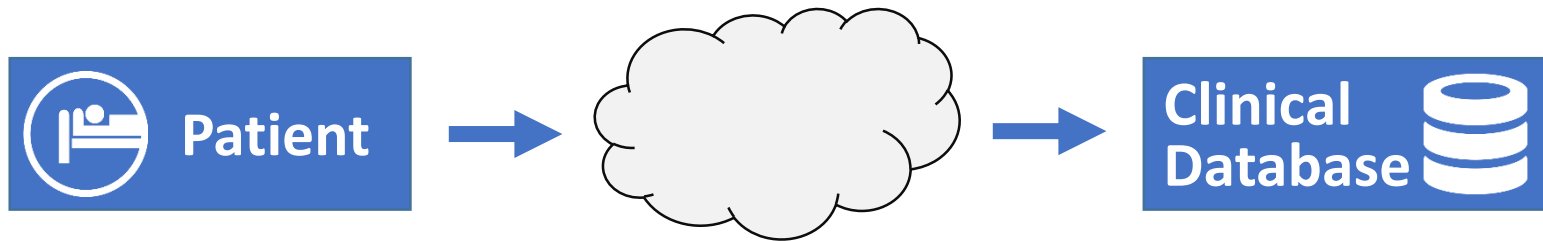


Data Integration



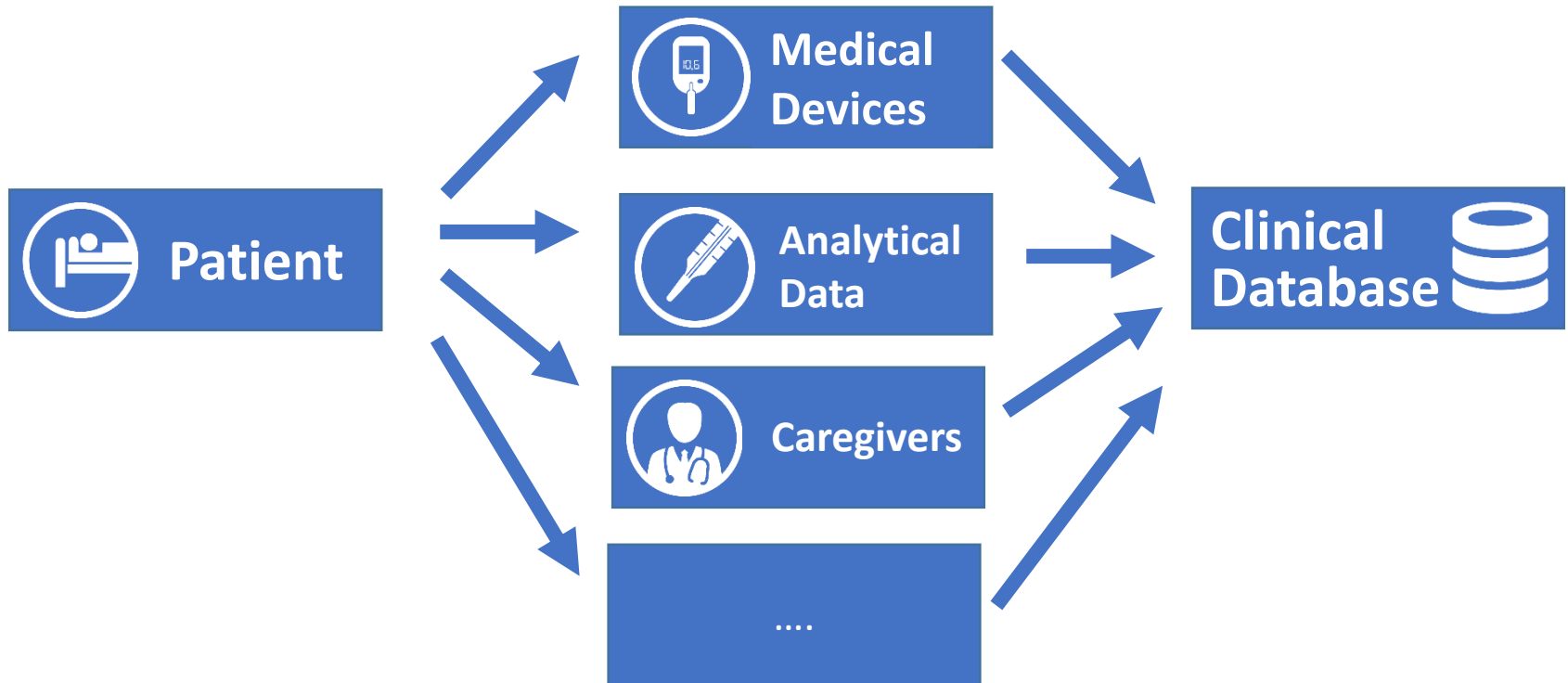
Theory

What is clinical data?



- Measurements from patient monitors
 - Laboratory analyses
 - Results of imaging procedures
 - Caregivers' notes
 - ...
- ➔ Complex & heterogenous information

What is clinical data?

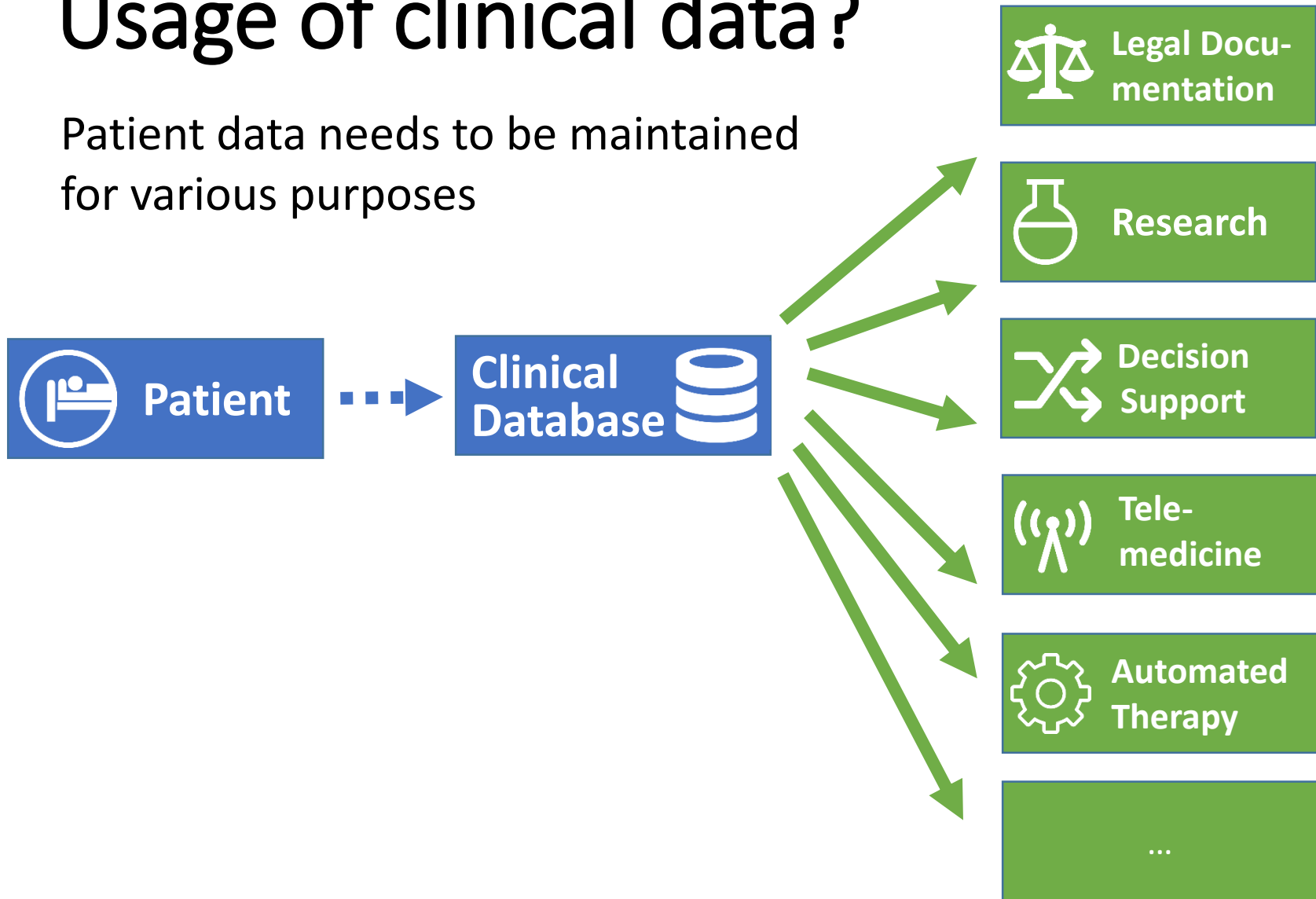


What is clinical data?

- Data needs to be collected
 - Data needs to be stored
 - May need to be transferred to different departments / hospitals
-
- ➔ Data collection is important
 - ➔ Need for integration & automated processing

Usage of clinical data?

Patient data needs to be maintained for various purposes



Importance of different data aspects

Highly dependent on the intended usage / further processing

	Legal Documentation	Clinical Decision Making	Scientific Research
Data density	O	+	++
Data validity	+	++	O
Data availability	+	++	+
Data completeness	+	+	++

Decision Making requires precise real-time information
→ one of the most challenging topics for data integration

Patient record

- Patient information
 - Patient history
 - Measurements & procedures
 - Therapeutic notes
 - ...
-
- Paper record or digital version

[illegible]

(Hand-written) paper record

Complex Information can be stored in tight space

But:



- Not easily retrieved / single point of access
 - Cannot be read by multiple users at the same time
 - Has to move with patient
 - If out of it's normal location – not accessible to caregivers
- Data entries are sometimes illegible
- No further automated processing

Electronic Health Record (EHR)

aka: Computer-based Patient Record (CPR)

Improve information storage & exchange

- Available to multiple users at the same time
- Timely access to patient data
- Combines past and current information about the patient
- Useful for building a clinical data repository

In integrated systems:

- Support clinical decision making
- Improve patient safety
- Promote quality improvement

Yet: Transfer between systems & departments often still manually / in paper form

Electronic Health Record (EHR)

- Strict specifications
- Precise information
- Limited complexity & freedom

Problem:

How to store additional & complex information?

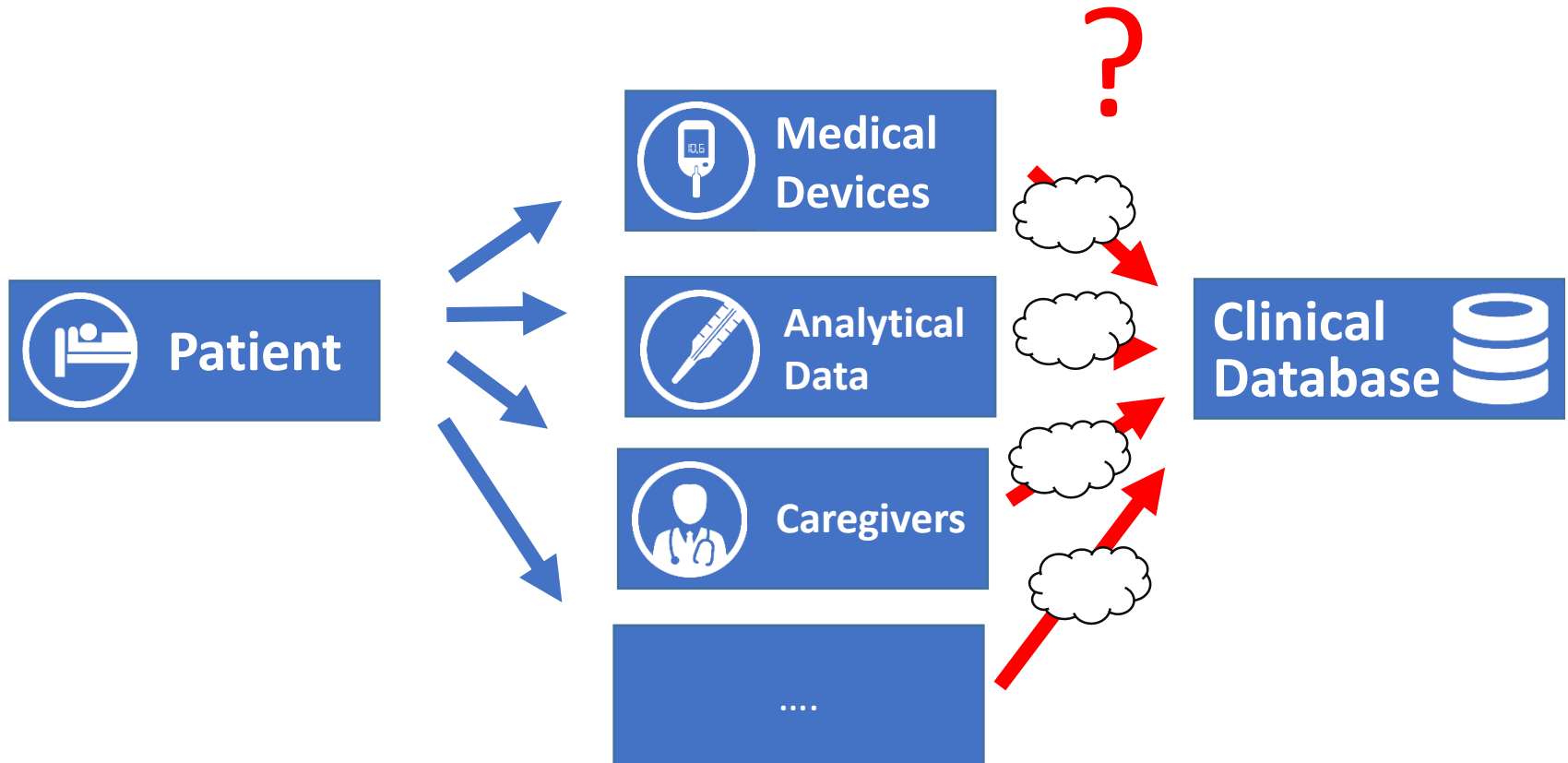
Can't find the correct field for entry?

→ Free-text comments that can hardly be further processed

Example for EPR guidelines and restrictions for input fields:

APP 065	Die Anzeige ist auf eine feste, systemweite Stellenanzahl begrenzt, längere Einträge sind markiert.
APP 066	In numerischen Feldern sind ausschließlich Zahlen erlaubt.
APP 067	Bei Datumseingaben erfolgt eine Formatkorrektur.
APP 068	Deutsche Datumsformate sind an jeder Stelle möglich.
APP 069	Datums- und Uhrzeiteingaben sind in verschiedenen Formaten (bei Freitextfeld) möglich (z.B. 15.4. -> 15.04.2012; 1234 -> 12:34, 12 -> 12:00)
APP 070	Die Auswahlfelder dienen der standardisierten Eintragung von Werten. Dazu werden Komboboxen oder einfache Wertelisten verwendet.
APP 071	Eine Mehrfachauswahl in Wertelisten ist möglich.
APP 072	Schlüsseltabellen der Auswahlfelder sind sortierbar und enthalten zum Wert eine Kurzbeschreibung.
APP 073	Werte in Schlüsseltabellen der Auswahlfelder sind durch Eingabe der ersten Buchstaben schnell auswählbar.
APP 074	Werte aus Schlüsseltabellen der Auswahlfelder werden mit einem spezifischen Filter angeboten z.B. Stations.- oder altersspezifisch.
APP 075	Eine Vorbelegung von Eingabeobjekten durch Defaultwerte ist möglich (diese müssen stationsspezifisch individuell einstellbar sein).
APP 076	Zur Anzeige in Sichten müssen Eintragungen mit Symbolen hinterlegt werden können (insbesondere in der Narkosedokumentation), die anstatt des Wertes angezeigt werden.

Data collection & integration



Data collection

- Why automated processing / interconnection?
 - No need for manual entry
 - More accurate
 - More reliable
 - Less resource-intensive
 - Higher frequency (not so often entered manually)
 - Time-critical information is transferred faster

Information systems

- Require
 - Data collection
 - Data storage (Database)
 - Data reporting / presentation
 - Communication
 - Interconnection
- Different system types
 - Departement-based
 - Information-source based
 - Administrative
 - ...

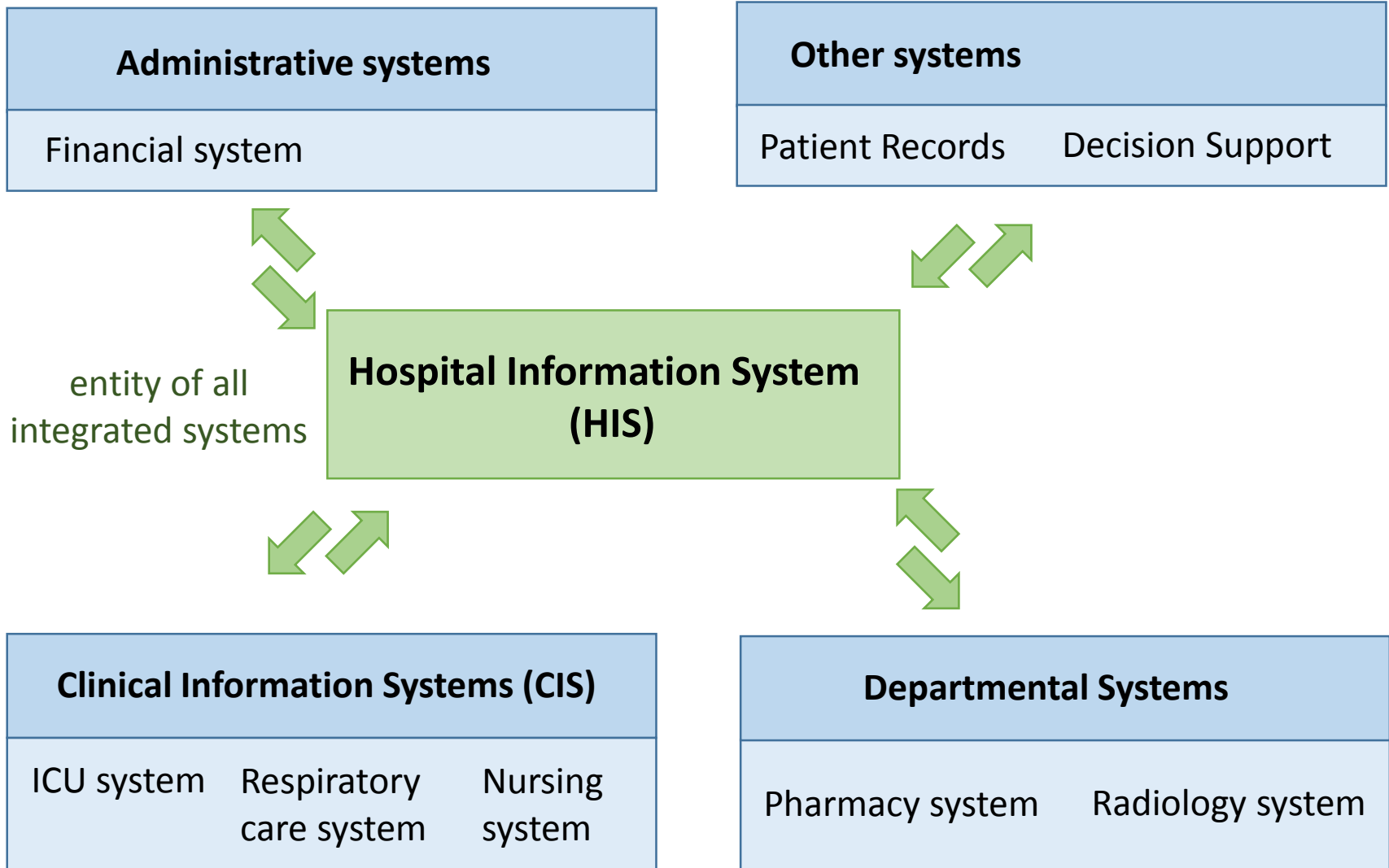
EHR System

- Includes
 - Data entry
 - Storage
 - Presentation (access to clinical decision maker)
- Entry
 - Keyboard, dictation, transcription, voice recognition, touch-screen, hand-held systems
 - Direct instrumentation from medical devices, barcodes, RFID, laboratory analyzers, ICU monitors
- Presentation
 - Text, tables, graphs, sound, images, video
 - Electronic, paper

Clinical Decision Support Systems (CDDS)

- Computer software to aid clinical decision making
- Provide caregiver with medical knowledge
 - Diagnostic suggestions
 - Testing prompts
 - Therapeutic protocols
 - Guidelines
 - Alerts
 - ...





Limited scope

- One-dimensional
- Focus on individual aspects

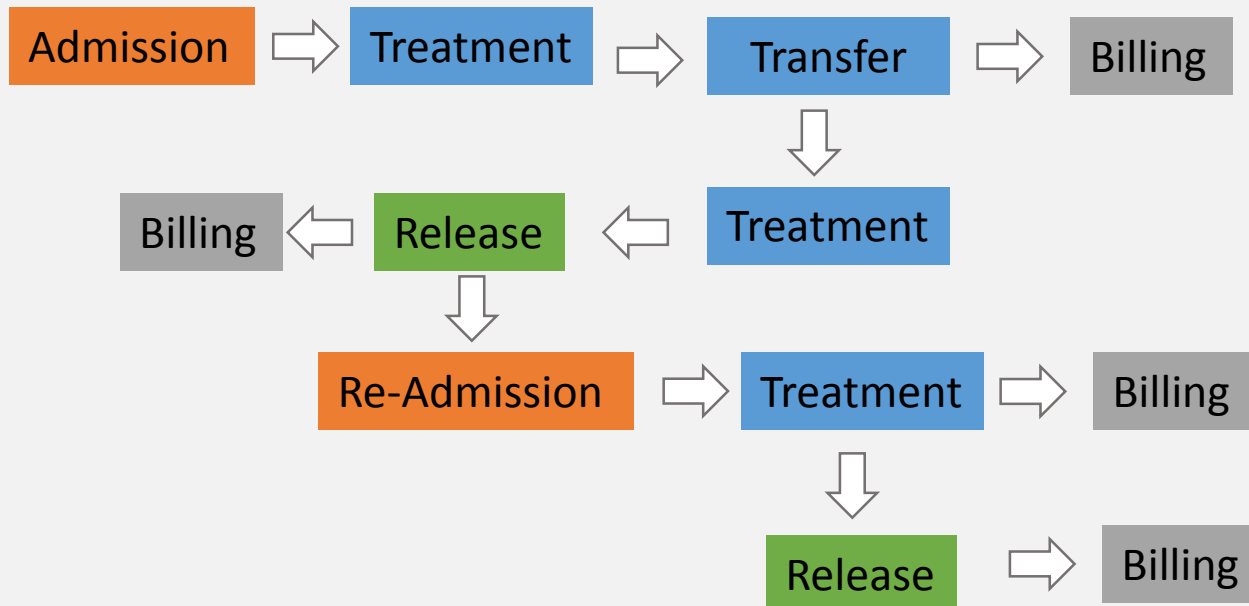
Isolated deployment

- Specific needs of individual units

System interconnection

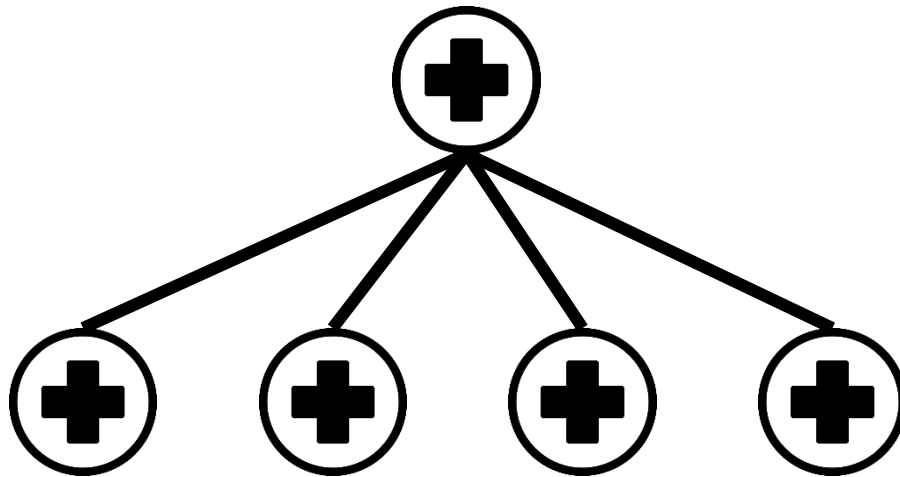
- Interconnection required for full EHR & HIS
- Systems need to exchange information
- have a universal „language“
 - Aka: understand each other
 - Coding standards

Complex interactions



Further integration layers

- Interaction between hospitals
- Interaction with healthcare insurers / government
- Other national and international levels



Reality

Aka: The challenges of data collection & integration



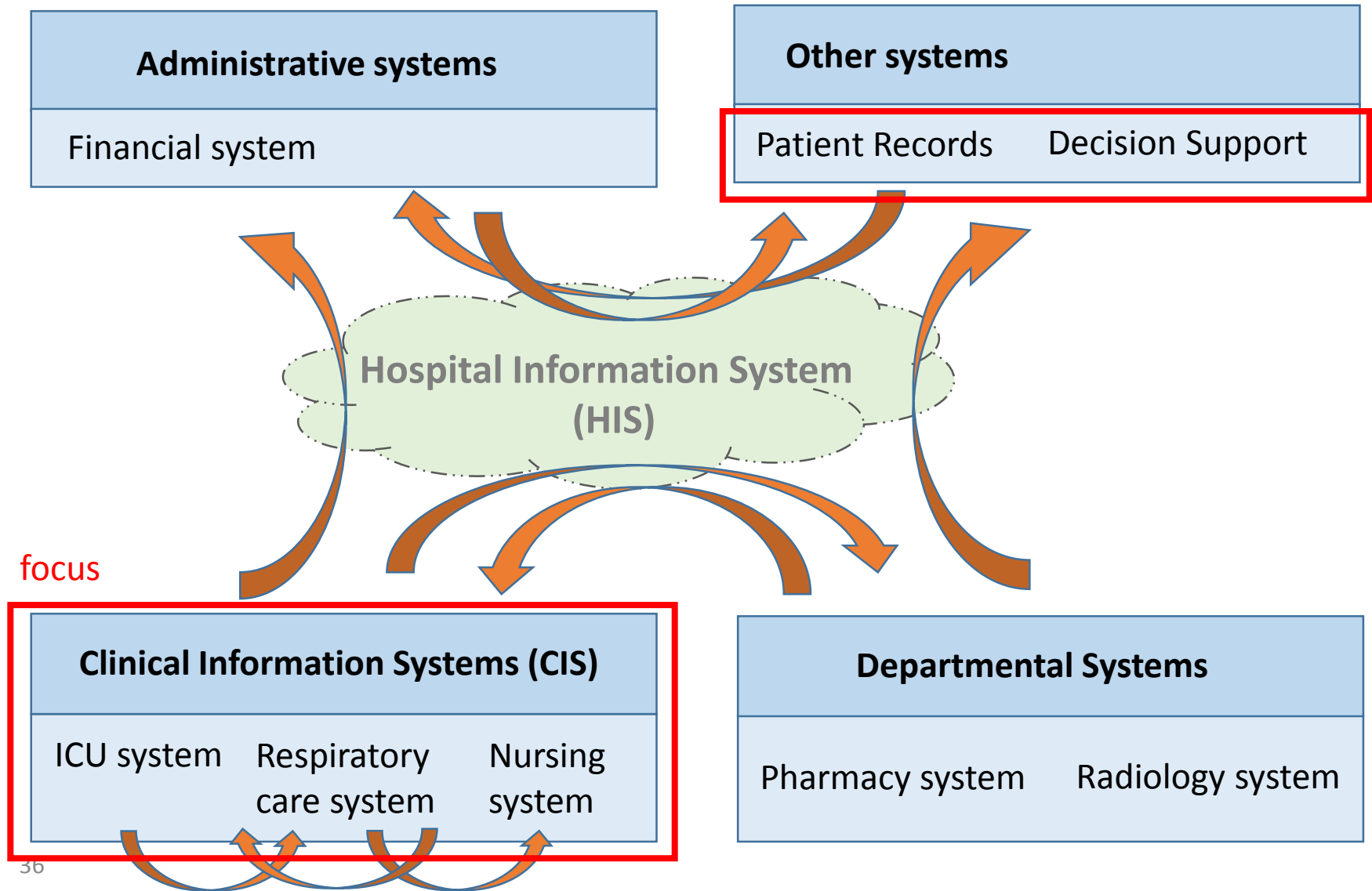
Compartmentalization

- Various types of measurements
 - Real-time patient monitoring
 - Laboratory & POC data (blood samples)
 - Billing, diagnostic & procedure codes
 - Imaging results
- Individual systems, no universal HIS
- Numerous devices / screens / interfaces
 - distributed, compartmented information

Data processing & storage

- Number of electronic devices steadily increasing
- Various individual systems
 - Clinical information systems
 - Electronic patient record
 - Departemental systems
 - ...
- Mostly Independent
 - Loose interconnections
 - Limited export options
 - Interconnection requires conversions between different data formats

Translation tables to map information from one system to another
(often high maintenance efforts required)



Various medical devices & interfaces



Modified from:

Crit Care Med. 2016;44(2):386-9 The Future of Critical Care Medicine: Integration and Personalization. Vincent JL.

Various Medical Devices



Intensive Monitoring
Ventilator
Infusion Pumps
Point-of-Care Monitoring
Blood Gas Analyzer
Blood Coagulation Monitoring

Neuro-Monitoring
Life-Support Devices
Dialysis
Clinical Lab
(Image-based Information)



Problems for data integration?

- Data collection
 - Complex information to be transmitted
 - Different manufacturers
 - Limited interconnection
 - Various different communication protocols & formats

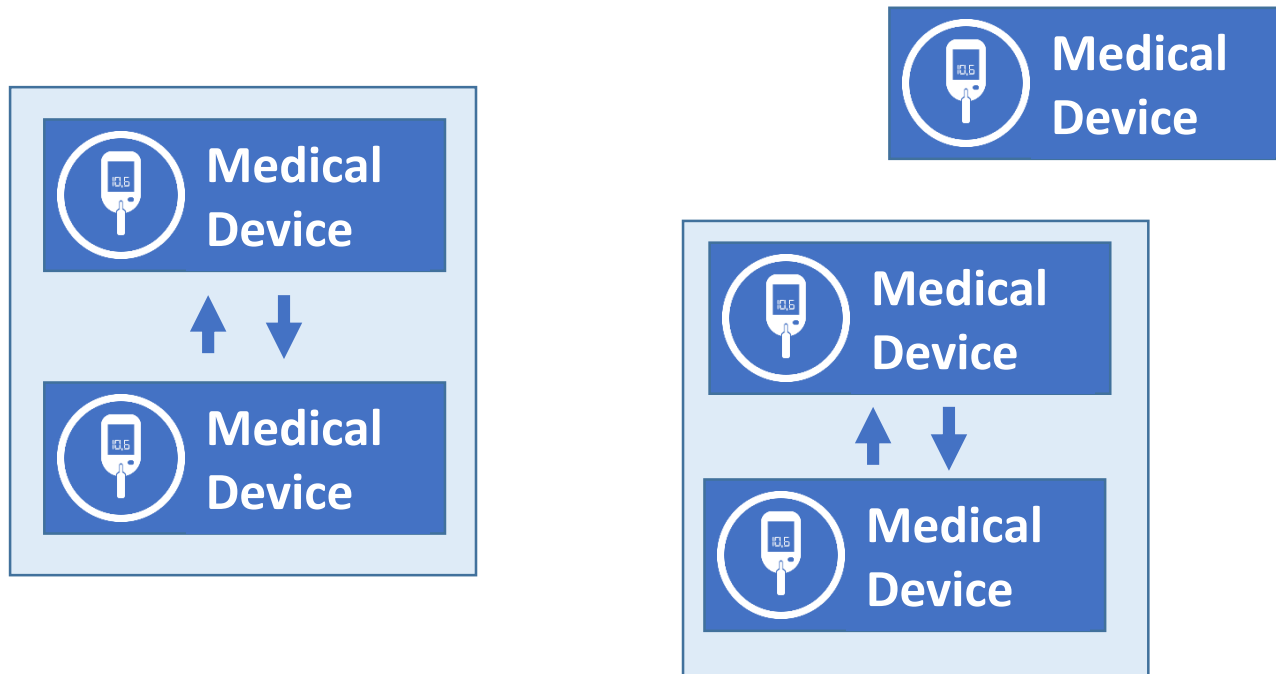
Heterogenous landscape

- Devices developed independently



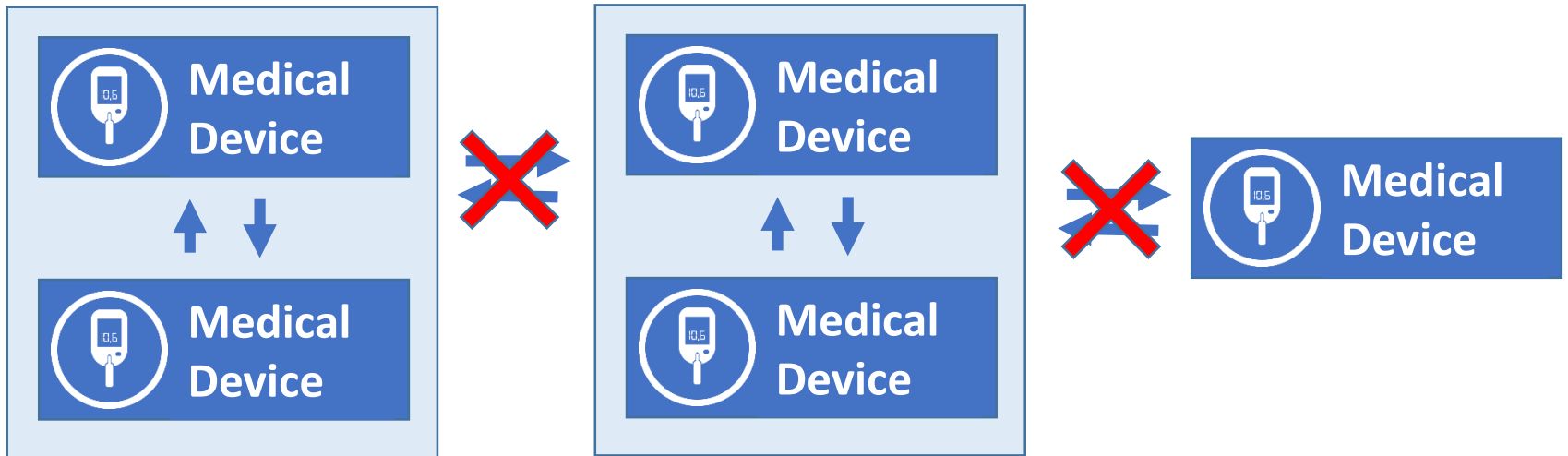
Heterogenous landscape

- Devices developed independently
- Different manufacturers



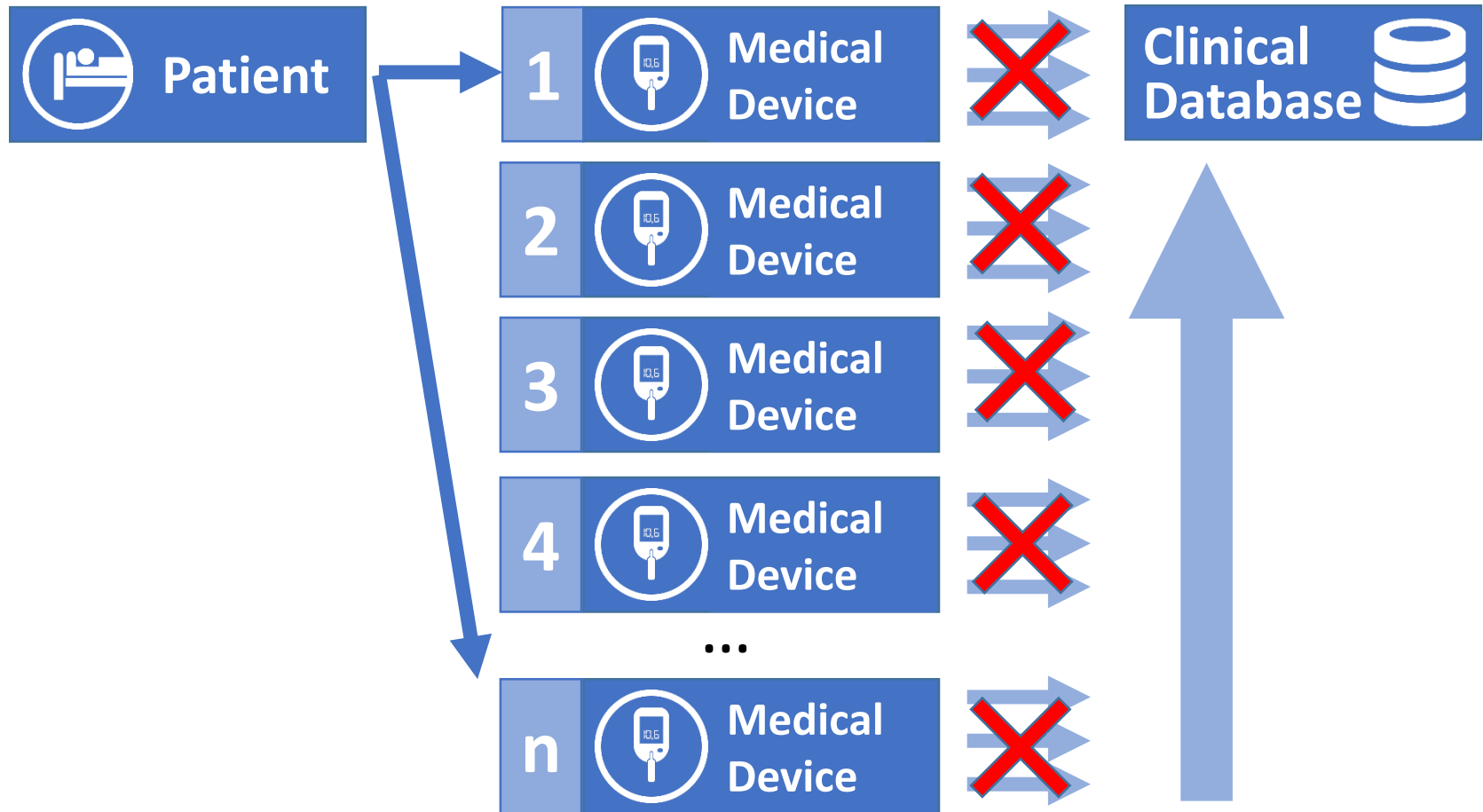
Heterogenous landscape

- Devices developed independently
 - Different manufacturers
- limited or missing compatability
- various device clusters



Result:

Limited interconnection



Data integration challenges

- Various manufacturers
- Limited availability of data from medical devices
 - Numerous interfaces to devices
 - Serial
 - Ethernet
 - ...
 - Numerous „standards“ & protocols
 - Limited export options
 - Still many manual processing steps

Clinical standardization approaches

- Examples:

- Health Level Seven (HL7) <http://www.hl7.org>



- ISO/IEEE 11073
Health informatics - Medical / health device
communication standards
 - DICOM
Digital Imaging and Communications in Medicine

Example: HL7 (v2)

- Originally created in 1989
- Message-based standard
- Text & delimiter based („|“ pipe character)

```
MSH|^~\&|Sen|SFac|Rec|RFac|20171010090105|  
|ADT|0123|P|2.5
```

Example: HL7 (v2)

- Different Message types

ADT: Admission, Discharge, Transfer

ORM: Order Message

ORR: Order Response

ORU: Observation Result Unsolicited

MDM: Medical Document Management

DFT: Detailed Financial Transaction

BAR: Billing Account Record

...

Example: HL7 (v2)

- Different Segment types

EVN: Event Type

MSH: Message Header

OBR: Observation Request

OBX: Observation Result

ORC: Common Order

PID: Patient Identification

PV1: Patient Visit

SFT: Software Segment

...

Example: HL7 (v2)

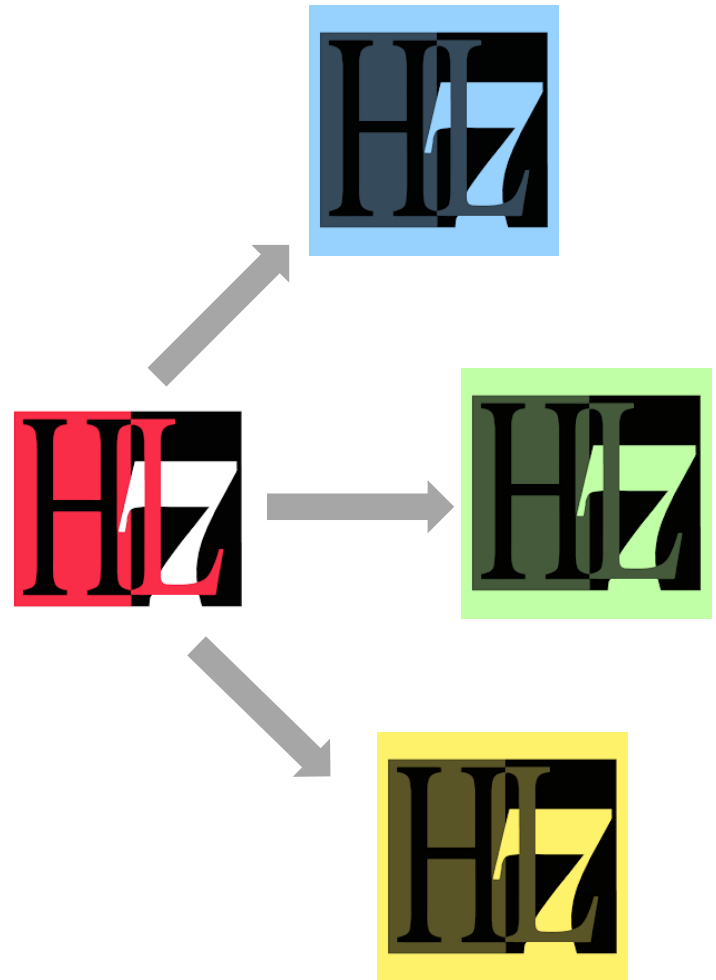
- Admission message example (abbreviated):

Header	Sender / Receiver	Data	Message-Type	-ID	Ver
MSH	^~\& Sen SFac Rec RFac 20171010090105		ADT	0123	P 2.5
Date					
EVN	201710100901	201710100901			
Patient ID List Name DOB Address					
PID	1234567	DOE^JOHN	19870605 M	100 Main Street	
Patient Class, Location, Attending Doctor Admission Date					
PV1	I W^123^1^BED^	3	12345^HOUSE^Gregory^	^MD ... 201710100900	
OBX 1 NM ^Body Height					
	1.80 m^Meter^ISO+	F			
OBX 2 NM ^Body Weight					
	79 kg^Kilogram^ISO+	F			

Example: HL7

- However, different versions:
 - HL7 V2
 - Delimiter-based
 - HL7 V3
 - XML-based
 - Extensible Markup Language

```
<block>  
  <key>value</key>  
  <key code=123>value2</key>  
</block>
```



Problems for data integration?

- Data collection
 - Complex information to be transmitted
 - Different manufacturers
 - Limited interconnection
 - Various different communication protocols & formats
- Data availability
 - Limited access to patient information & parameters
 - No automated measurement devices

Limited availability of data



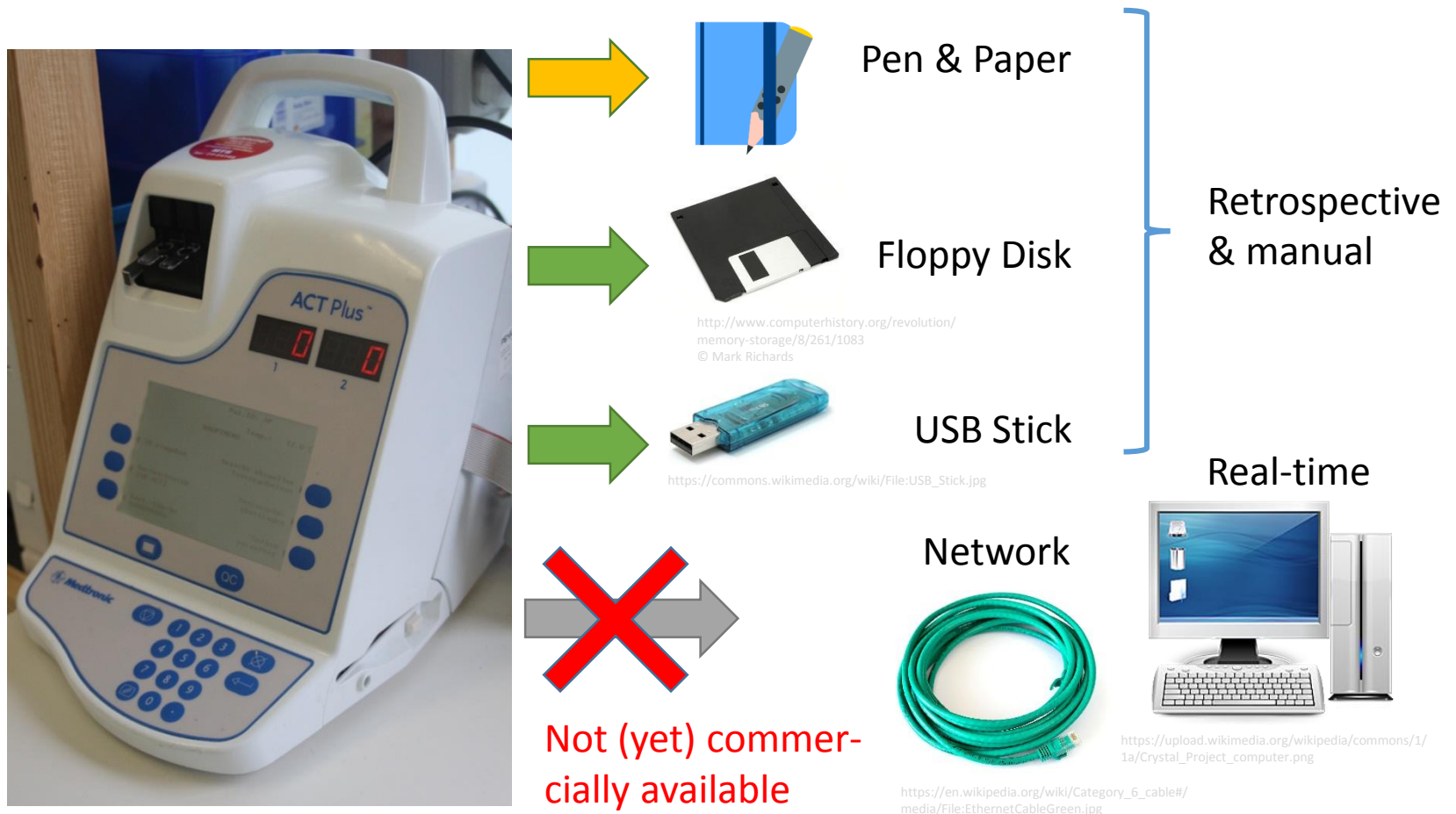
No standard can help if data isn't collected or available

Examples for missing interconnection
and experimental solutions at the Schenk Lab:

- Clotting time measurements
- Diuresis assessment

Problem: Availability of data

Example 1: Point-of-care ACT measurement



Problem: Availability of data

Example 1: Point-of-care ACT measurement

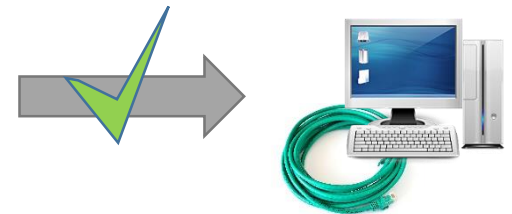
Solution:

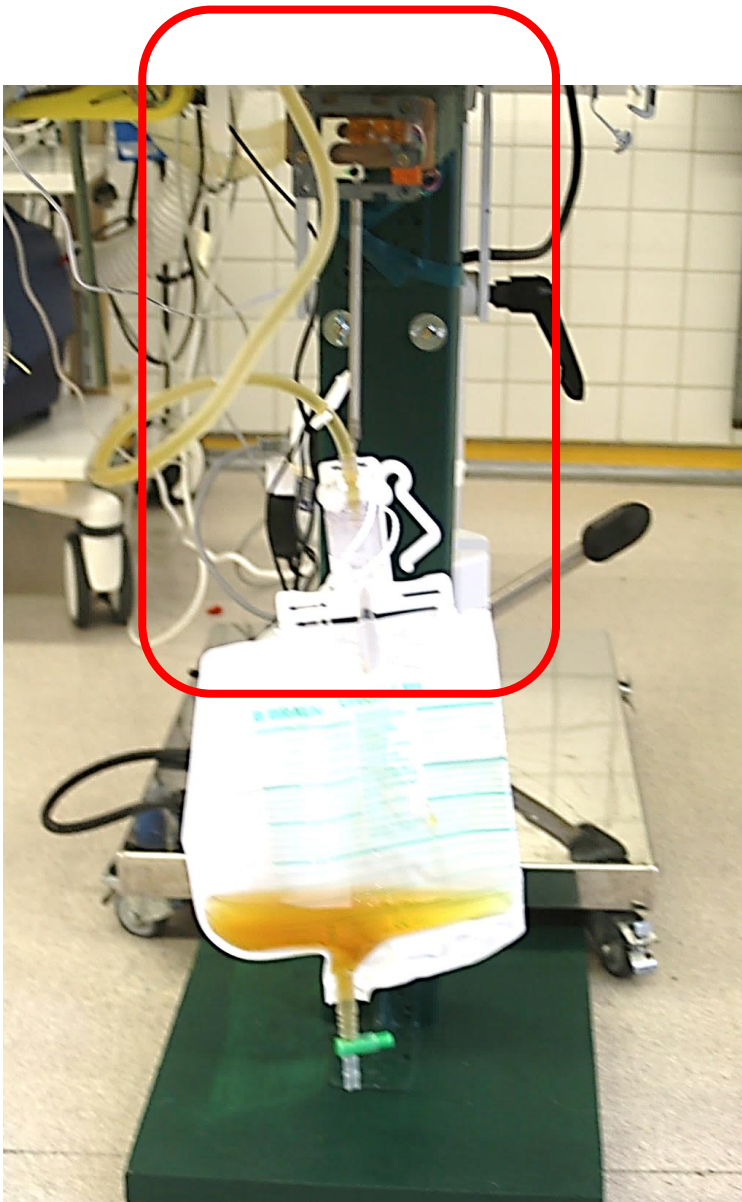


Signal extraction with
Converter board &
Network transmission
with Raspberry Pi
micro-computer



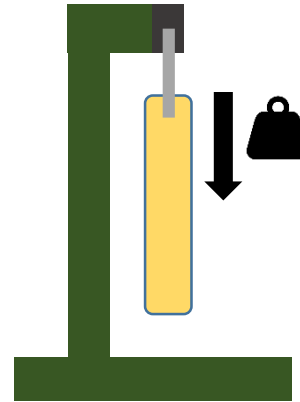
https://en.wikipedia.org/wiki/Raspberry_Pi#/media/File:Raspberry-Pi-3-Flat-Top.jpg





Solution:

Urine collection bag
suspended on a load cell
for weight measurement



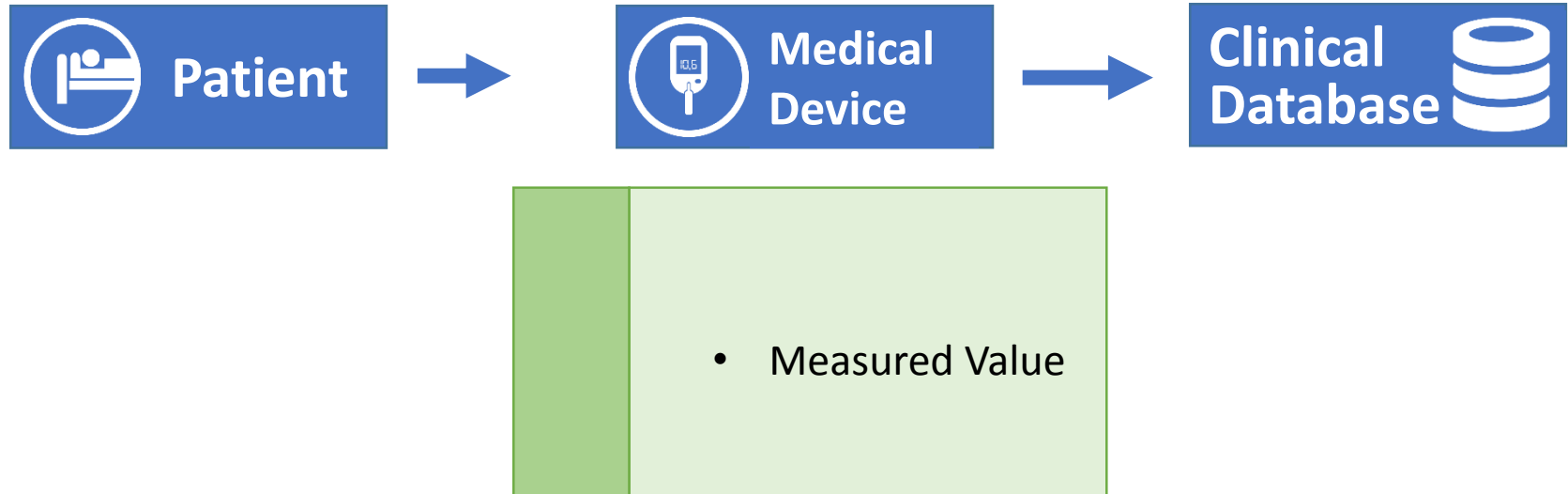
Automatic processing
& storage of the
measurements
by serial communication
with a computer



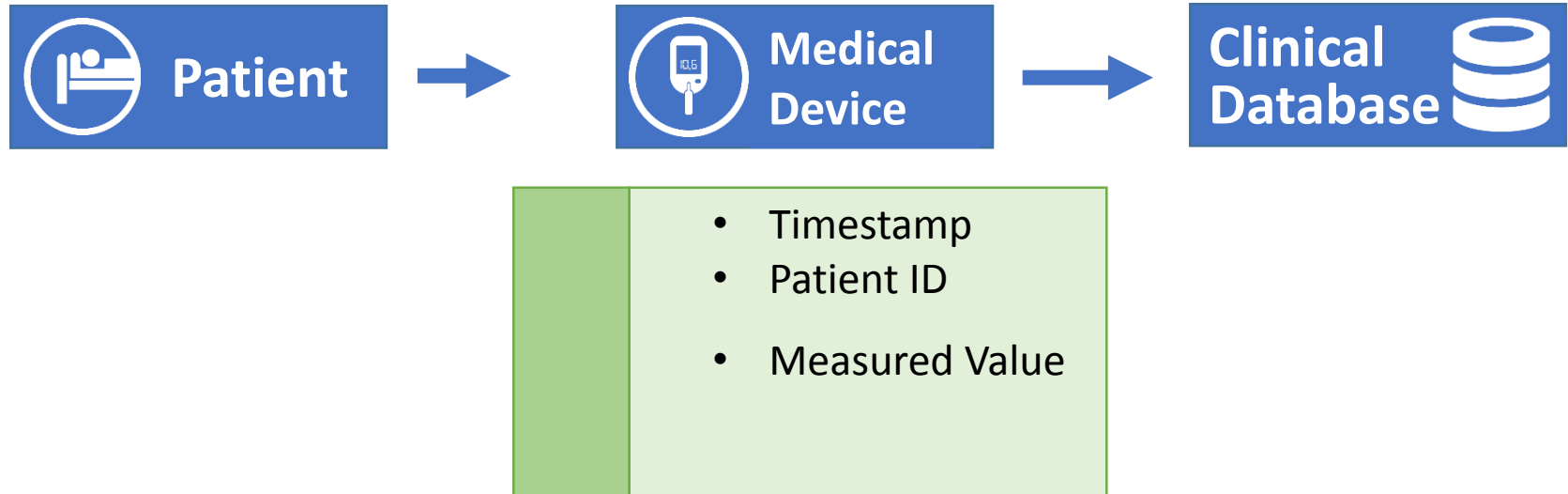
Problems for data integration?

- Data collection
 - Complex information to be transmitted
 - Different manufacturers
 - Limited interconnection
 - Various different communication protocols & formats
- Data availability
 - Limited access to patient information & parameters
 - No automated measurement devices
- Data storage & further processing
 - Databases for huge amounts of data required
 - Potentially Incomplete, corrupted data

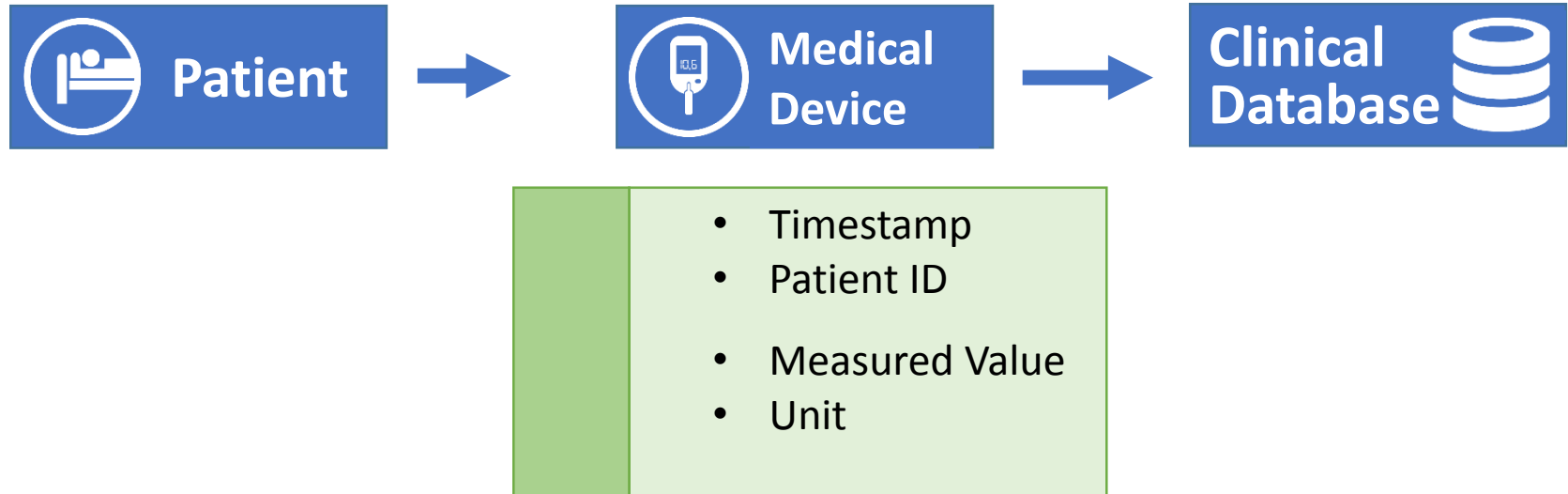
Data variety & complexity



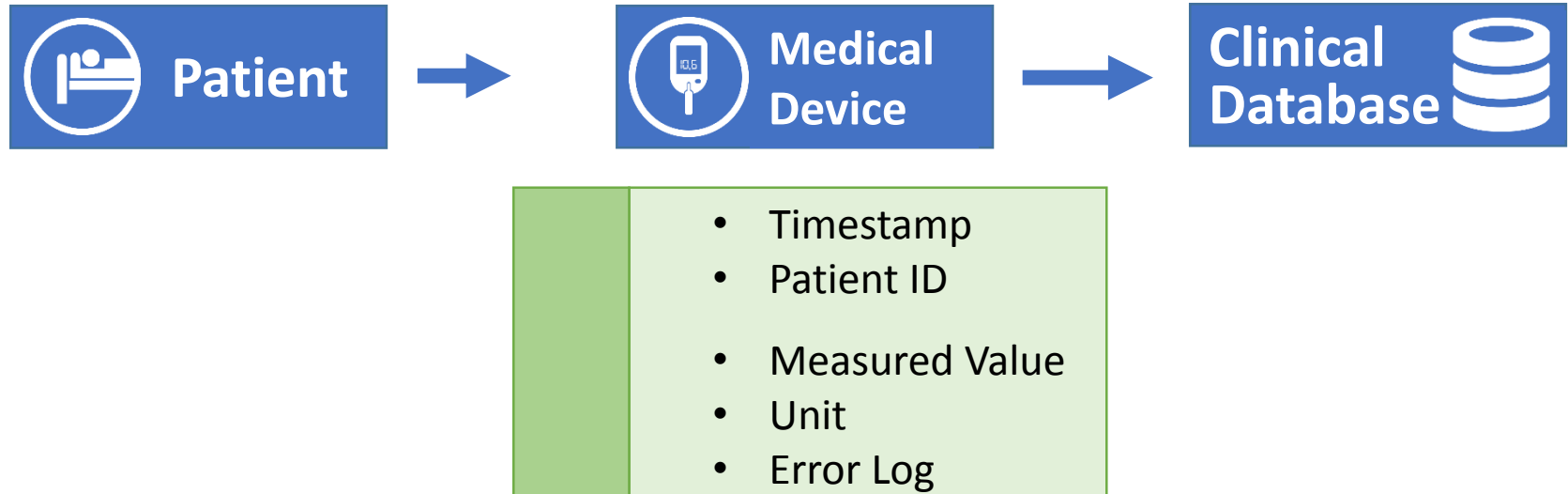
Data variety & complexity



Data variety & complexity



Data variety & complexity



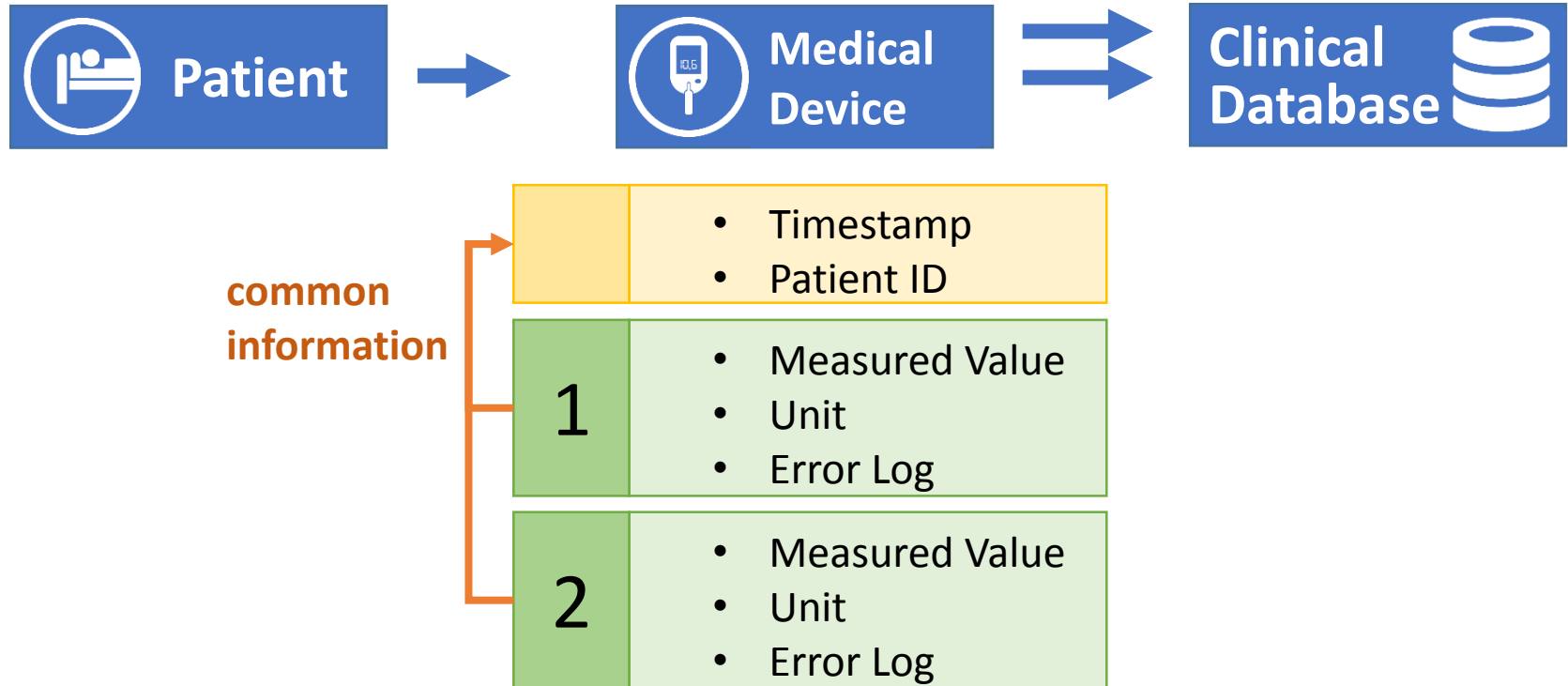
Data variety & complexity



1	• Timestamp • Patient ID • Measured Value • Unit • Error Log
---	--

2	• Timestamp • Patient ID • Measured Value • Unit • Error Log
---	--

Data variety & complexity

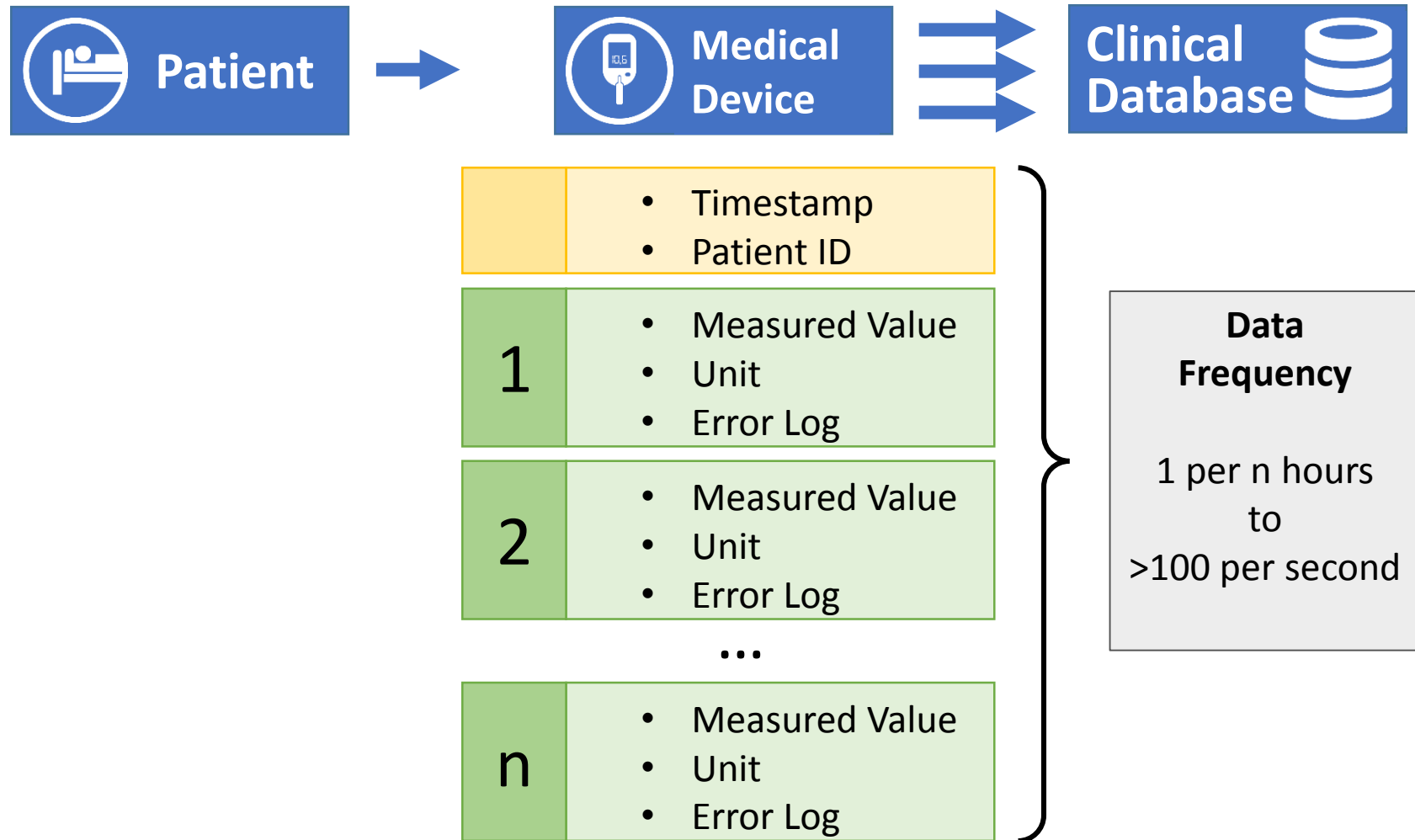


Data variety & complexity

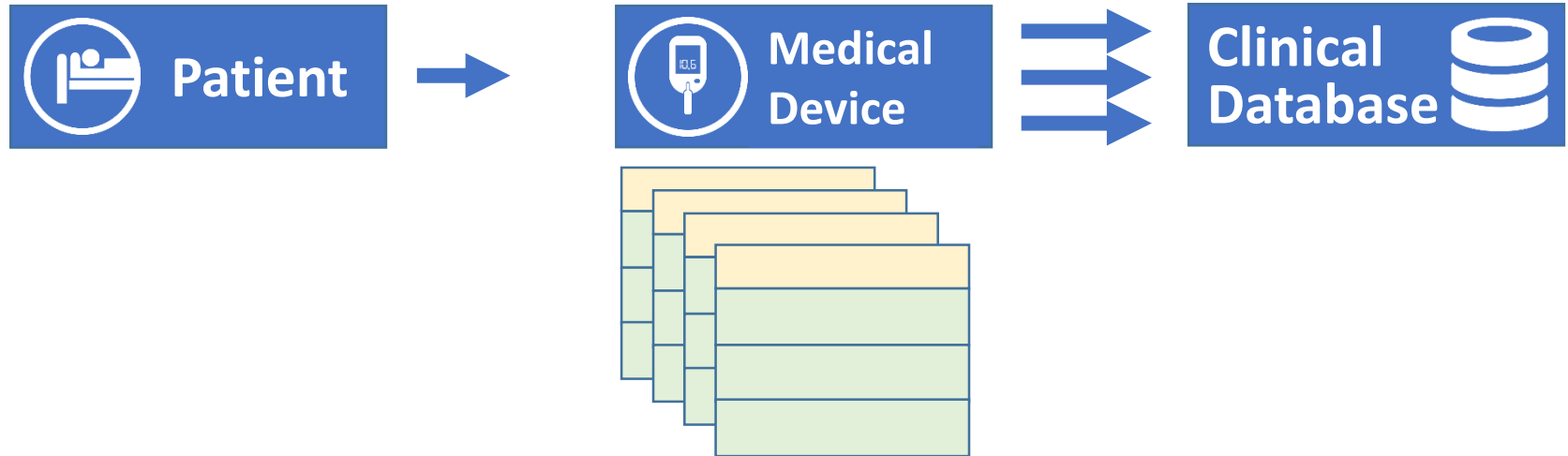


	• Timestamp • Patient ID
1	• Measured Value • Unit • Error Log
2	• Measured Value • Unit • Error Log
...	
n	• Measured Value • Unit • Error Log

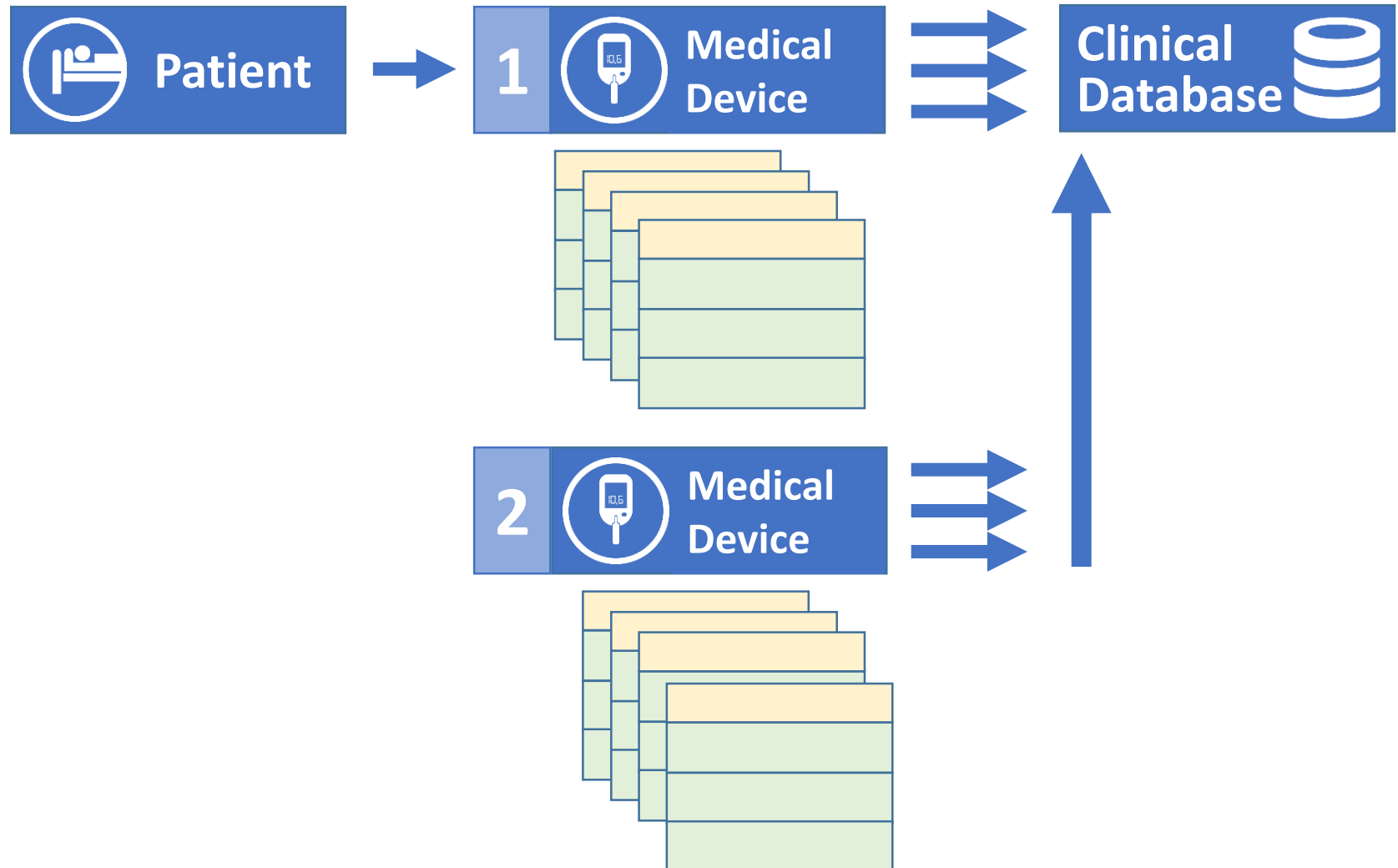
Data variety & complexity



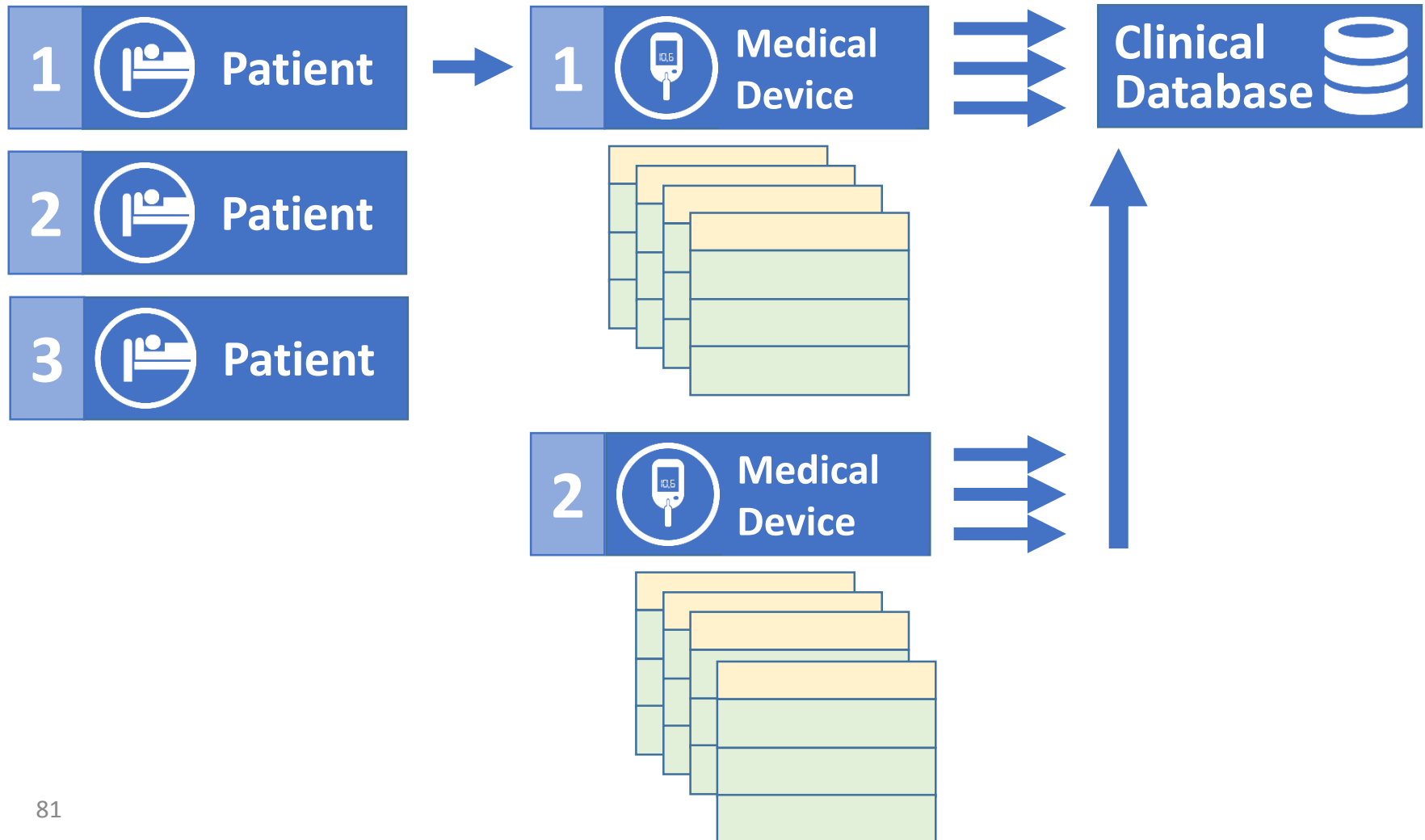
Data variety & complexity



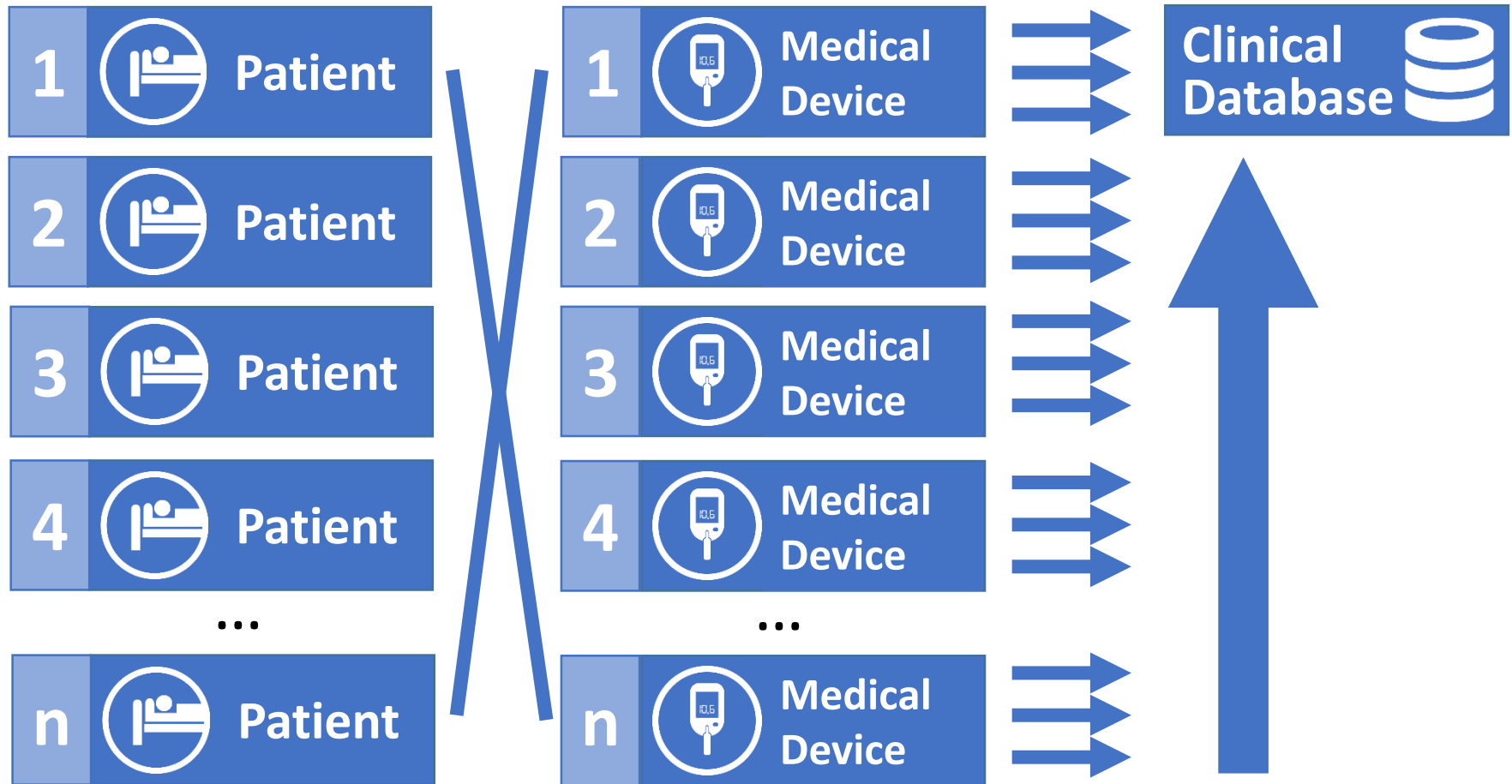
Data variety & complexity



Data variety & complexity



Data variety & complexity



Data corruption

- Data most often collected to guide caregivers and document clinical activity for reporting, liability, and billing reasons

But not: to facilitate analysis & research (*„secondary“ use*)

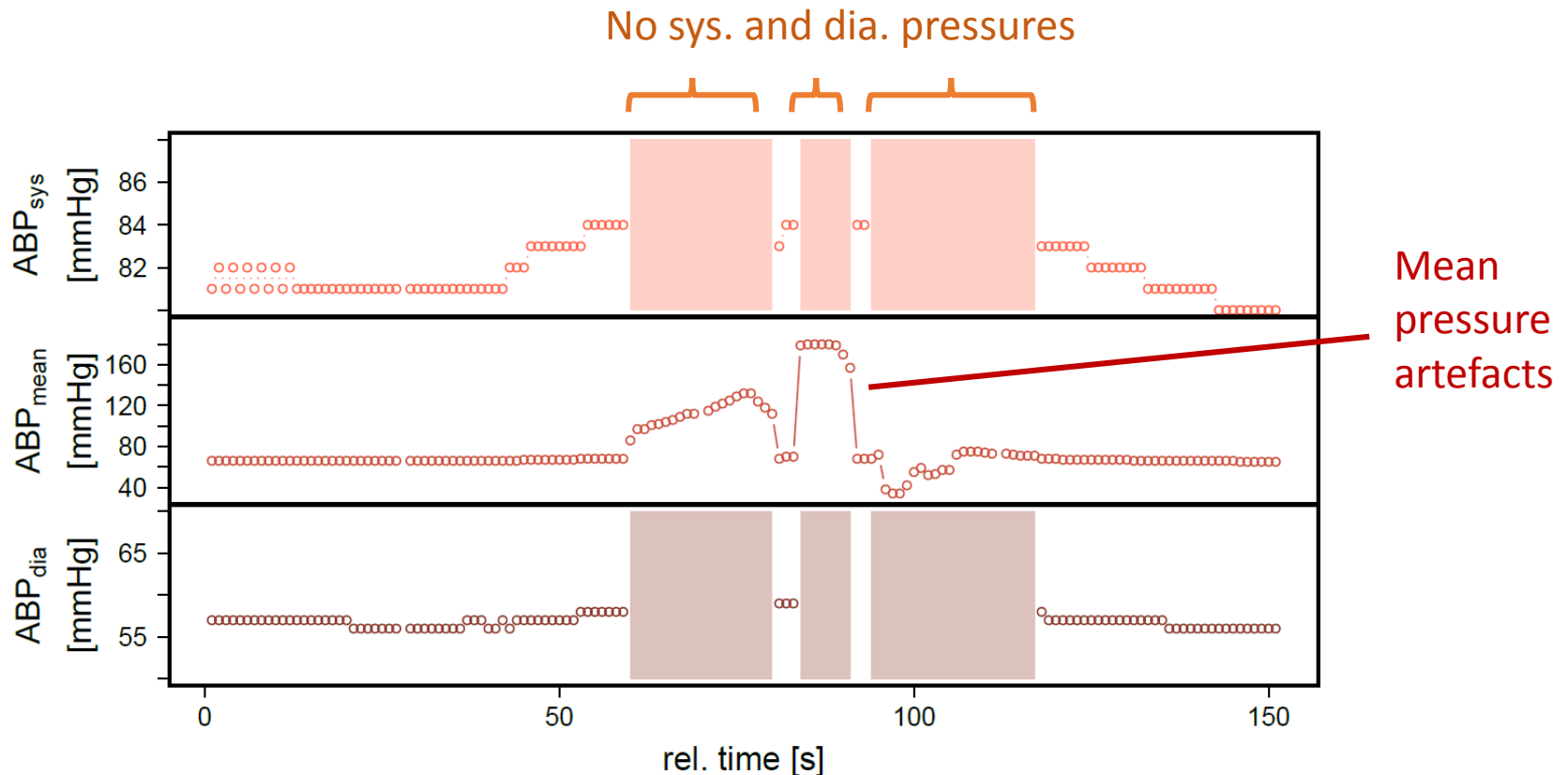
- Automatically collected data must be handled with care!
 - Missing data
 - Erroneous data
 - Impercise data

Example: sensor corruption

- Sensor drop-offs
- Artifacts
- Treatment interventions
- Incomplete measurements

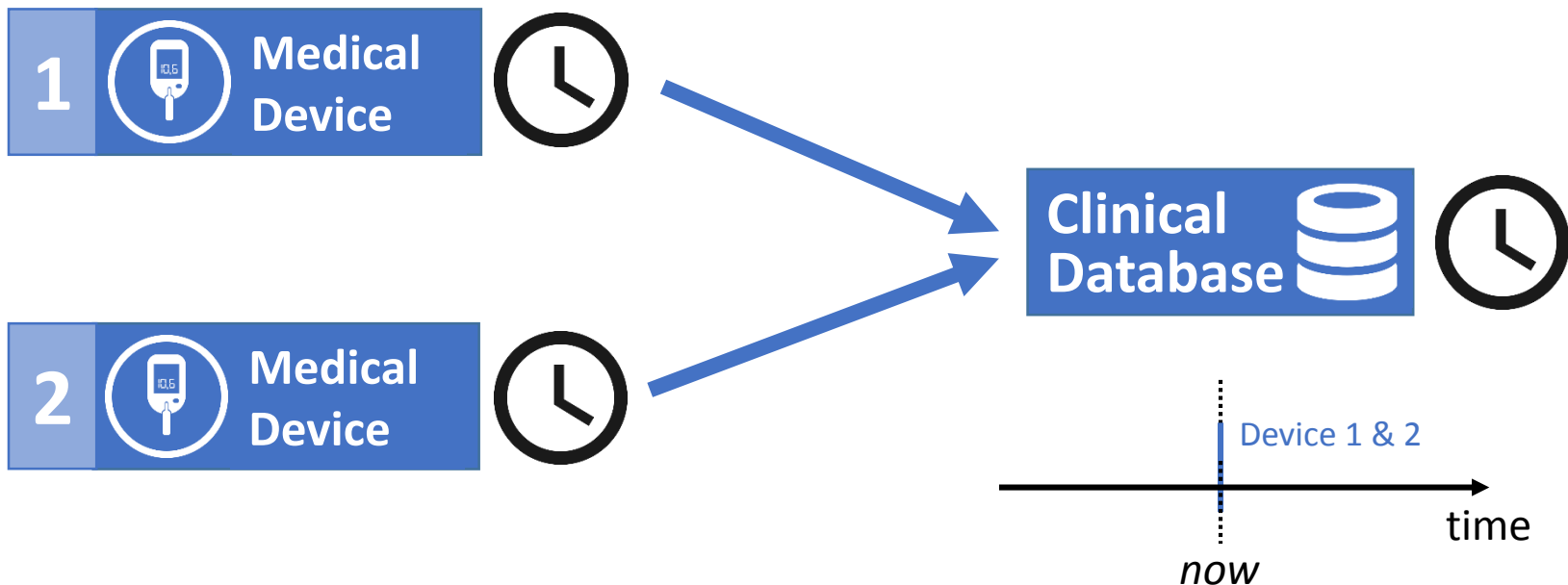
Artefact & missing data example

Arterial pressures during blood withdrawal from same access (three-way tap)



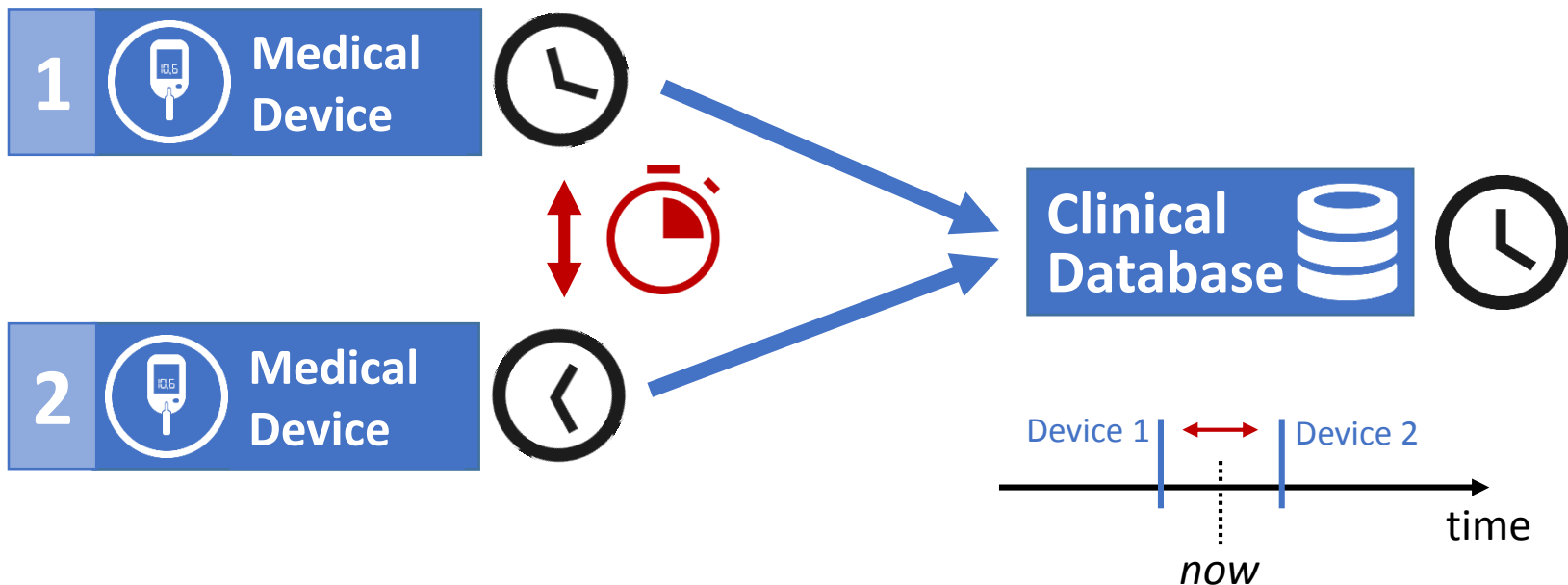
Data registration

- Data from different sources needs to be matched to each other in the time domain

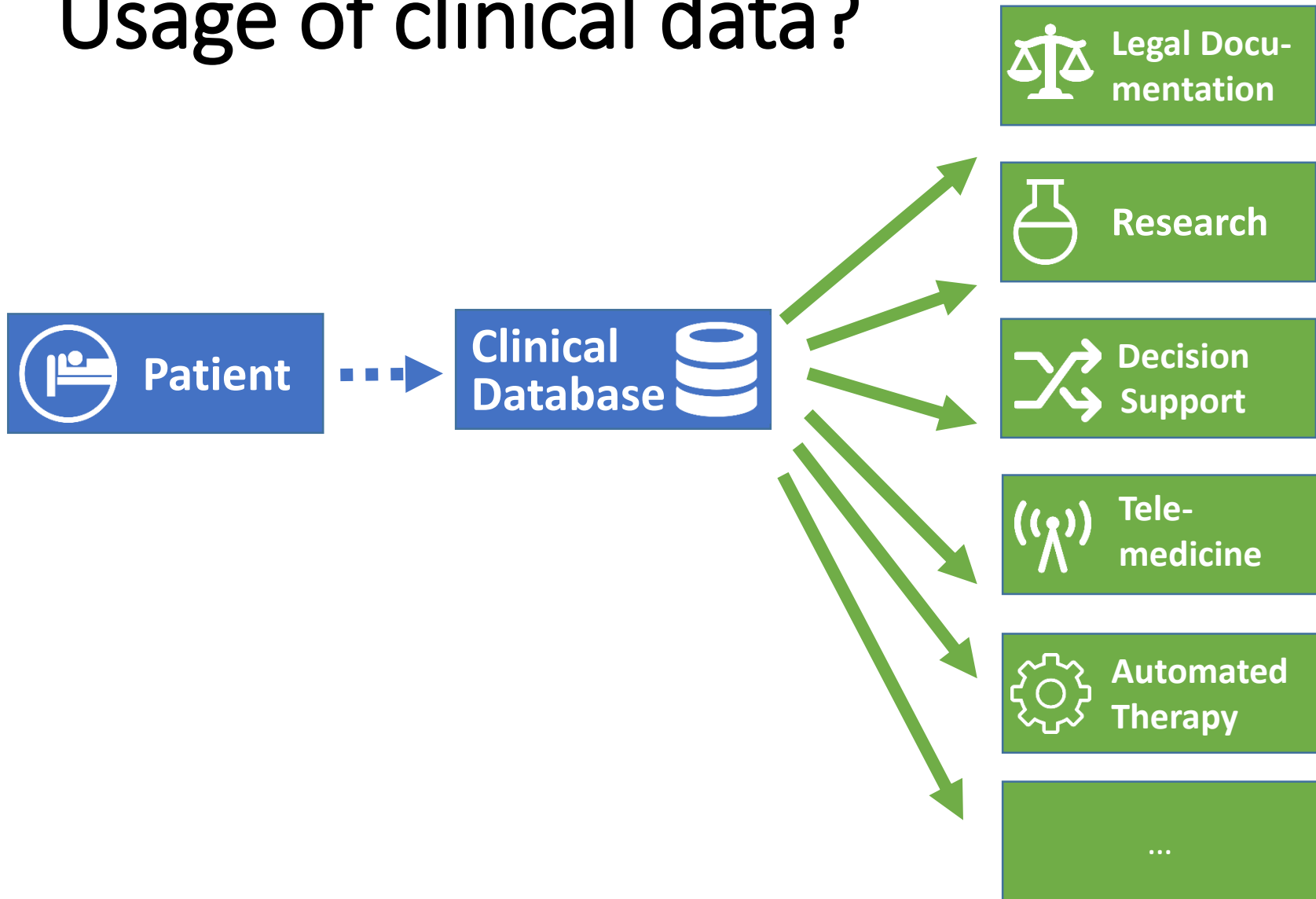


Data registration

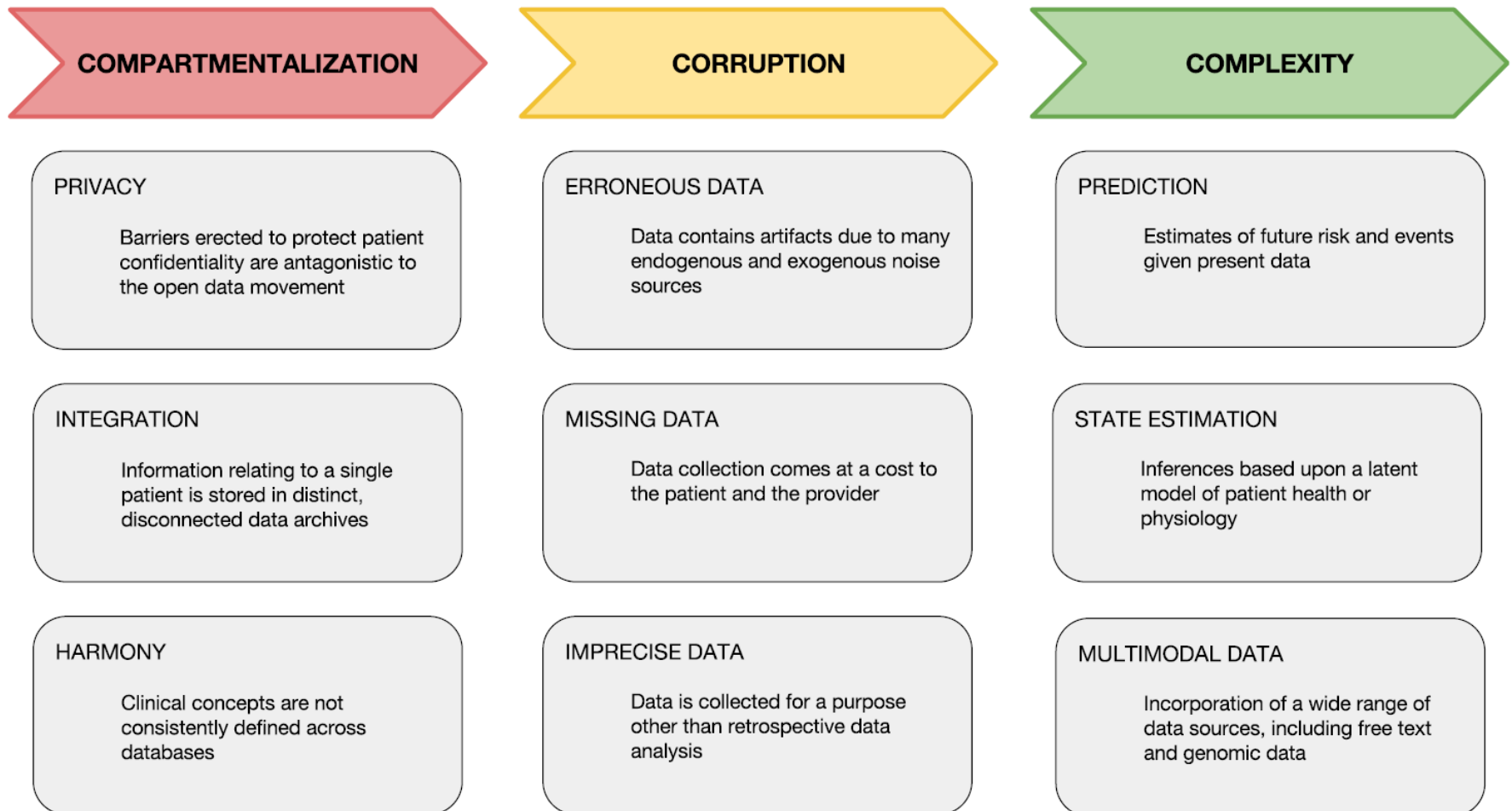
- Data from different sources needs to be matched to each other in the time domain
- Problem for time-critical applications



Usage of clinical data?



Major challenges for processing & analysis



from: Johnson et al. *Machine Learning and Decision Support in Critical Care Proceedings of the IEEE* Vol. 104 Issue 2 Feb 2016 p. 444 -- 466

Summary

- Complex, heterogenous environment
 - Difficult to gather the required data
 - Still a long way to complete HIS
- Complex, incomplete & corrupted data
 - Automated processing requires validations
 - Manual therapeutic interactions / data artifacts
- Different data needs
 - Intended further usage defines the most important aspects
- ➔ Data integration is an important challenge for the next decade(s)
 - Needed for digital health and personalized medicine
 - Different interests of involved parties

Which way to go?

DATA

WE OFFER 3 KINDS OF SERVICES

GOOD-CHEAP-FAST

BUT YOU CAN PICK ONLY TWO

GOOD & CHEAP WON'T BE **FAST**

FAST & GOOD WON'T BE **CHEAP**

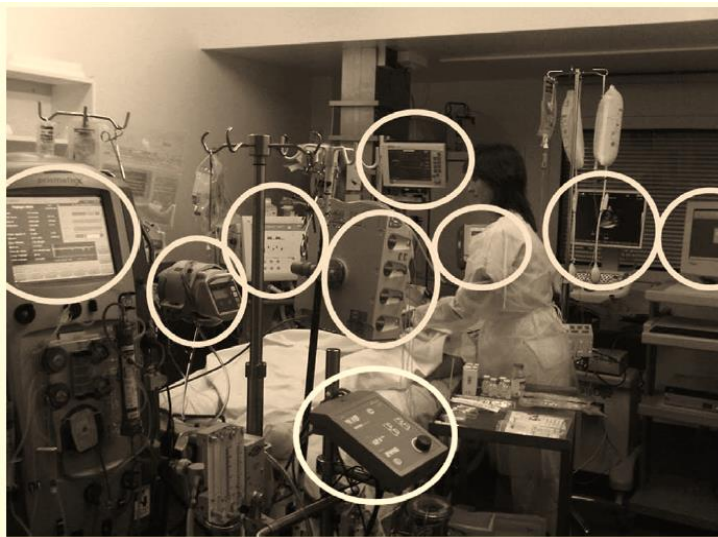
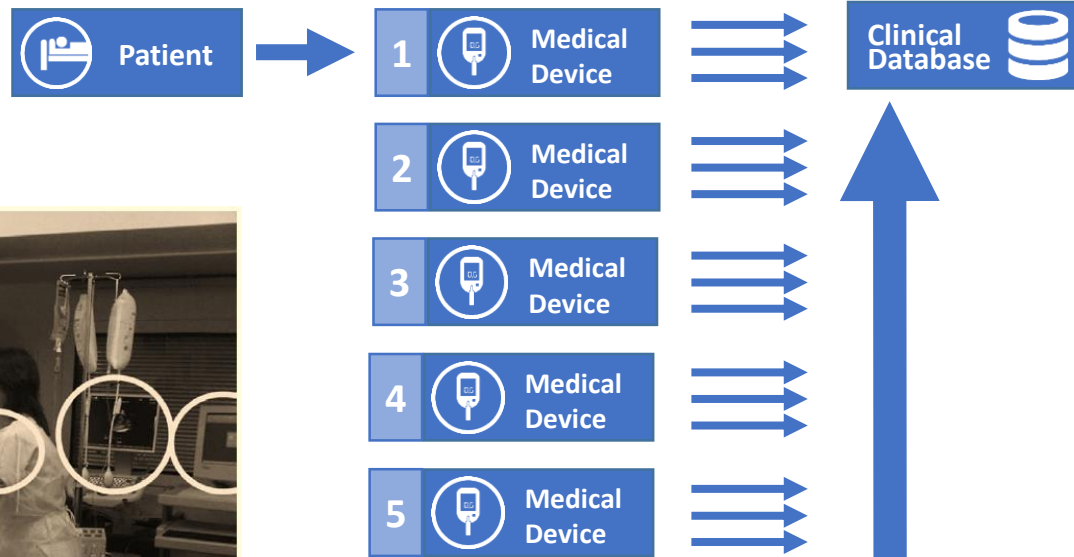
CHEAP & FAST WON'T BE **GOOD**

Modified from: <https://blog.cloudflare.com/the-trouble-with-tor/>

Experimental Research

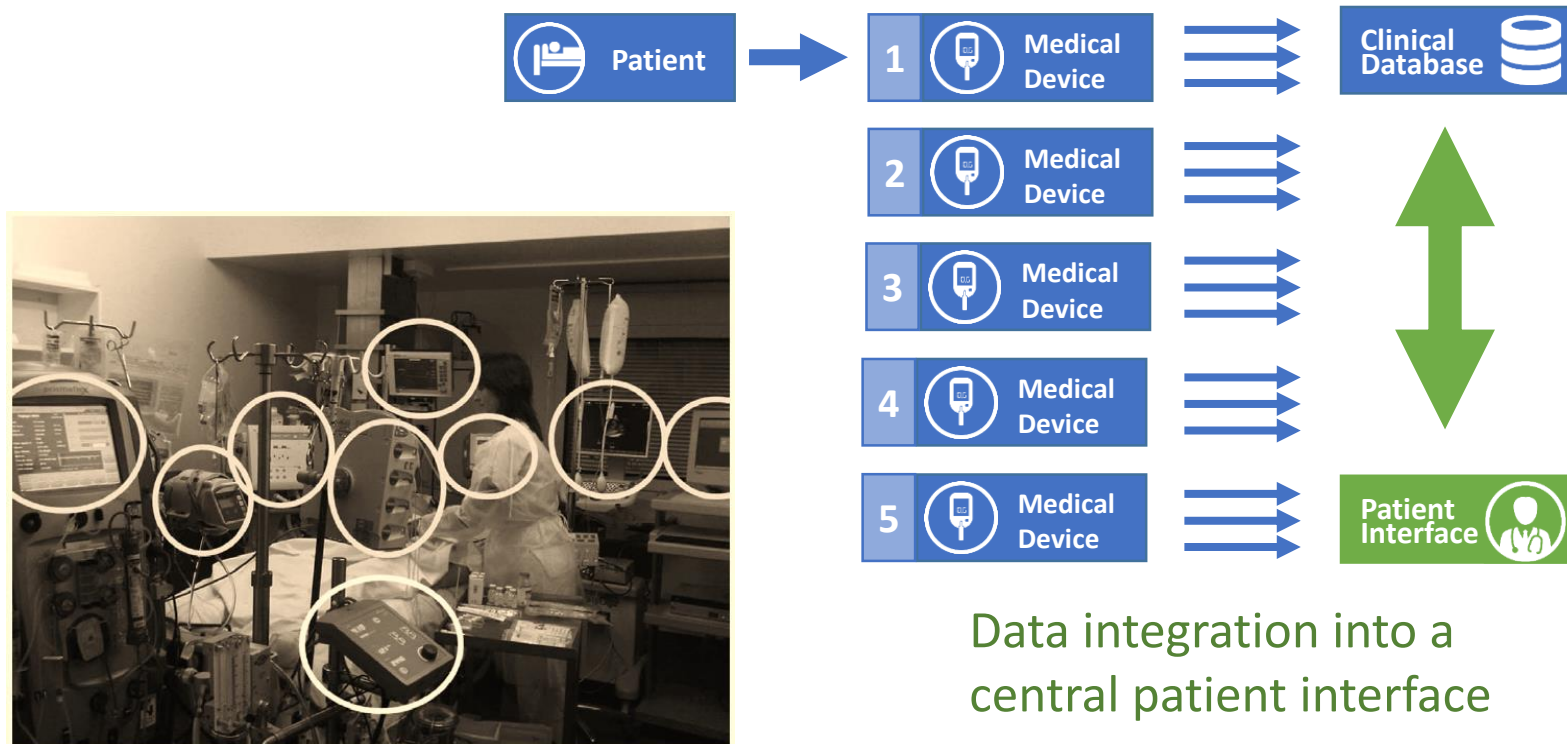
Outlook into a possible future with data integration

Distributed Information

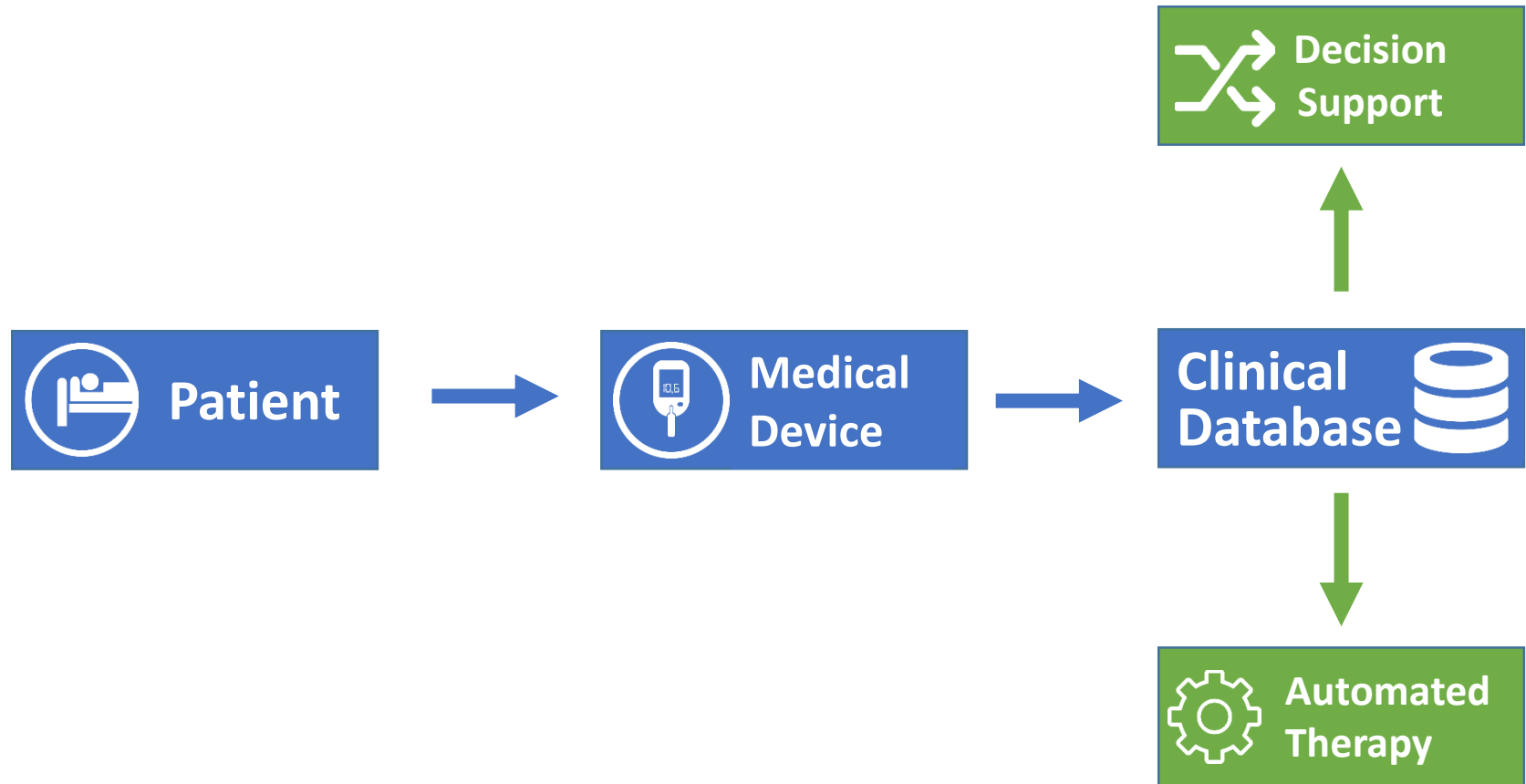


Modified from:
Crit Care Med. 2016;44(2):386-9 The Future of Critical Care Medicine:
Integration and Personalization. Vincent JL.

Distributed Information



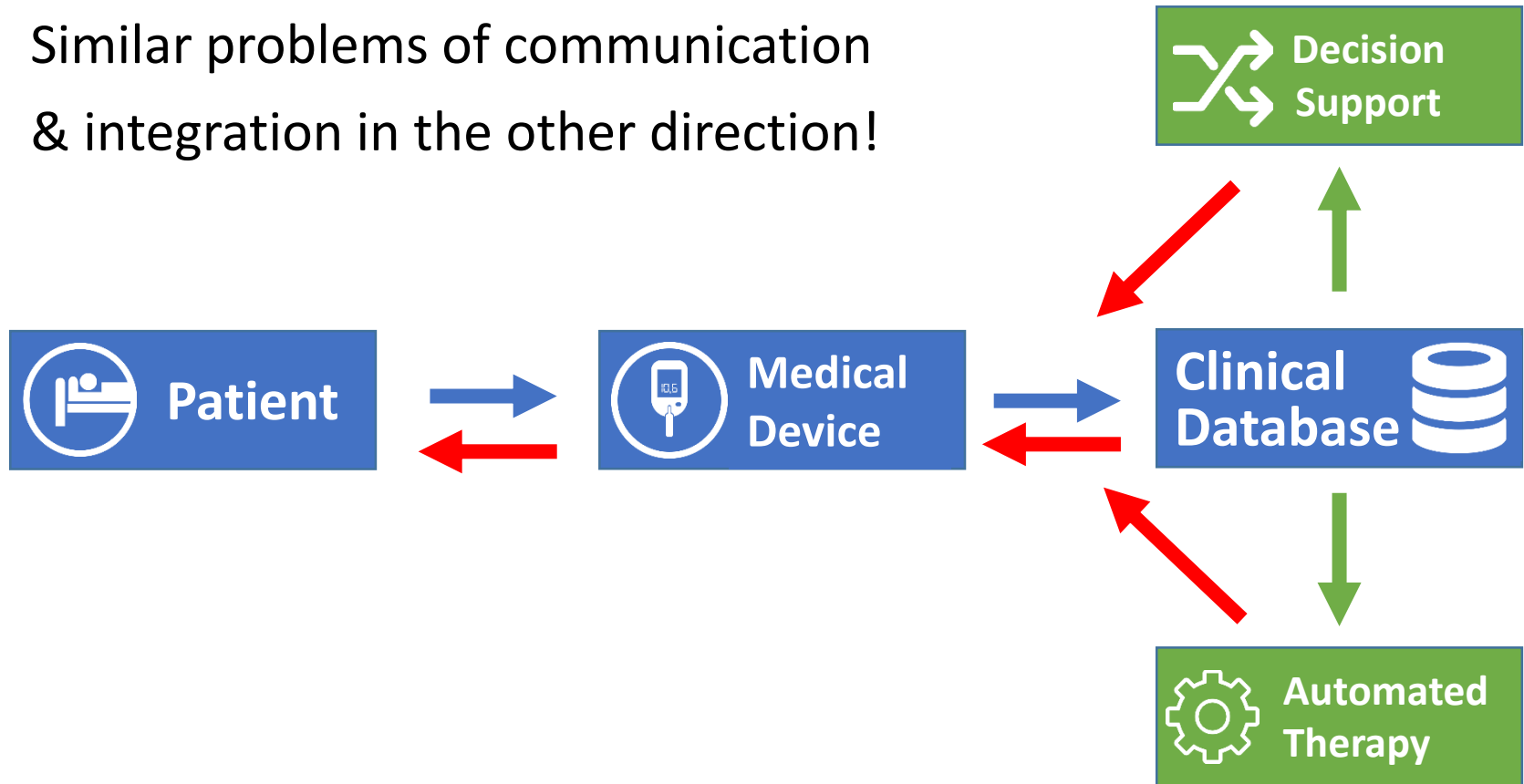
Assisted / Automated Therapy



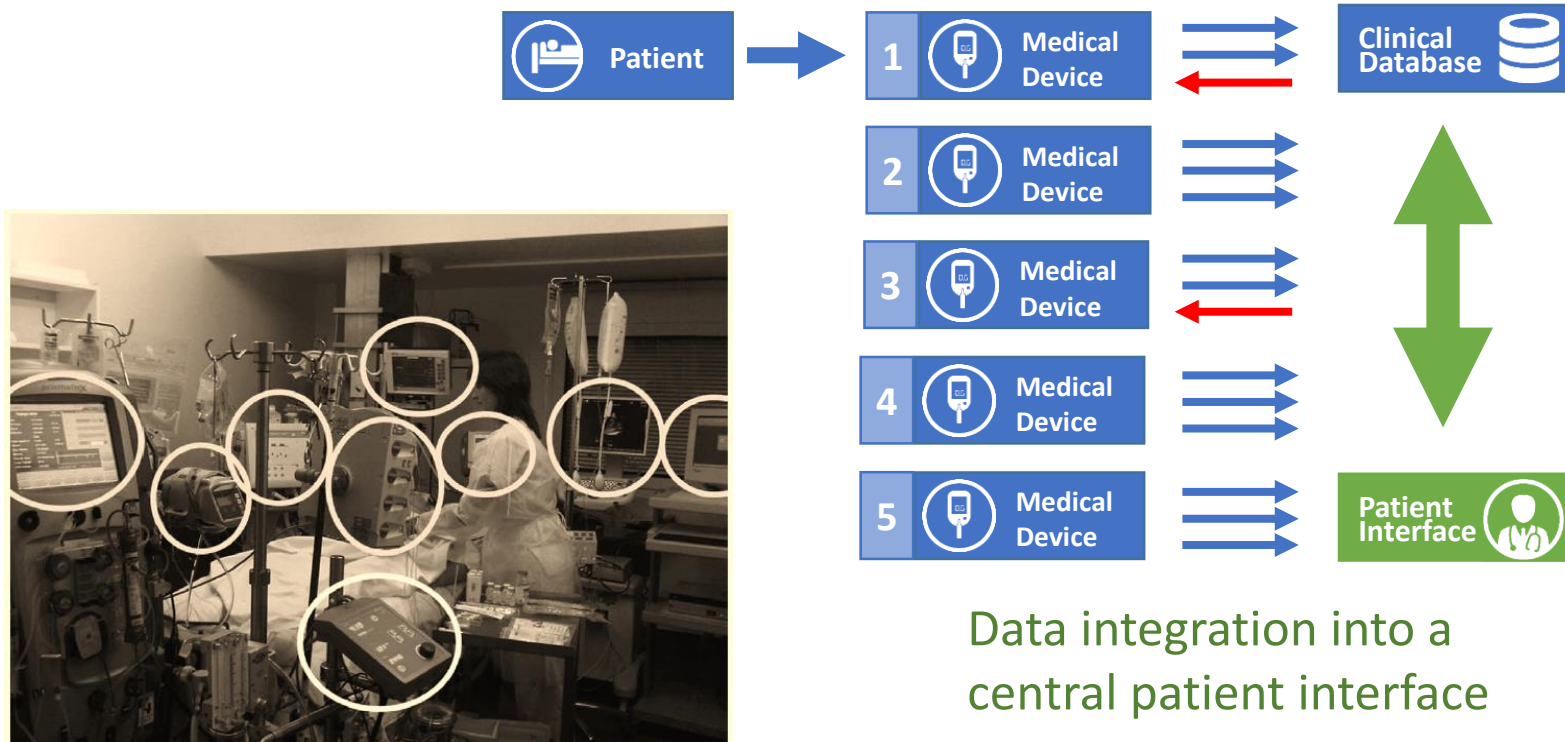
Assisted / Automated Therapy

How to control medical devices?

Similar problems of communication
& integration in the other direction!



Assisted / Automated Therapy



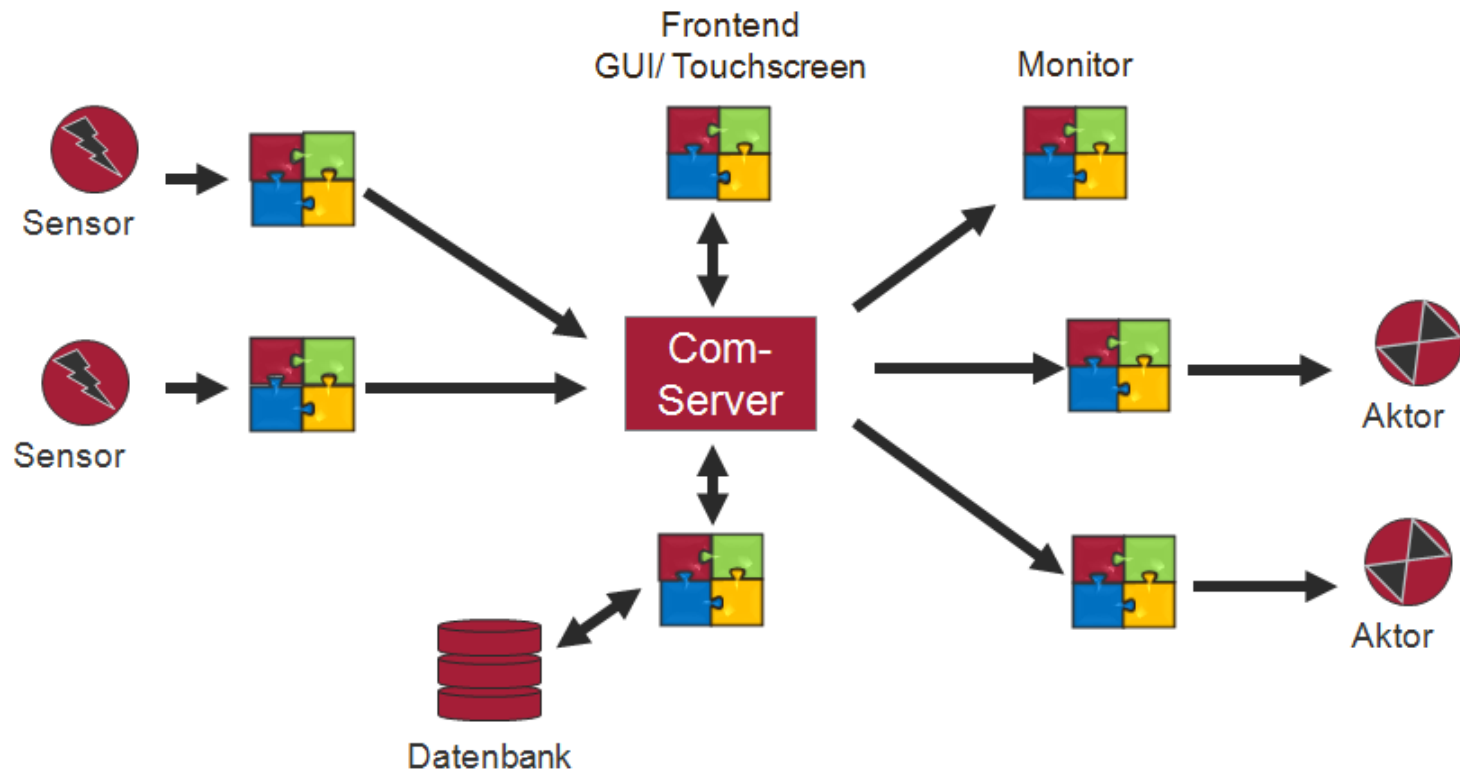
Monitoring &
control

Experimental research

- Establishment of data collection
 - Accessing device interfaces
 - Novel data collection (ACT, Diuresis, ...)
- Developement of integrated frameworks
 - Bridging the information gap
 - Interconnection of various medical devices
- Assisted / automated therapies
 - Goal-directed therapies
 - Closed-loop management

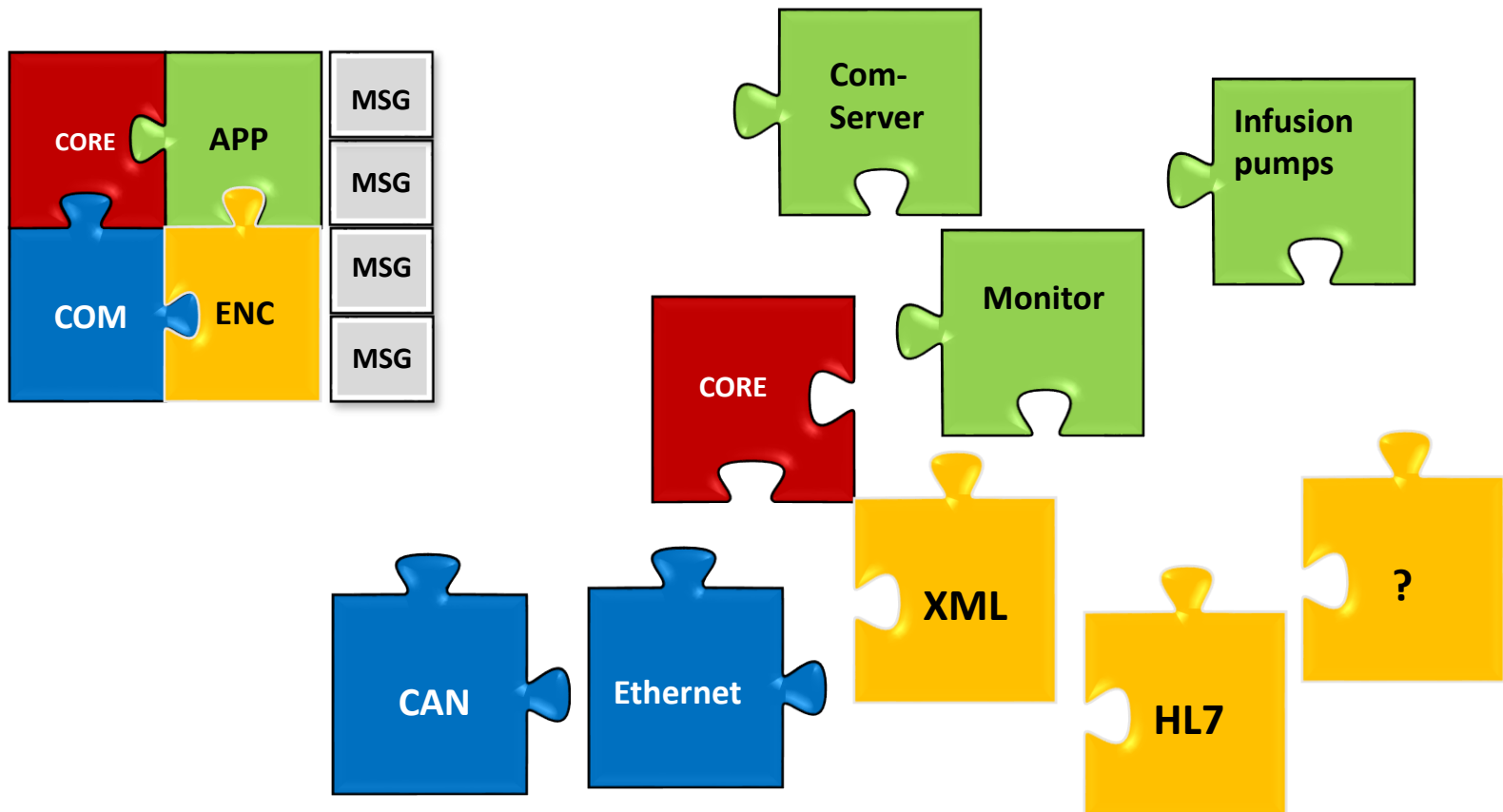
Integrated ICU Framework

Modular & reusable software components



Integrated ICU Framework

Inclusion of various applications, interfaces and devices
→ Universal system



One patient - one screen



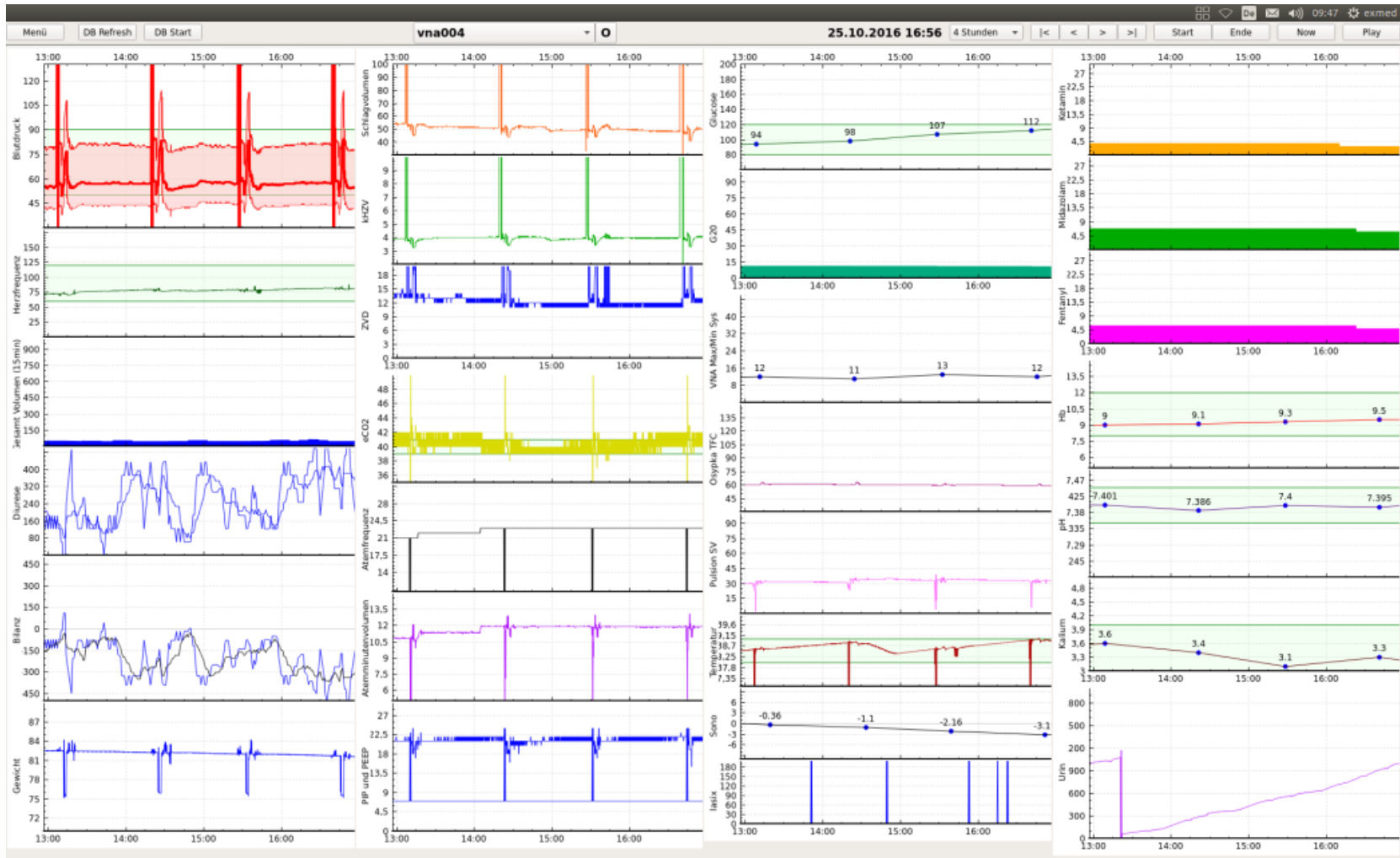
Gather all relevant patient information

- Real-time data from medical devices
- Laboratory results
- Historical data
- ...

Control medical devices & therapies

- Set infusion pumps
- Ventilator settings
- Checklists
- Stepwise therapeutic protocols
- Manouvers
- Caregiver's comments
- ...

Real-time & historic patient data



Adaptable configuration

The screenshot shows a software interface titled "Display Editieren" for configuring a medical display. The interface is organized into four columns labeled "Spalte 1" through "Spalte 4". Each column contains a list of medical parameters, each with a "Graphen löschen" (Delete Graph) button and a "bearbeiten" (Edit) button. The parameters are arranged in a grid with arrows indicating movement between columns. At the bottom, there are buttons for "Graphen hinzufügen 0", "Graphen hinzufügen 1", "Graphen hinzufügen 2", and "Graphen hinzufügen 3".

Spalte 1: Blutdruck, Herzfrequenz, Gesamt Volumen (15min), Diurese, Bilanz, Gewicht.

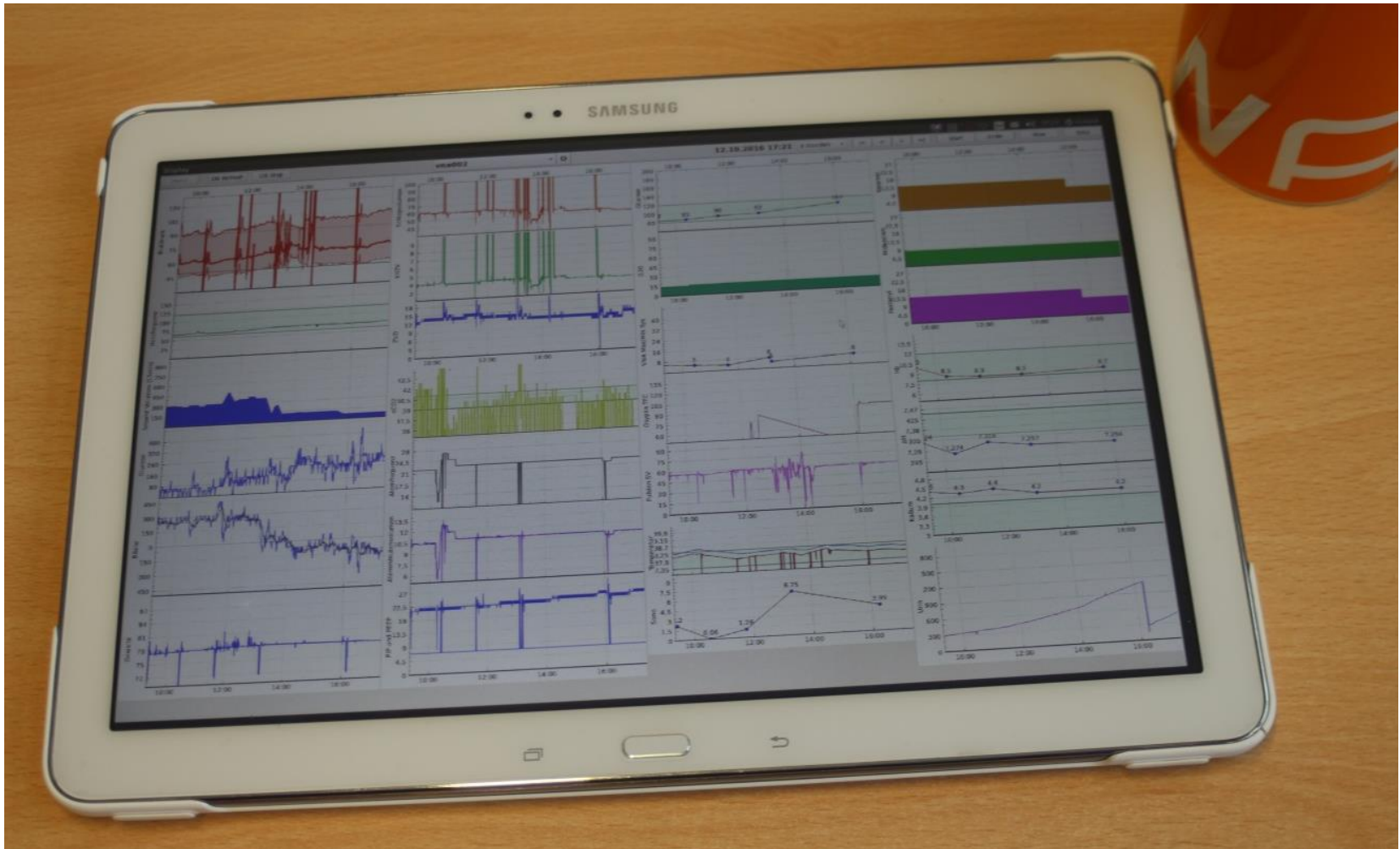
Spalte 2: Schlagvolumen, kHzV, ZVD, eCO2, Atemfrequenz, Atemminutenvolumen, PIP und PEEP.

Spalte 3: Glucose, G20, VNA Max/Min Sys, Oxygka TFC, Pulsion SV, Temperatur, Sono, lasix.

Spalte 4: Ketamin, Midazolam, Fentanyl, Hb, pH, Kalium, Urin.

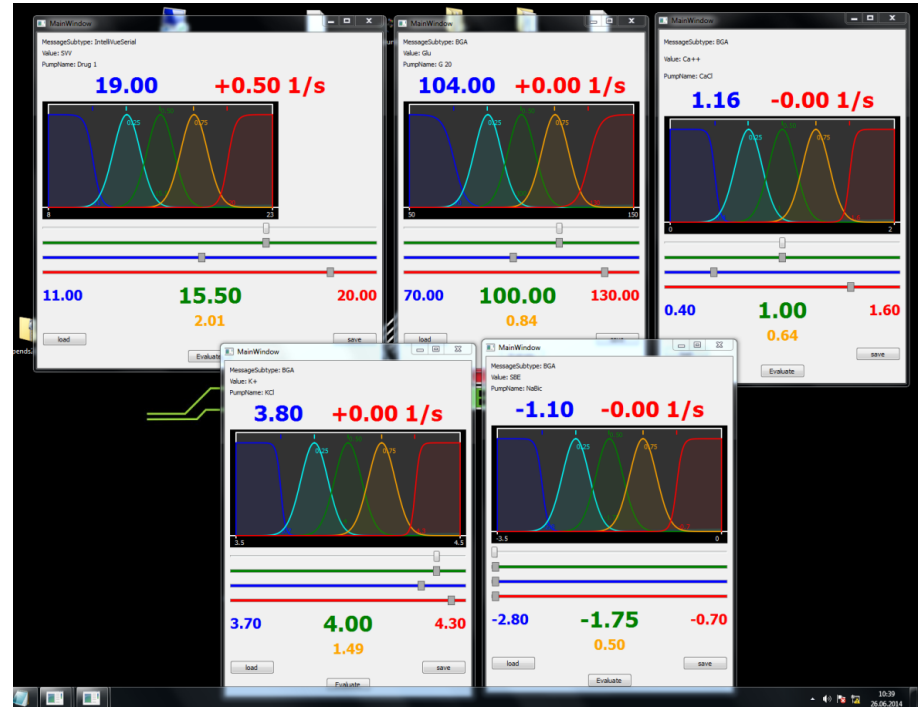
Buttons: Load Config, Save Config, Edit Display, Beenden, Neue Spalte hinzufügen, Letzte Spalte löschen, Graphen löschen, bearbeiten, Graphen hinzufügen 0, Graphen hinzufügen 1, Graphen hinzufügen 2, Graphen hinzufügen 3.

Portable on hand-held devices



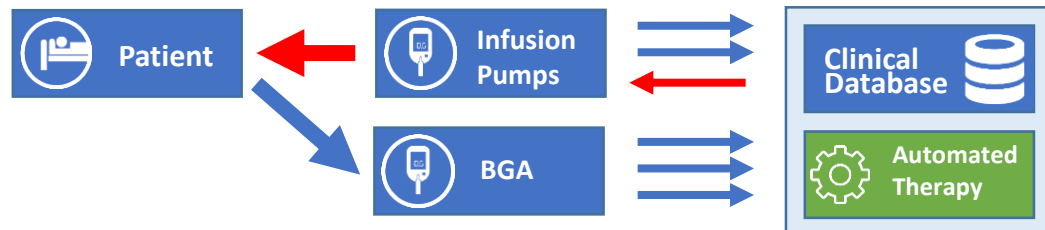
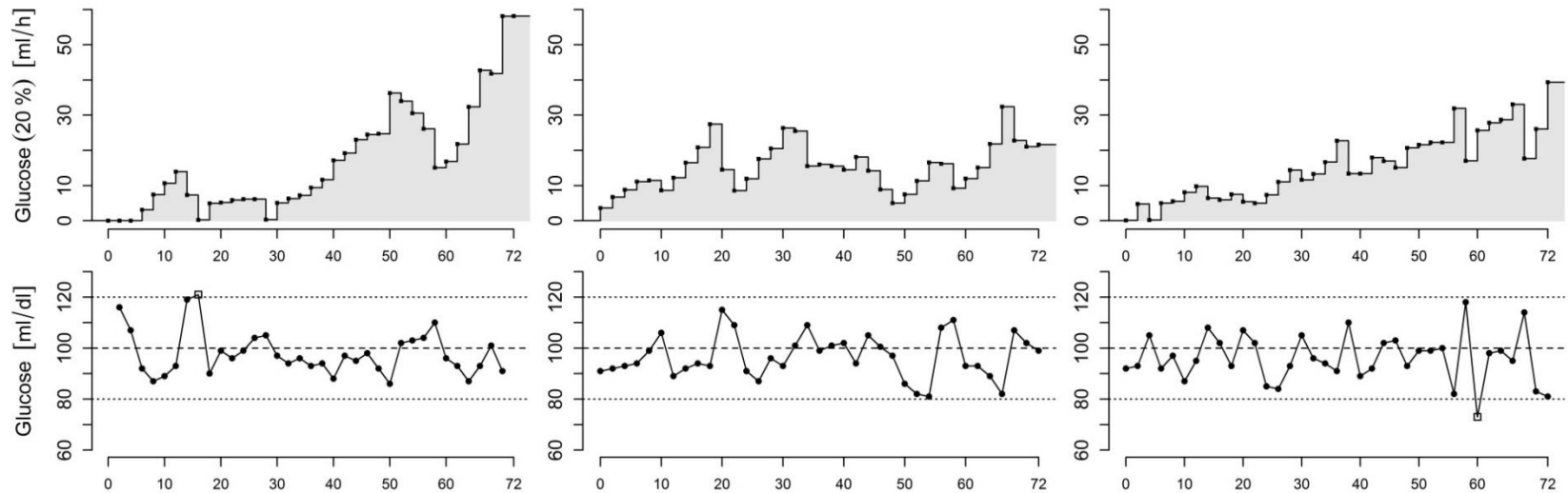
Assisted / automated therapy

- Goal-directed therapy
- Closed-loop control

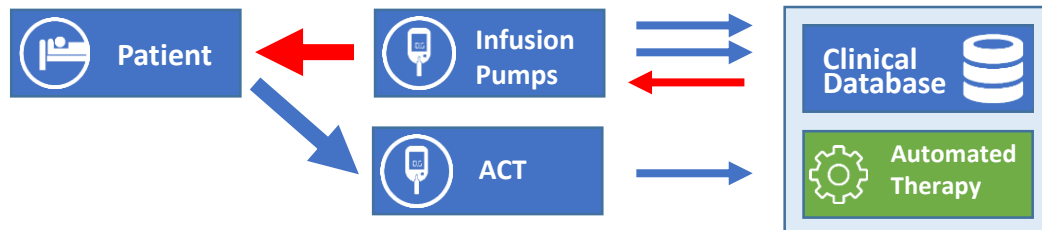
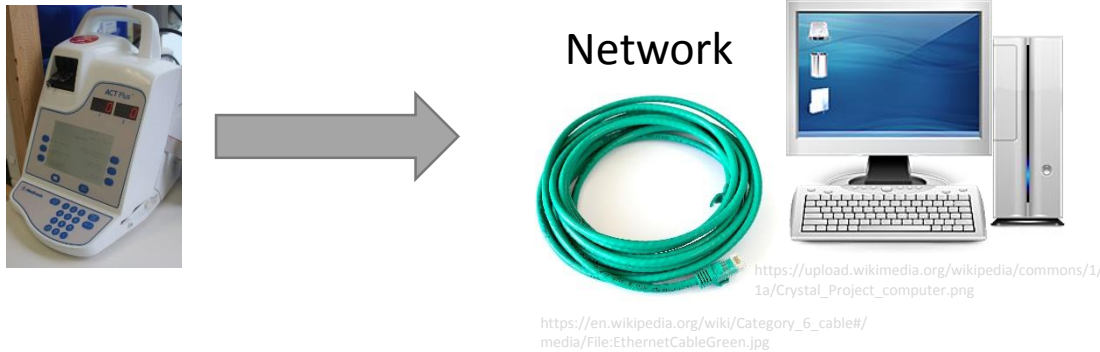


Development Interface for fuzzy logic-based goal-directed therapies

Automated glucose management



Automated heparinization



- Automated processing of the ACT measurements
- Weight-adapted dose calculation with look-up table
- Automated adaption of infusion pump & bolus

Literature

- The Biomedical Engineering Handbook, 4th Edition
Bronzino, J.D. and Peterson, D. R.
Taylor & Francis, 2015
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