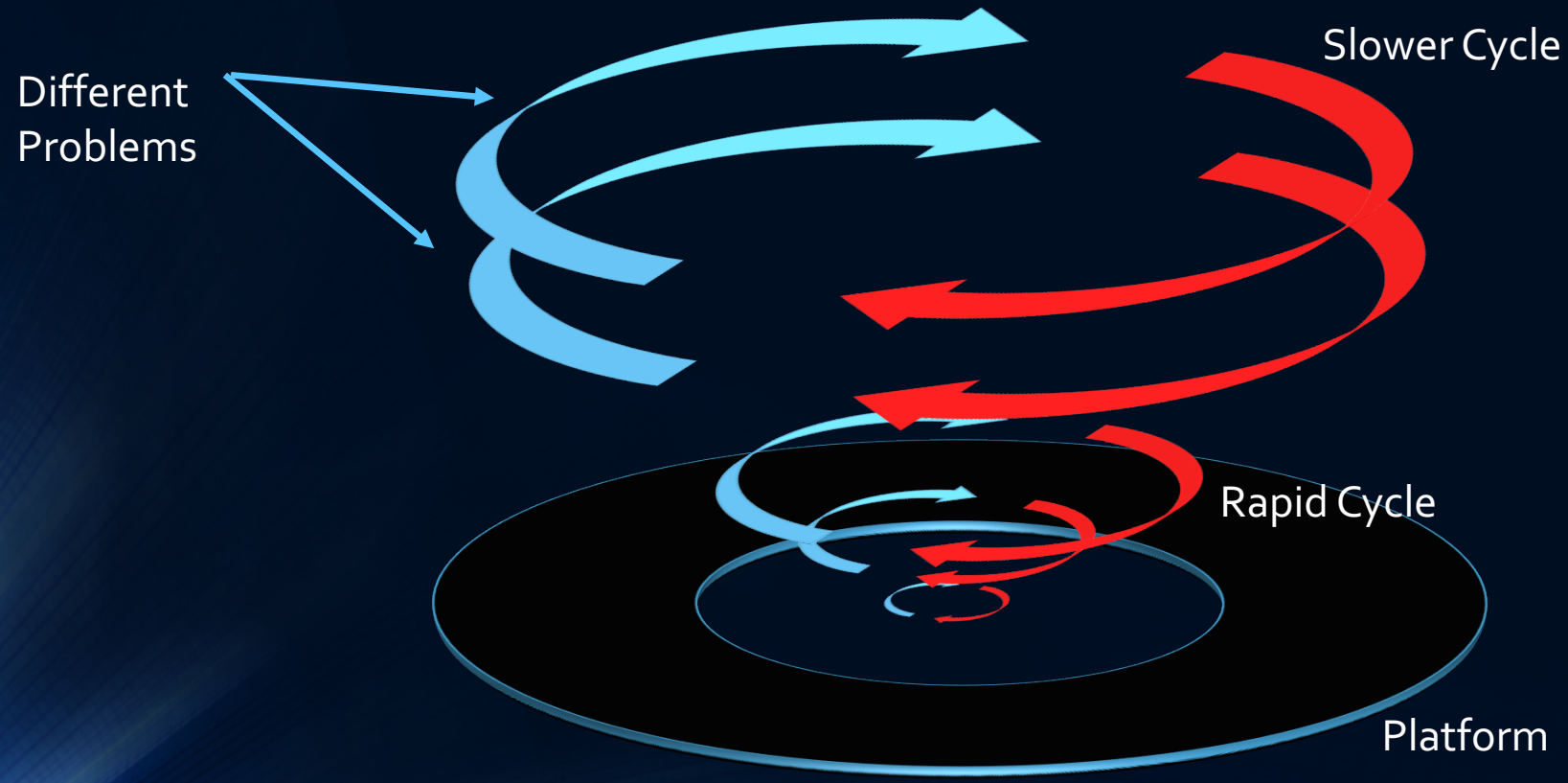
Medical Internet of Things Creates Platform



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http://www.learninghealthcareproject.org/section/background/learning-healthcare-system

What is Next?

- Add a Virtual Care Domain and associated Apps
- Implementation in pre-hospital environments
- SDK and Regulatory Framework for 3rd Party Apps
- Increased Bed Role Out for Data Collection
- More Apps
- mIoT testbeds for interoperability and cybersecurity

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Thank You
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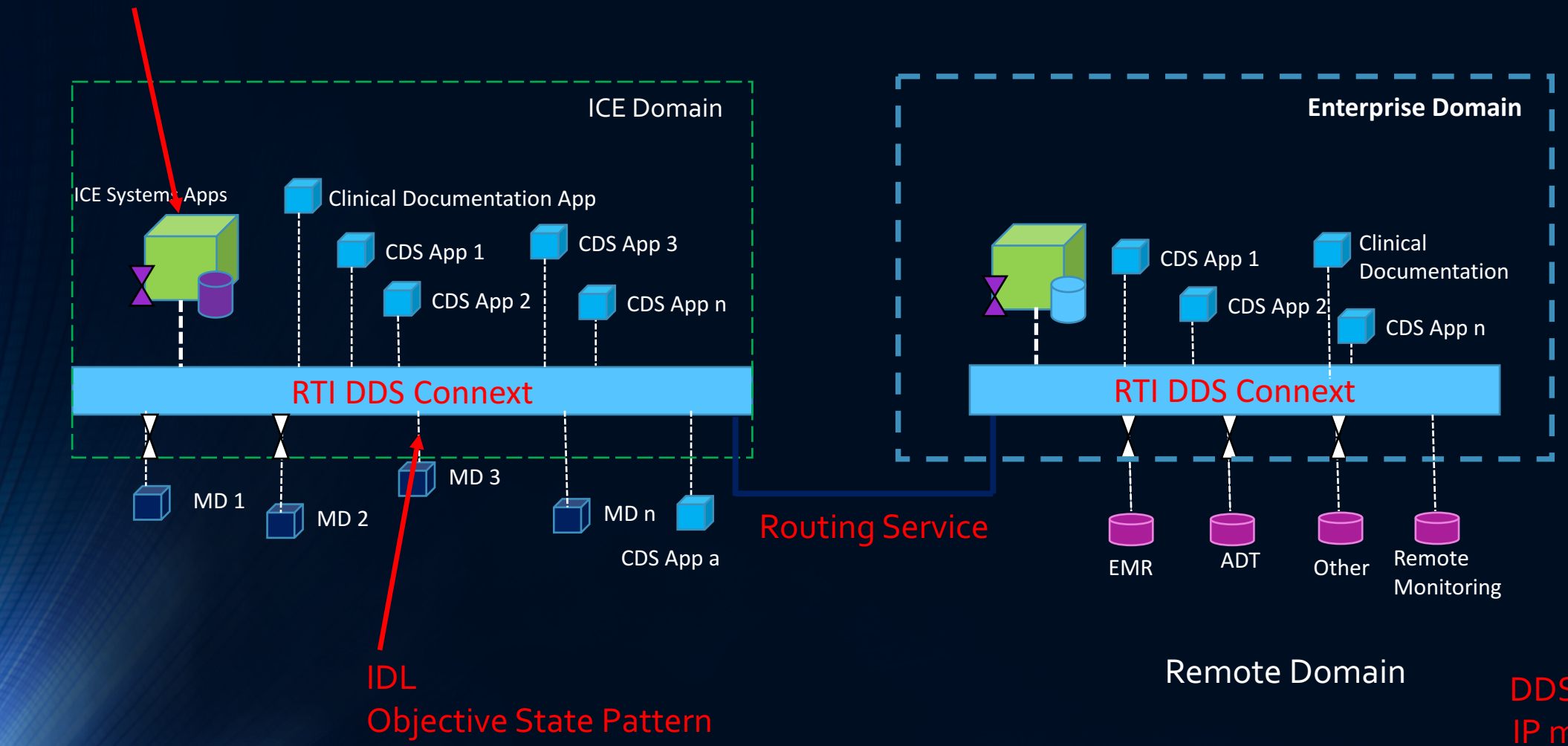
ICE with DDS



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