Anesthesia simulation of a digital patient's physiological status in the operating room.

Application to computer assisted anesthesia training

Hugo Boisaubert[1], Corinne Lejus-Bourdeau[2] & Christine Sinoquet[1]

[1] Laboratory of digital Science of Nantes, Nantes University

[2] Nantes University Hospital, Laboratory of experimental simulation in intensive medicine

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Simulation of the evolution of a virtual patient's physiological status in the operating room

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Simulation in anesthesia ?

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Introduction

Practice of simulation in medical teaching

- 2012 : New regulation in medical school by the French Health High Authority

Never a first time on a patient !

Development of new training practices ➡ Simulation

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Types of simulation

Software simulator

Role playing

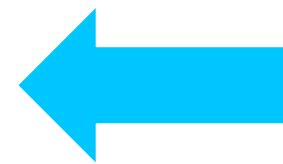**Interprofessional realistic simulation**

Training scenarios must be written in advance

Trainer has to evolve the physiological parameters of the mannequin by hand

High fidelity mannequin

Trainees immersion in a full-scale interprofessional medical team.

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Introduction - Type of simulation practices

Our proposal

Several computer assisted types of simulation can be envisaged

Database :
- 500 000 anesthetic profiles
- Recorded in Nantes University Hospital
- Since 2004.
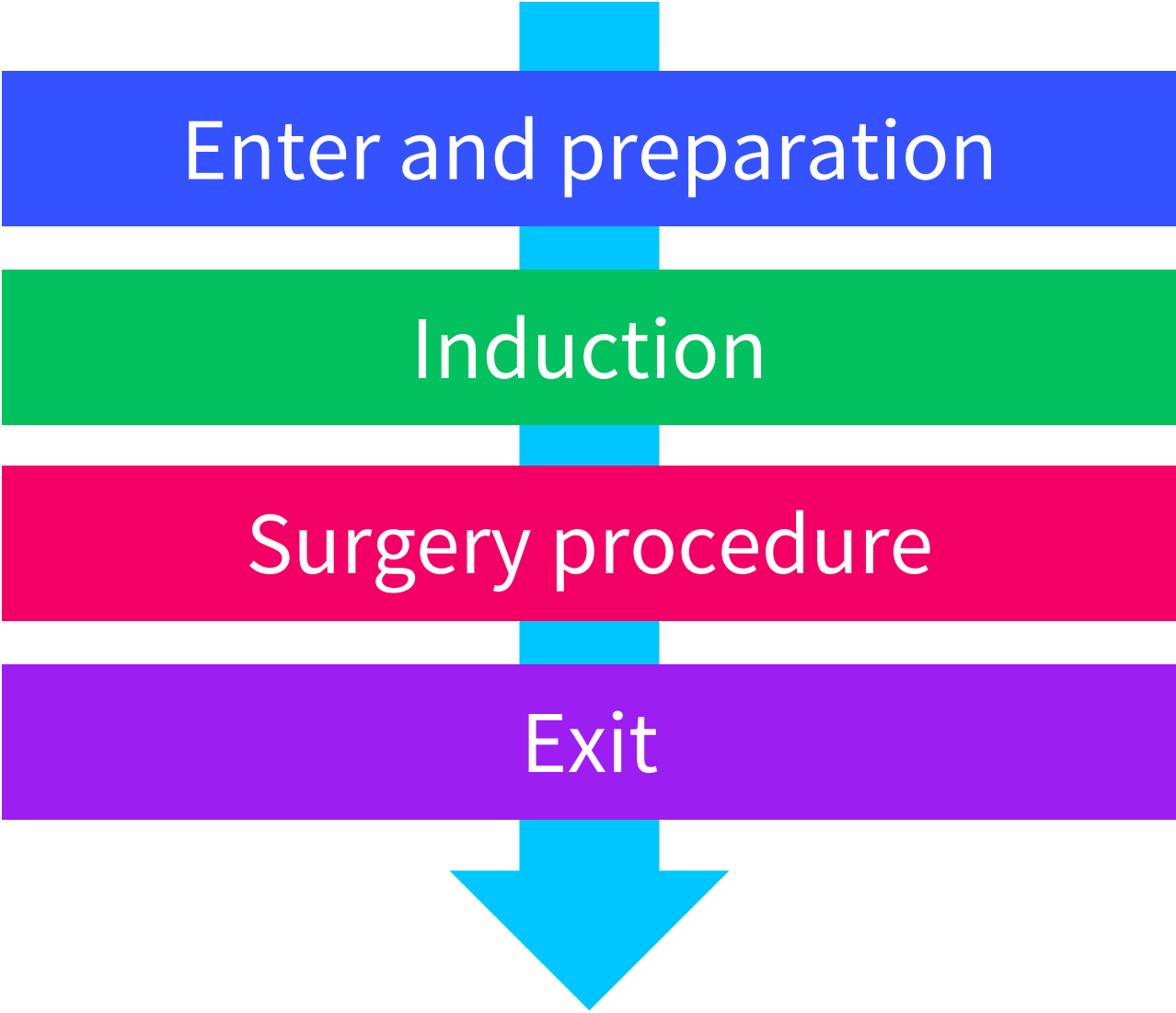
Proposal : Data driven simulation

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How to simulate a realistic digital patient, based on real data ?

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Introduction - How to simulate a realistic numerical patient based on real data ?

Anesthesia events and time series

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Anesthesia structure

Anesthesia structure

Enter	Setting up	Patient enter
		Patient setting
	Monitoring	Heart rate monitoring
		Arterial pressure monitoring
		Oxygen saturation monitoring
		BIS monitoring
		TOF check
	Premedication	Bair hugger
		Venous route installation
		Prophylactic antibiotic
		Vascular filling

Induction	Preoxygenation	Facial mask
		Preoxygenation administration
		Morphinic
		Analgesia
	Medication	Hypnotic
	Intubation	Curare
		Controled mechanical ventilation
		Eyelid closing
		Intubation
	Control and end of induction	Controled ventilation
		Maintenance of anesthesia
		Oxygen 30%
		Pulmonar auscultation
		Intubation balloon presure check
		Lung volume recruitment
		Temperature monitoring

Procedure	Procedure preparation	Surgery setting
		Pulmonar auscultation
		Support point check
		Ready for surgery
	Procedure	Incision
		Ubumbilical trocar
		Pneumoperitoneum inflation
		Pulmonar auscultation
		Lung volume recruitment
		Preperitoneal space dissection
		Spermatic cord dissection
		Hernia space dissection
		Prosthetics setting
		Pneumoperitoneum deflation
		Closing
		Bandage

Exit	Decurarization	Decurarization check
		Decurarization
	Ending	Patient setting before exit
		Patient exit

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Anesthesia events

Trainee & team medical actions

Impact on patient's physiological parameters
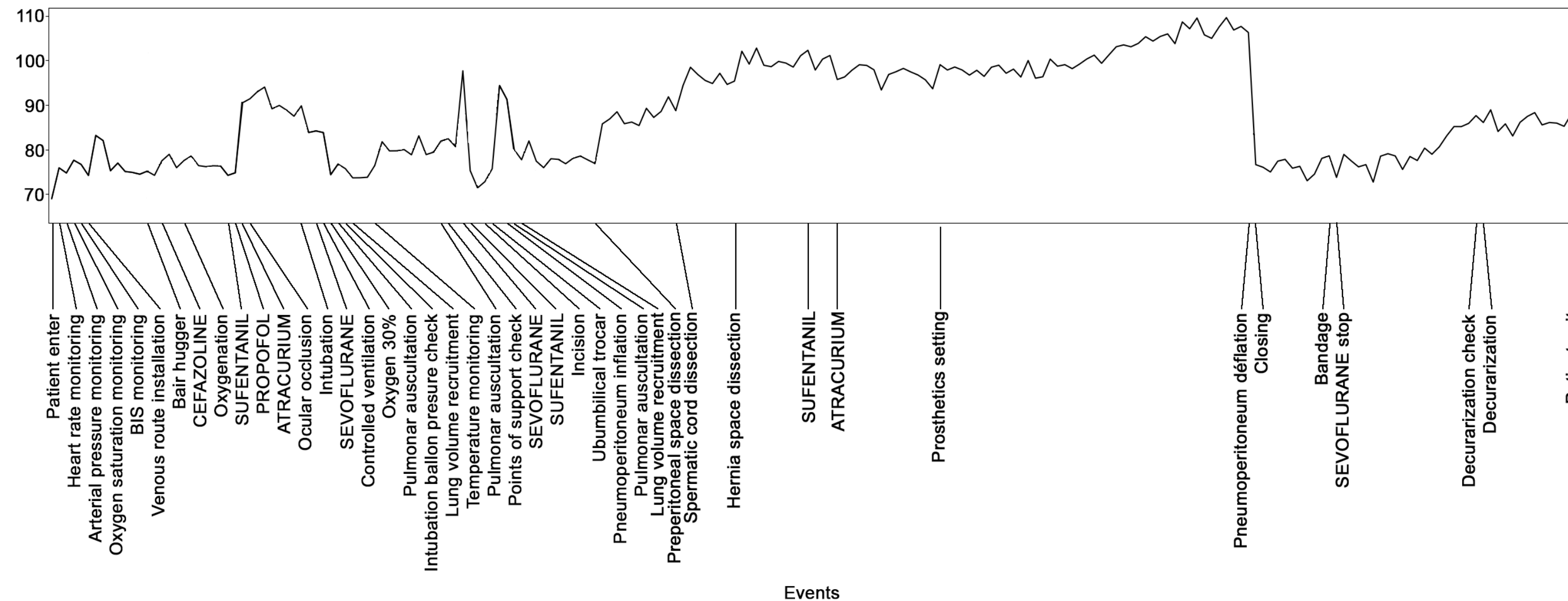
Hemodynamic

Blood pressure
Cardiac frequency

Physiological

Temperature
Oxygen blood concentration

Gaz

Inspired/expired oxygen
Anesthetic product concentration

Main variables and time series

Available data

500 000 anesthesic profiles

Events

Physiological parameters

Simulation of digital patient

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Numerical patient simulation
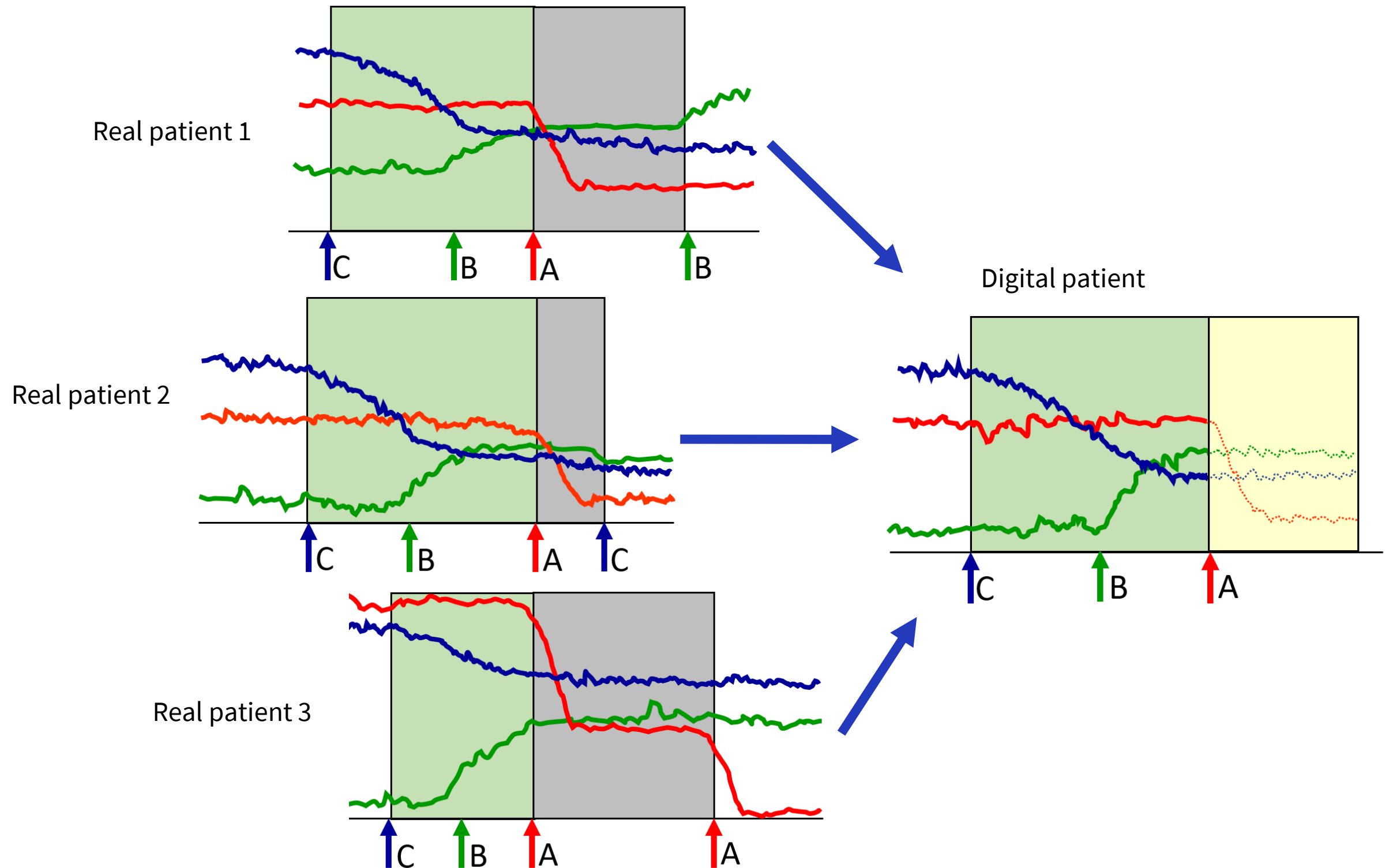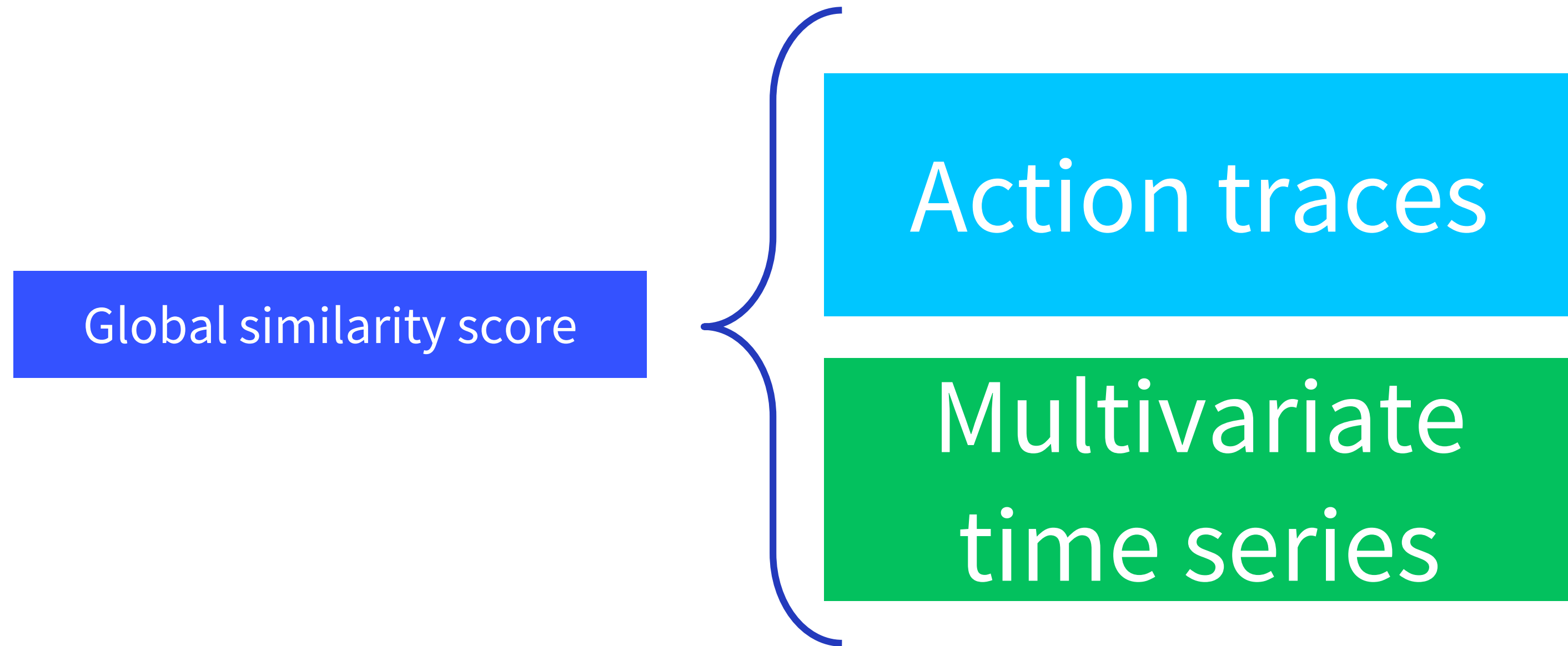
Simulation Approach

Case-based reasoning approach

1   Identification of real patients similar to the digital patient

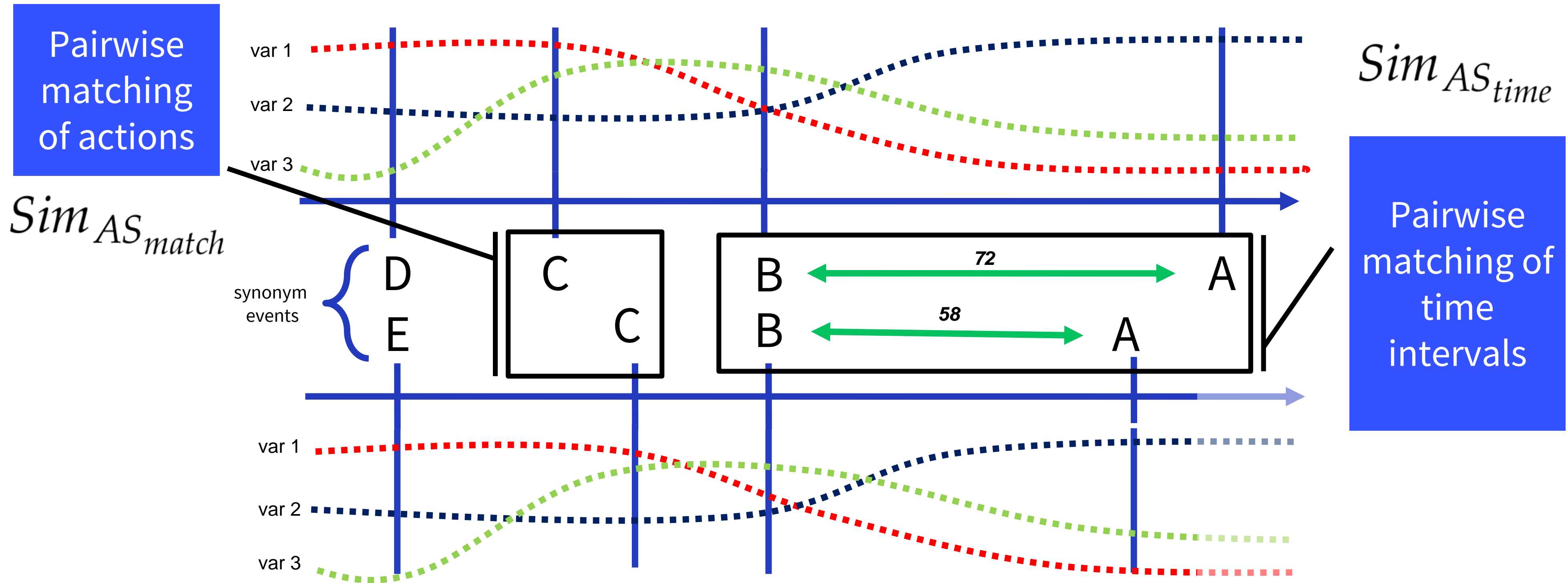2   Prediction of the near future of the digital patient from those real patients
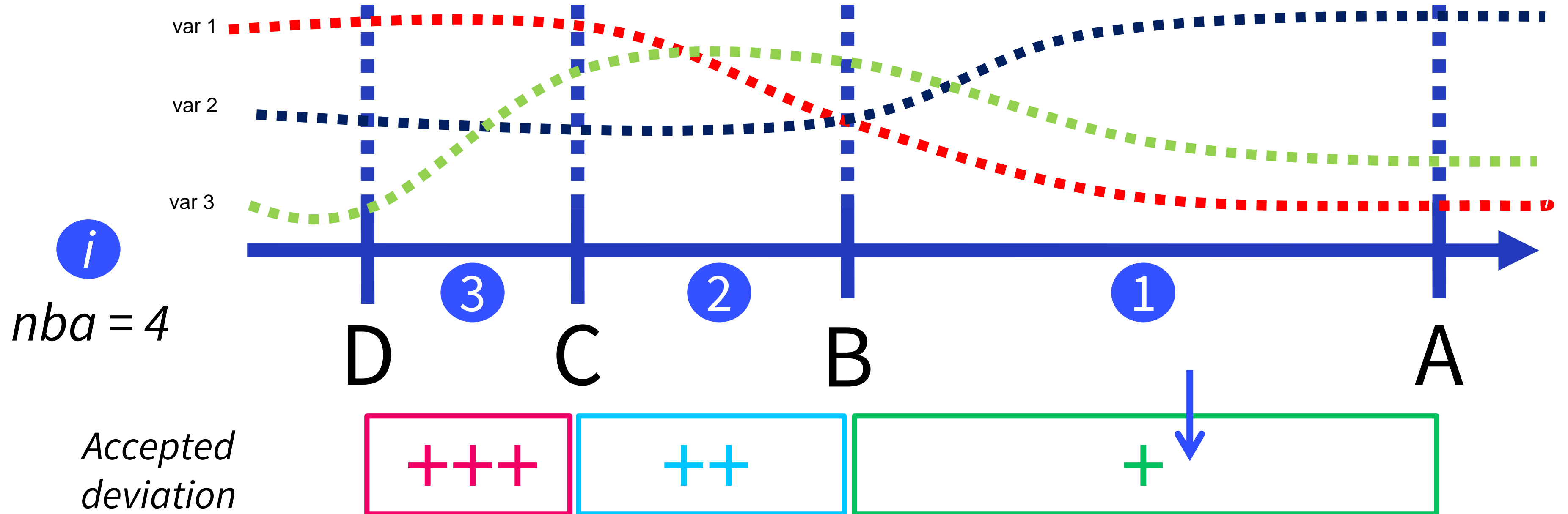

Real patient 1

Real patient 2

Real patient 3

Digital patient

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Numerical patient simulation - Simulation approaches

Similarity score

Global similarity score

Action traces

Multivariate time series

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Similarity between action-signatures - Event score

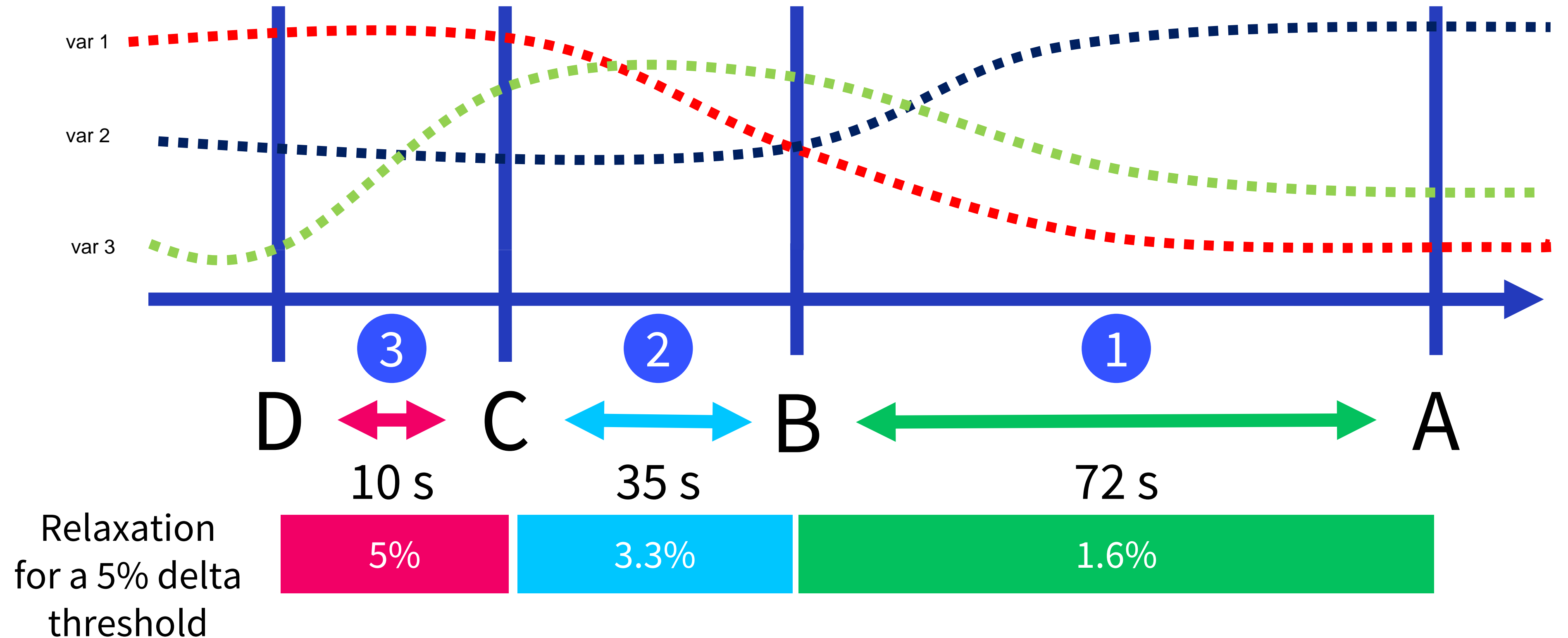Numerical patient simulation - Action signature similarity

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Similarity between action-signatures - Time-interval score

$$Dev_{time}(i) = \Delta \left(1 - \frac{i-1}{nba-1} \right)$$

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Numerical patient simulation - Action signature similarity deviation

Similarity between action-signatures - Time-interval score

var 1

var 2

var 3

| D | 3 | C | 2 | B | 1 | A |

D ←→ C ←→ B ←→ A

10 s   35 s   72 s

Relaxation for a 5% delta threshold

| 5% | 3.3% | 1.6% |

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Numerical patient simulation - Action signature similarity deviation - Example

Similarity between time subseries
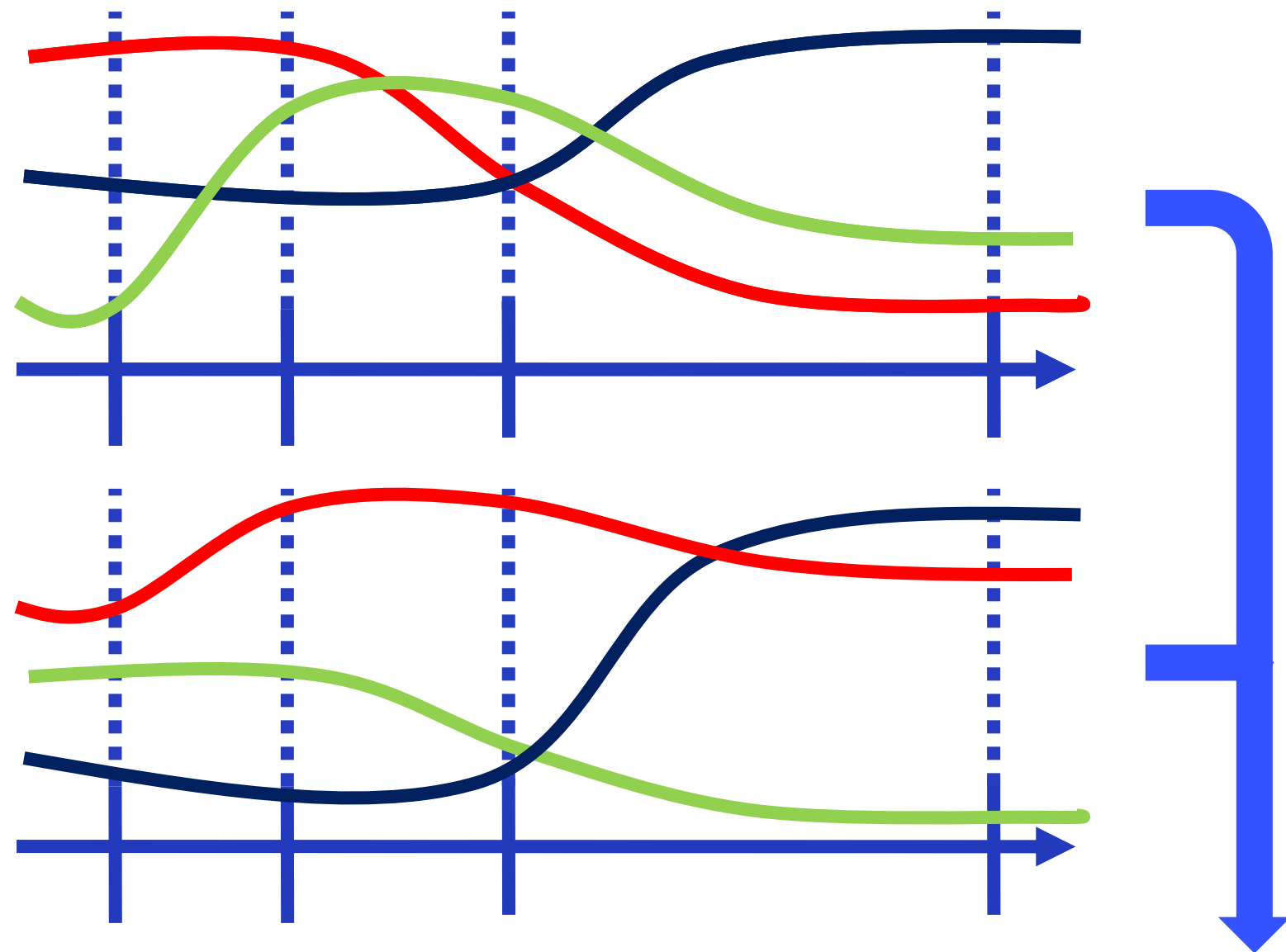
Multivariate dissimilarity measure (expensive)
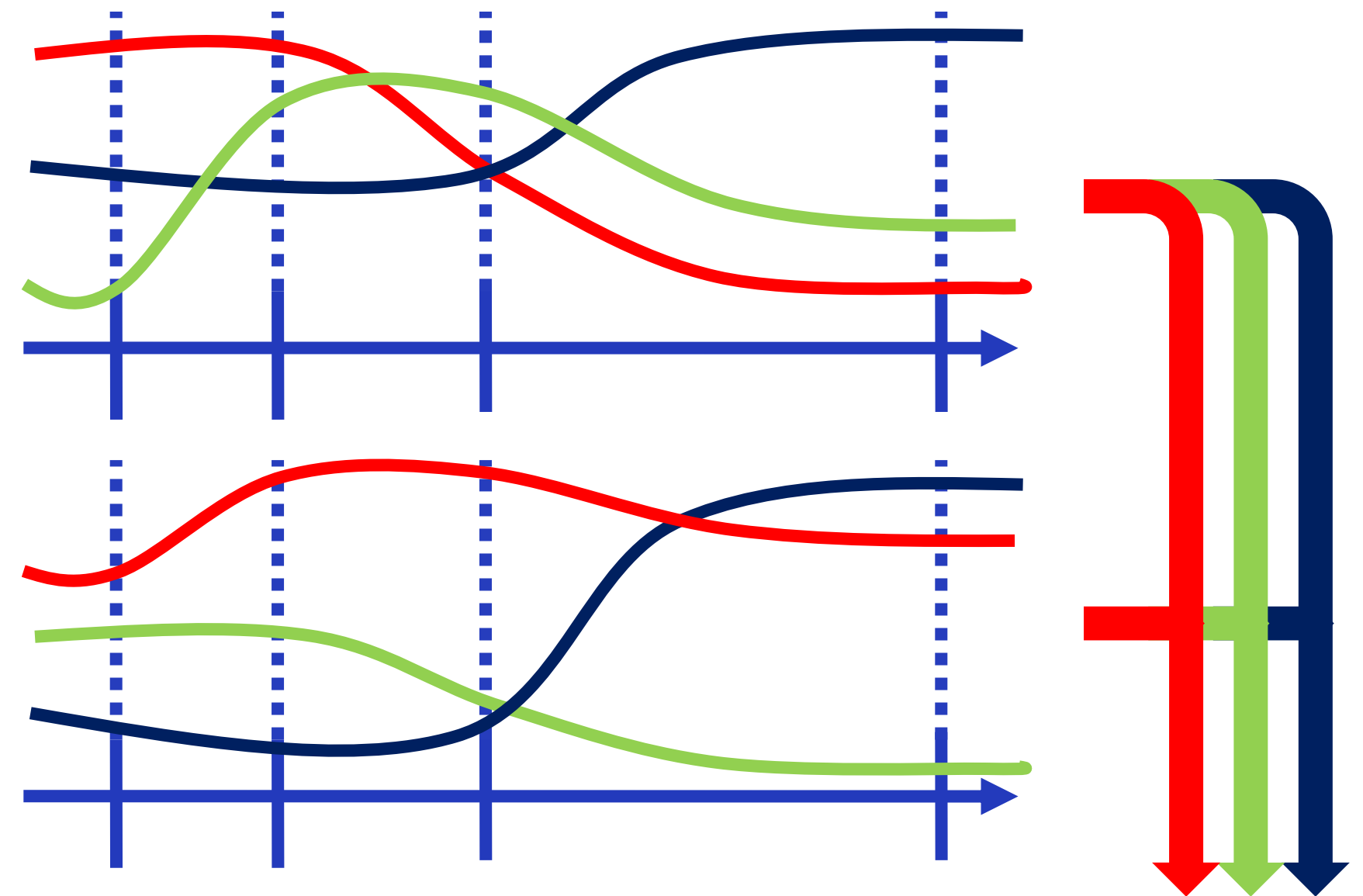
Univariate dissimilarity measure (affordable)

Average

Global similarity score

Global similarity score

$$Sim_{AS+TS} = K_1 Sim_{AS_{match}} + K_2 Sim_{AS_{time}} + K_3 Sim_{TS}$$

Action traces

Pairwise matching of actions $Sim_{AS_{match}}$

Pairwise matching of time intervals $Sim_{AS_{time}}$

Multivariate time series

Average of univariate time series dissimilarity Sim_{TS}

Where K_1, K_2 and K_3 are coefficients

SVP-OR algorithm

Représentation synthétiques

Simulation of Virtual Patient (VP)
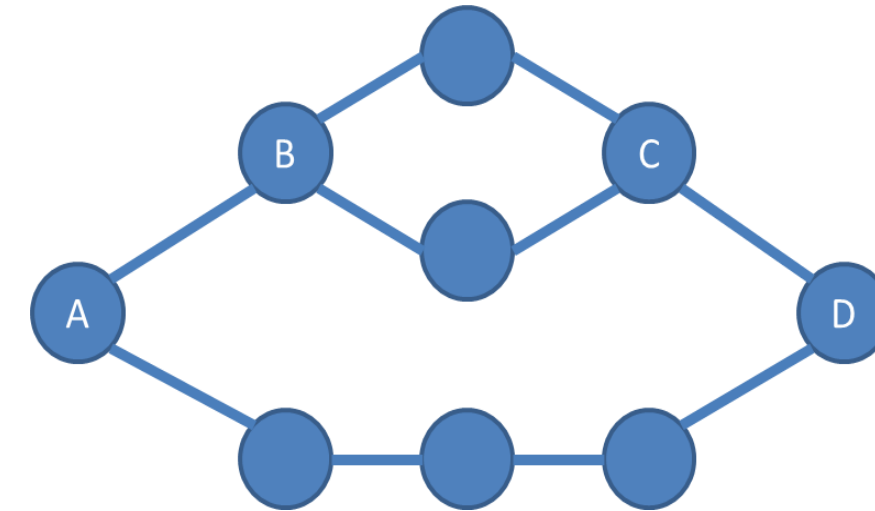at the Operating Room

1 Pre-processing

An action is triggered

2 Identification of real patients
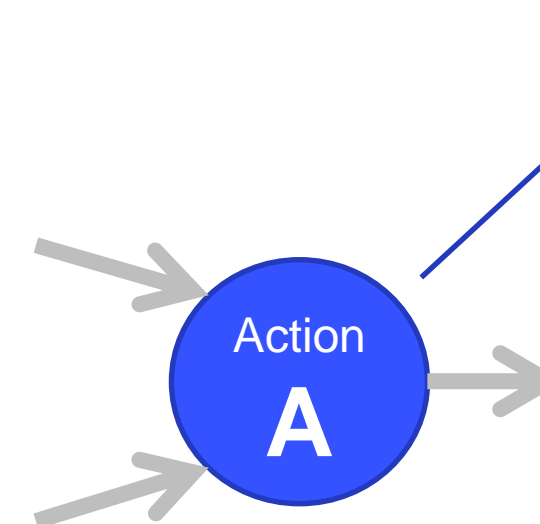most similar to VP

The real patients most similar are ranked

3 Prediction of patient's evolution

Oriented graph with all action traces from patients

Similar traces are merged

Action
A

In node :
- Each subtraces for *n* last
  events
- Each Sub time series for n
  last events

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Numerical patient simulation - SVP-OR algorithm

SVP-OR algorithm

Cohort of real patients with same characteristics

Simulation of Virtual Patient (VP) at the Operating Room

1 Pre-processing

An action is triggered

2 Identification of real patients most similar to VP

The real patients most similar are ranked

3 Prediction of patient's evolution

Surgery

Co-morbidity

Medical history

Physical features

Age

Weight

Height

SVP-OR algorithm

Simulation of Virtual Patient (VP) at the Operating Room

① Pre-processing
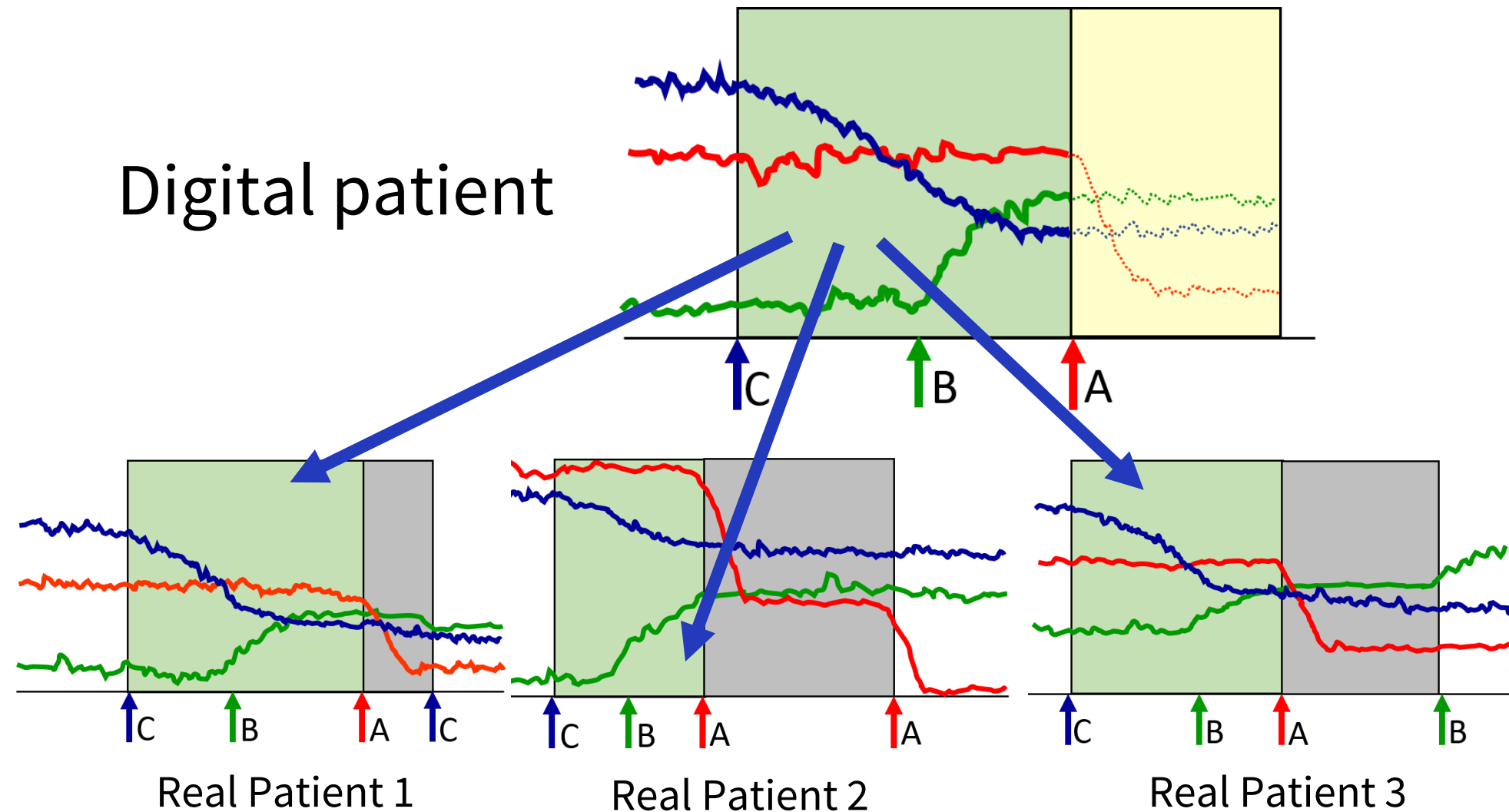
An action is triggered

② Identification of real patients most similar to VP

The real patients most similar are ranked

③ Prediction of patient's evolution

Digital patient

Real Patient 1   Real Patient 2   Real Patient 3

Global similarity score

$$Sim_{AS+TS} = K_1 Sim_{AS_{match}} + K_2 Sim_{AS_{time}} + K_3 Sim_{TS}$$

Ranking of the real patients most similar to VP

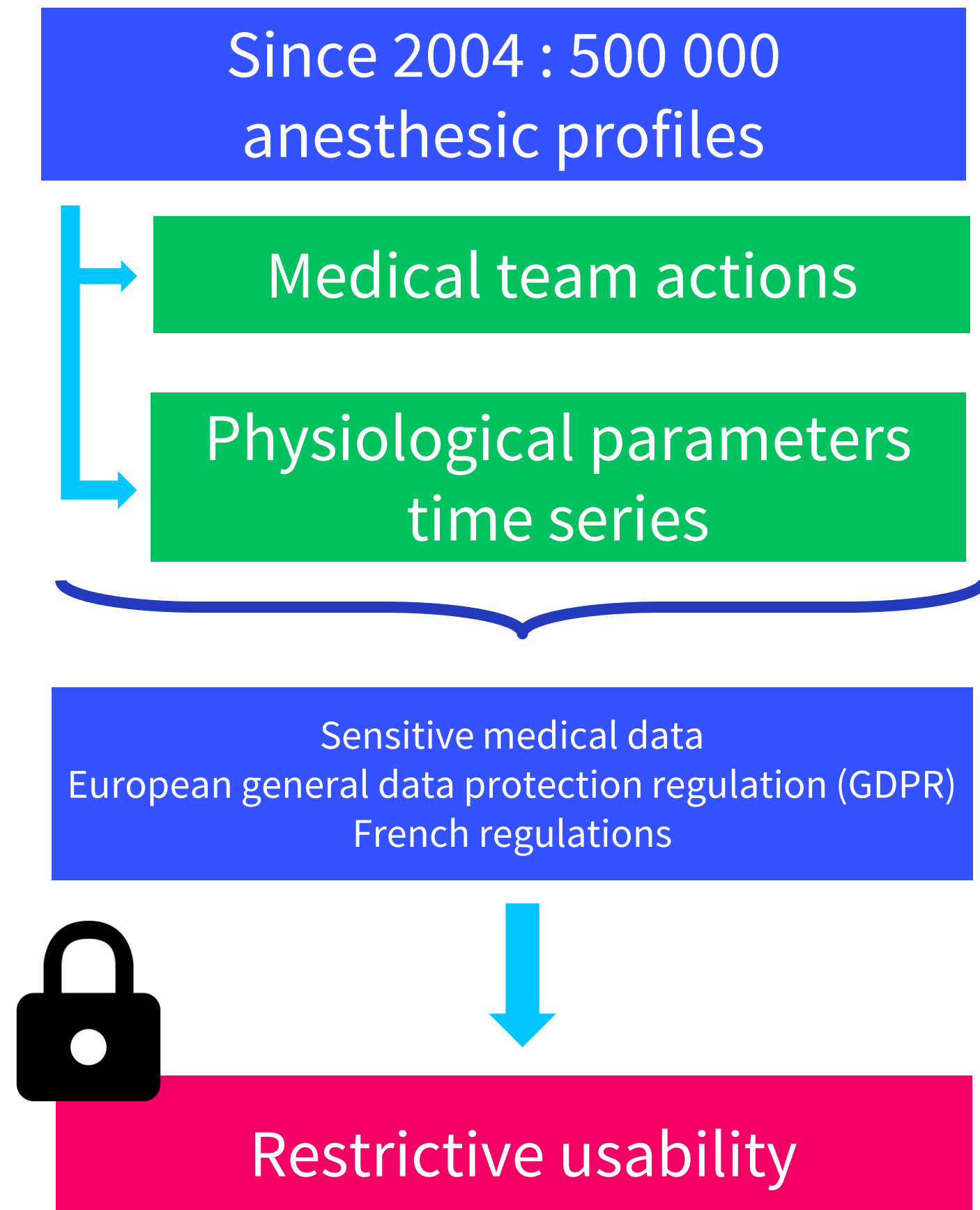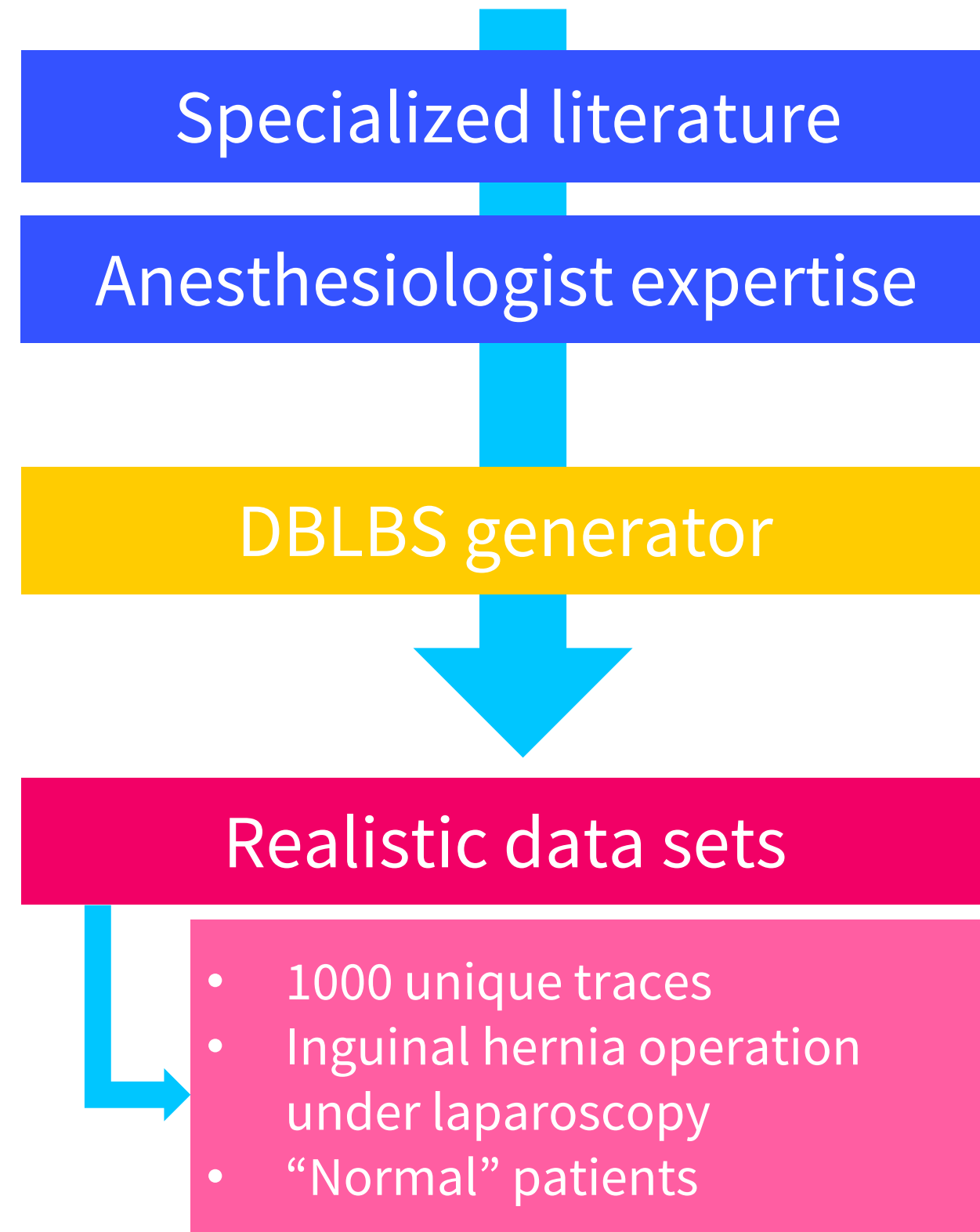#1 - Patient n°X
#2 - Patient n°Y
#3 - Patient n°Z
...

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Variants for the SVP-OR framework

#	Approaches	Parametrization	Prediction
1	The patient most similar to VP	1st ranked patients	Copy
2	Average from patients most similar to VP	1st to 10th ranked patients	Averaging over the univariate subseries
3	Consensus from patients most similar to VP	1st to 10th ranked patients	Bottom up hierarchical process with dynamic time warping

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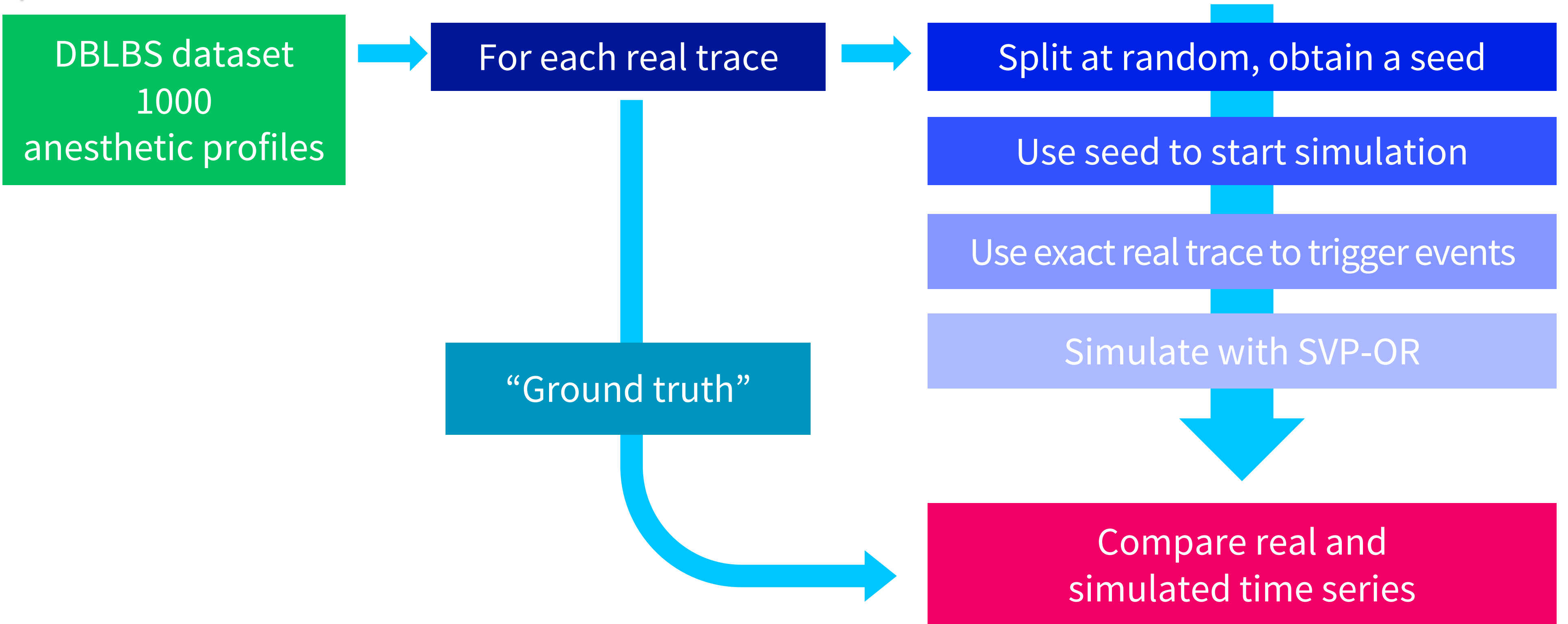Numerical patient simulation - Variants for the SVP-OR instantiation

Experimental protocol and results

1. Introduction

2. Anesthesia events and time series

3. Simulation of digital patient

4. **Experimental protocol and results**

5. Conclusion

Data

Specialized literature

Anesthesiologist expertise

DBLBS generator

Realistic data sets

- 1000 unique traces
- Inguinal hernia operation under laparoscopy
- "Normal" patients

Since 2004 : 500 000 anesthesic profiles

Medical team actions

Physiological parameters time series

Sensitive medical data
European general data protection regulation (GDPR)
French regulations

Restrictive usability

SVP-OR evaluation protocol

DBLBS dataset 1000 anesthetic profiles

For each real trace

Split at random, obtain a seed

Use seed to start simulation

Use exact real trace to trigger events

Simulate with SVP-OR

"Ground truth"

Compare real and simulated time series

Time series comparison

"Ground truth"
Real time series

vs

Simulated times series

Dynamic Time Warping Matching
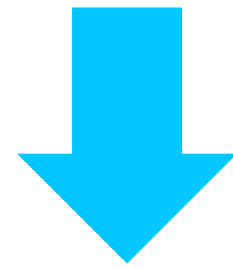
DTW-based multivariate dissimilarity
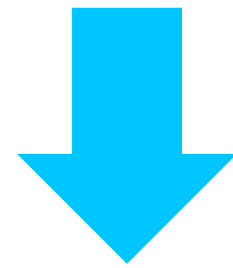
Normalization

$$Sim(j) = \frac{D_{max} - D_j}{D_{max}}$$

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Protocol and results - Time series comparison

Time series comparison

Cardiac frequency for the inguinal hernia

——— Real patient time series

········· Virtual patient time series with "Consensus variant"

– – – Virtual patient time series with "Average variant"

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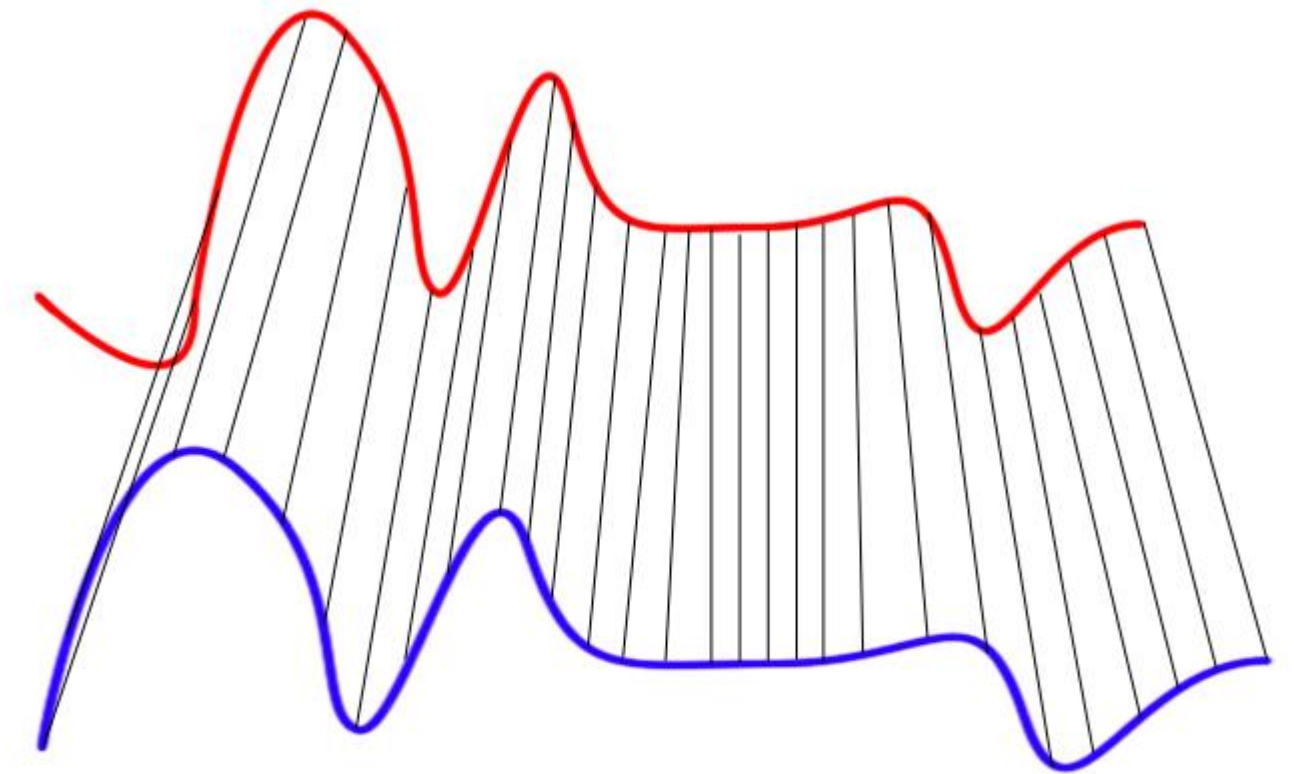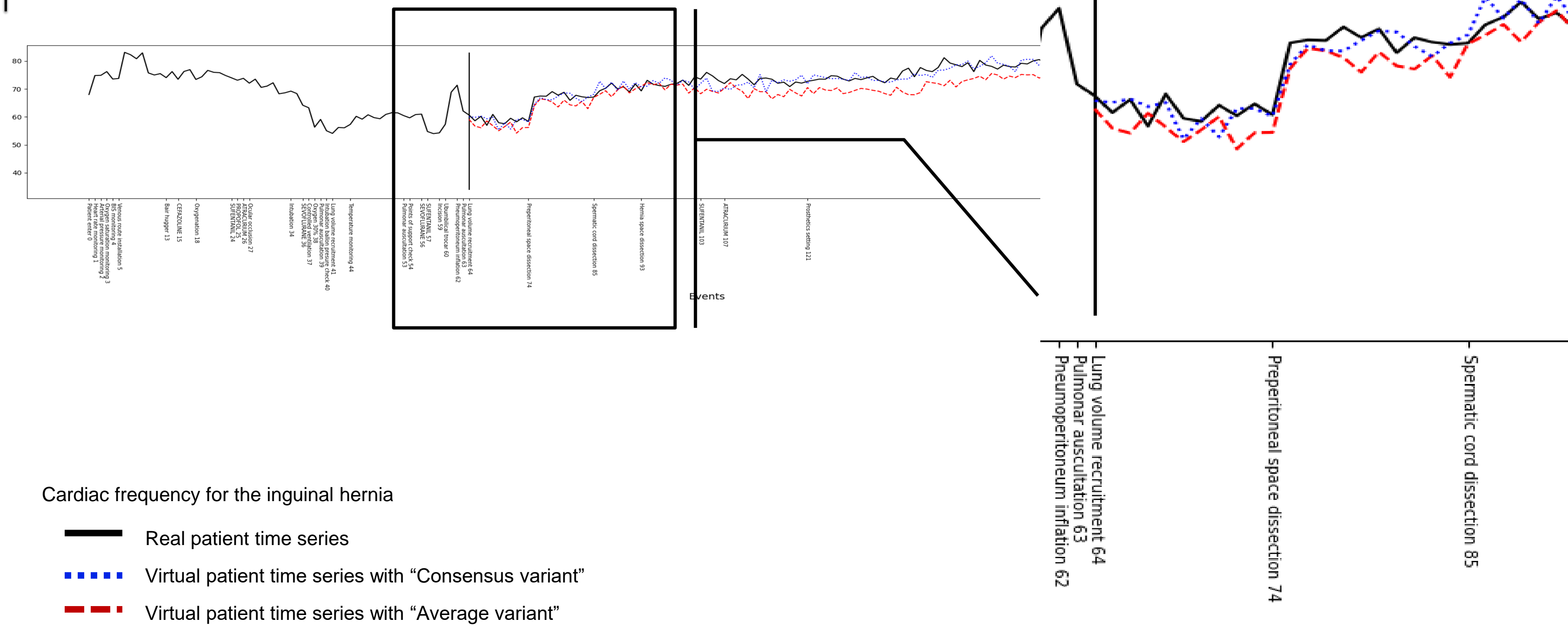
Comparison of dissimilarity distributions
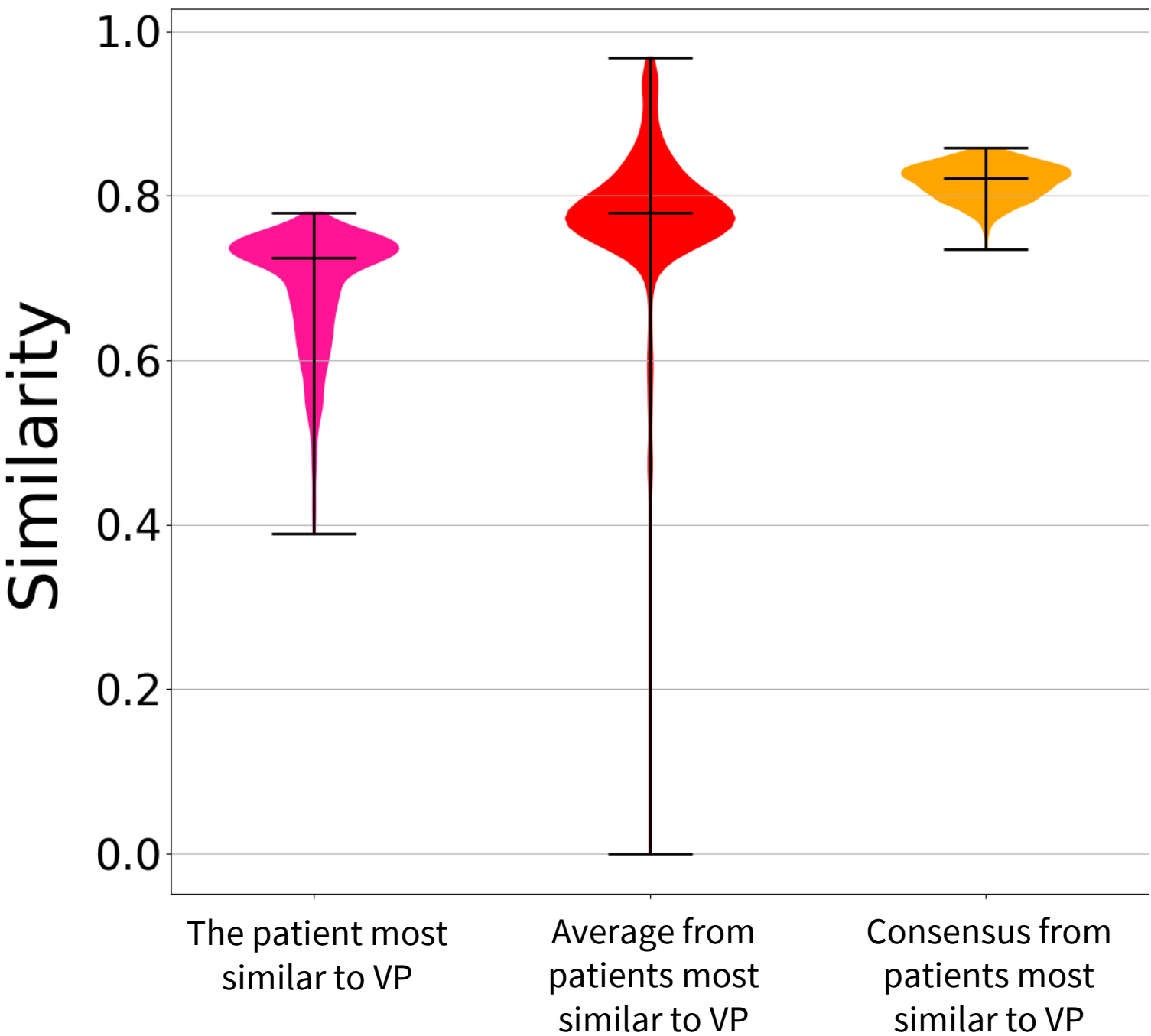
#	Variant	Mean		Variant 1	Variant 2	Variant 3
1	The patient most similar to VP	0.73	MW	-	$1.18e^{-224}$	0.0
			KS	-	$9.36e^{-275}$	0.0
2	Average from patients most similar to VP	0.78	MW	$1.18e^{-224}$	-	$1.46e^{-88}$
			KS	$9.36e^{-275}$	-	$3.27e^{-119}$
3	Consensus from patients most similar to VP	0.83	MW	0.0	$1.46e^{-88}$	-
			KS	0.0	$3.37e^{-119}$	-

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4. Conclusion

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Conclusion

4. Conclusion

Next work

SVP-OR
Simulation of Virtual Patient at the Operating Room

Evolution of a digital patient in response to the actions of a user and of a virtual medical team.

Contextualised multidimensional pattern retrieval

Short-term prediction of real patients.

Case-based reasoning approach

No need to learn a complex model in machine learning

Digital twin for a patient undergoing a surgery.

Anticipation of the risks in the operating room

Application of our approach to other type of surgery

Integrating factors that may mislead the trainee.

Personalized medicine.

Thank you for your attention

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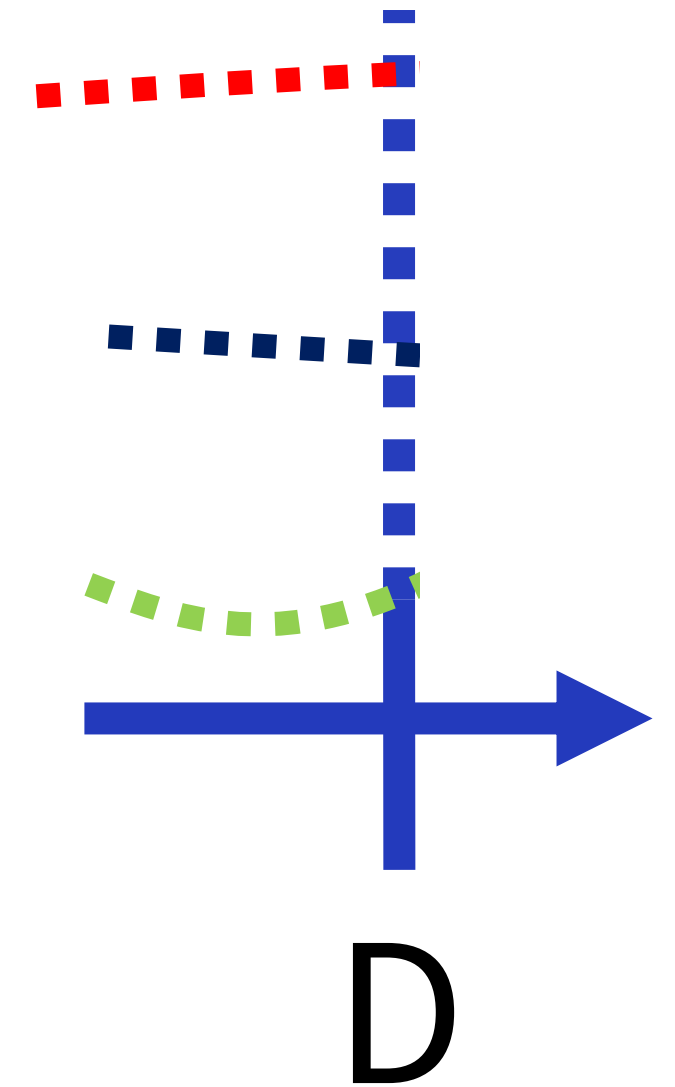
SVP-OR algorithm - Parallelisation

Simulation of Virtual Patient (VP) at the Operating Room

1 Pre-processing

An action is triggered

2 Identification of real patients most similar to VP

The real patients most similar are ranked

3 Prediction of patient's evolution

Digital patient

Real Patient 1

Real Patient 2

Real Patient 3

Identification Delta 1

Identification Delta 2

Identification Delta 3

Ranking of the real patients most similar to VP

#1 - Patient n°X
#2 - Patient n°Y
#3 - Patient n°Z
…

SVP-OR algorithm - Initialisation

Global similarity score

Action traces

Multivariate time series

Action = 1

None

D

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SVP-OR algorithm - Initialisation

Variant 3 - Time series consensus

DTW similarity matrix

Pairs of most similar time series

DTW Distance

Warping Path

DTW consensus

DTW consensus

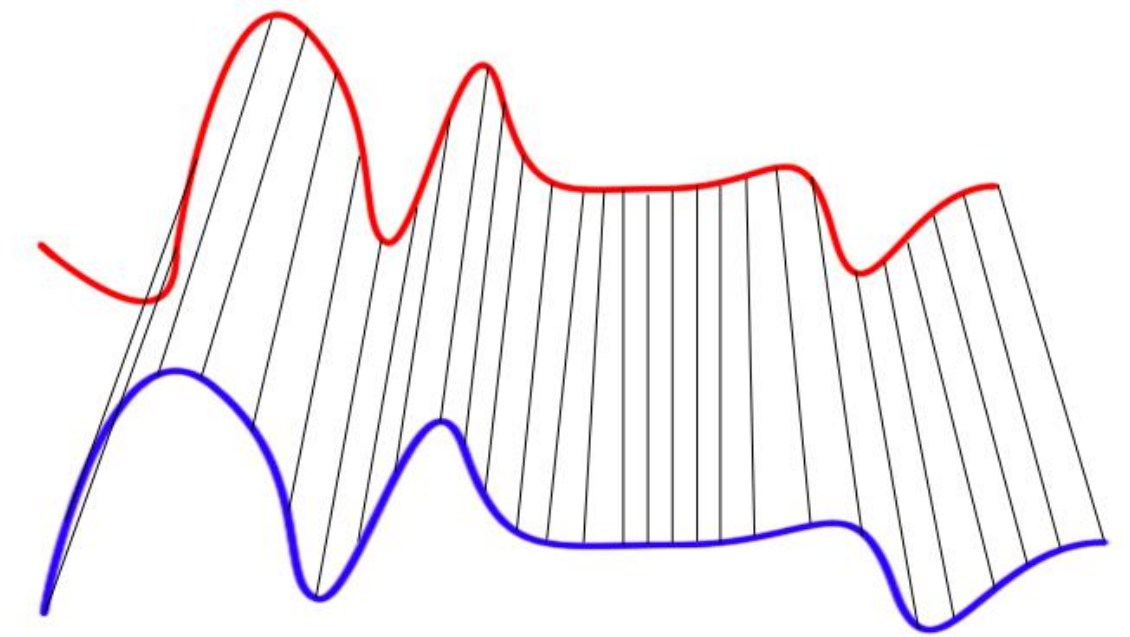Final consensus

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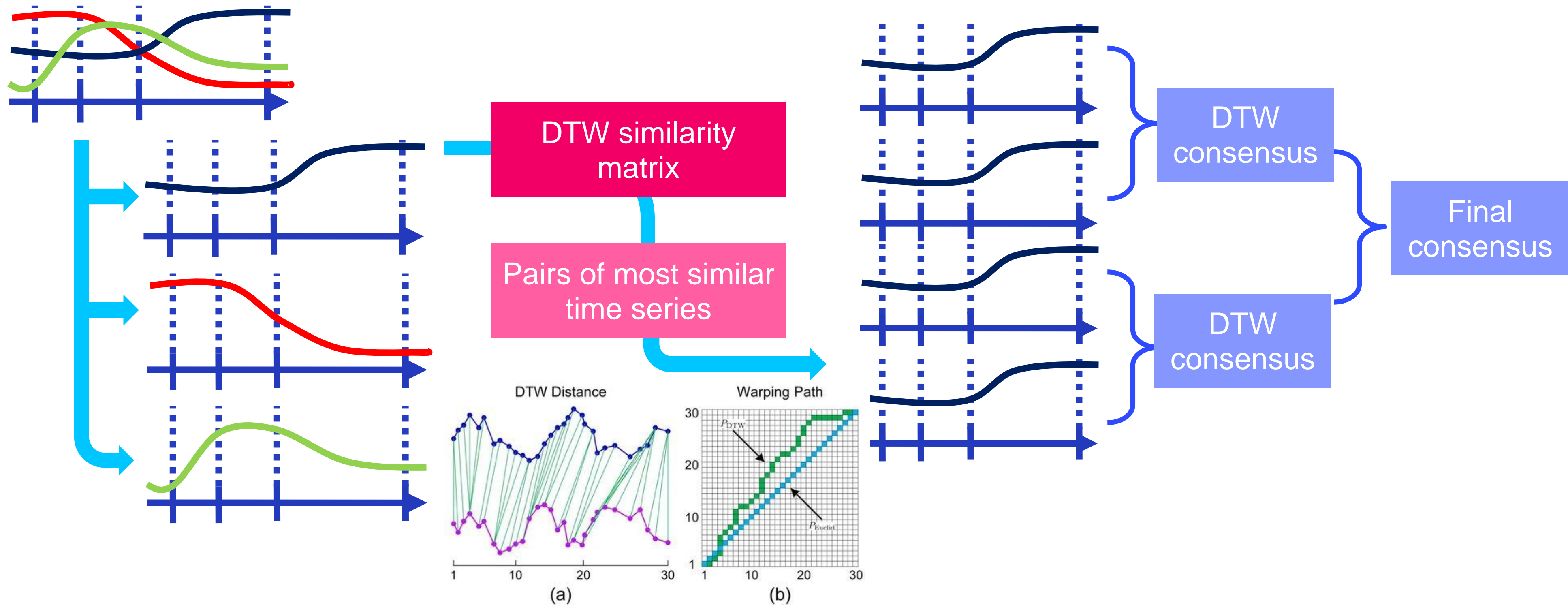
Variant 2 - Time series average
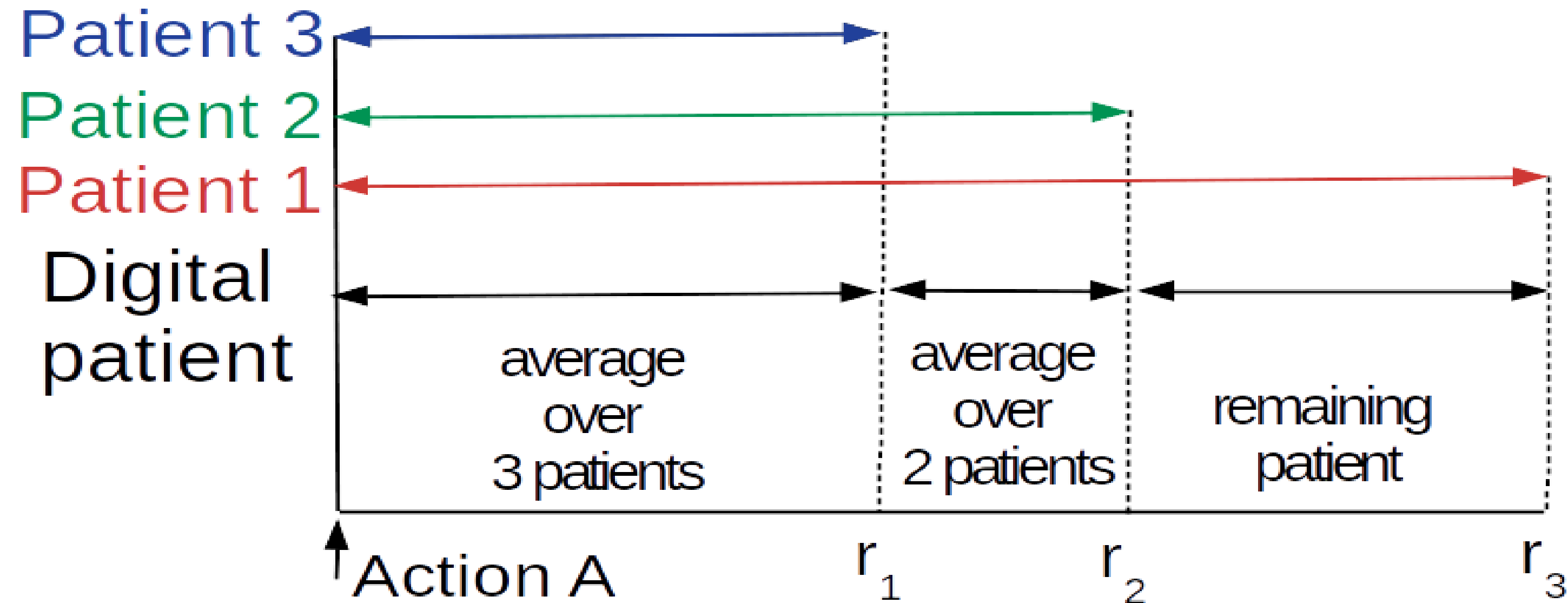
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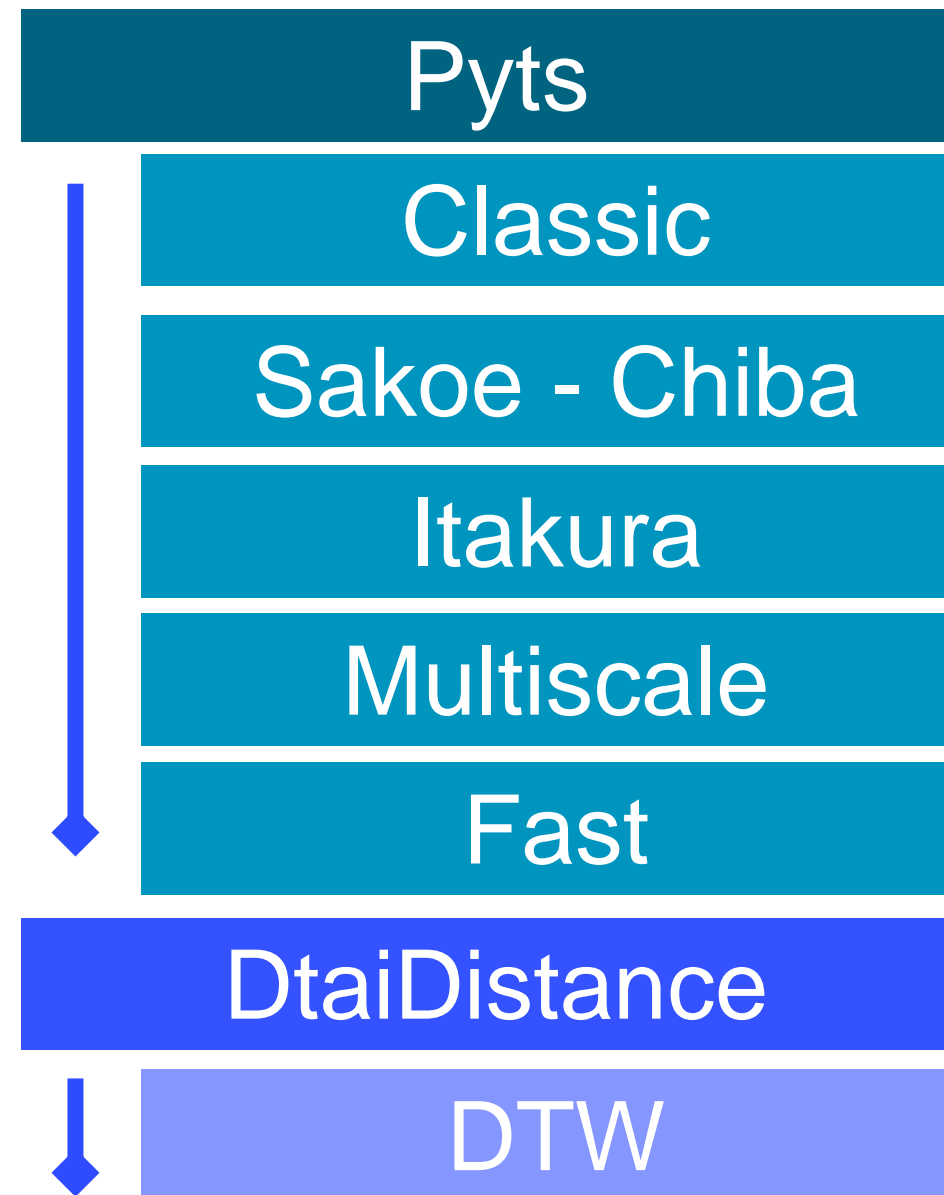
Choice of dissimilarity measure and benchmark

- Type of dissimilarity measure
  - DTW based
  - Feature based

Multiple variants and implementations

Pyts
Classic
Sakoe - Chiba
Itakura
Multiscale
Fast

DtaiDistance
DTW

Dynamic Time Warping Matching

Euclidean Matching

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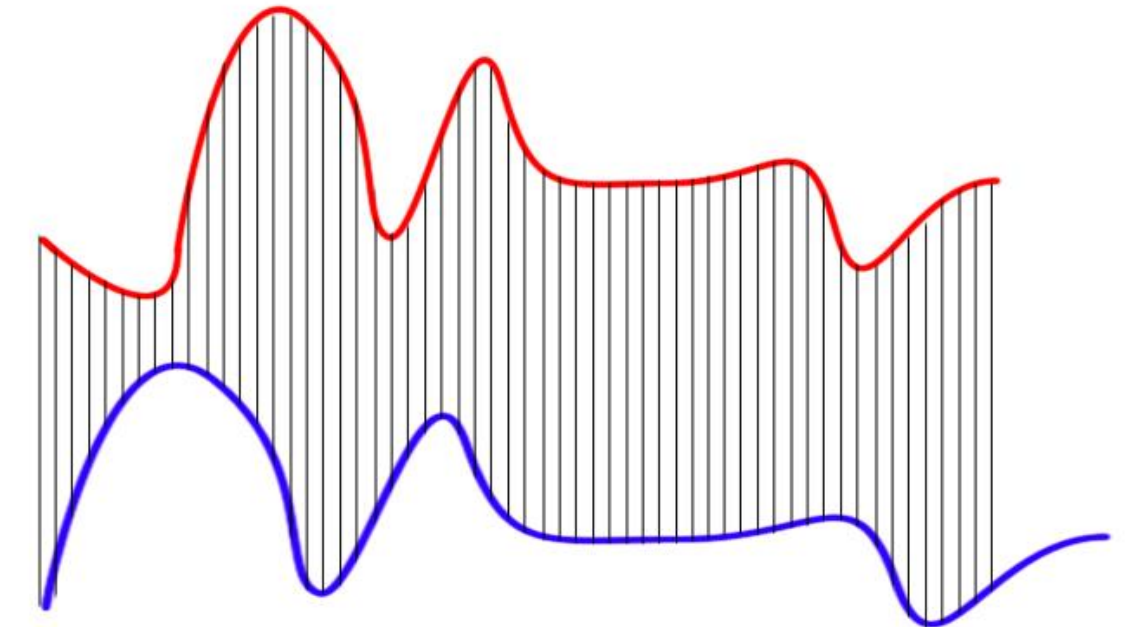
Choice of dissimilarity measure and benchmark

- Type of dissimilarity measure
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Multiple variants and implementations

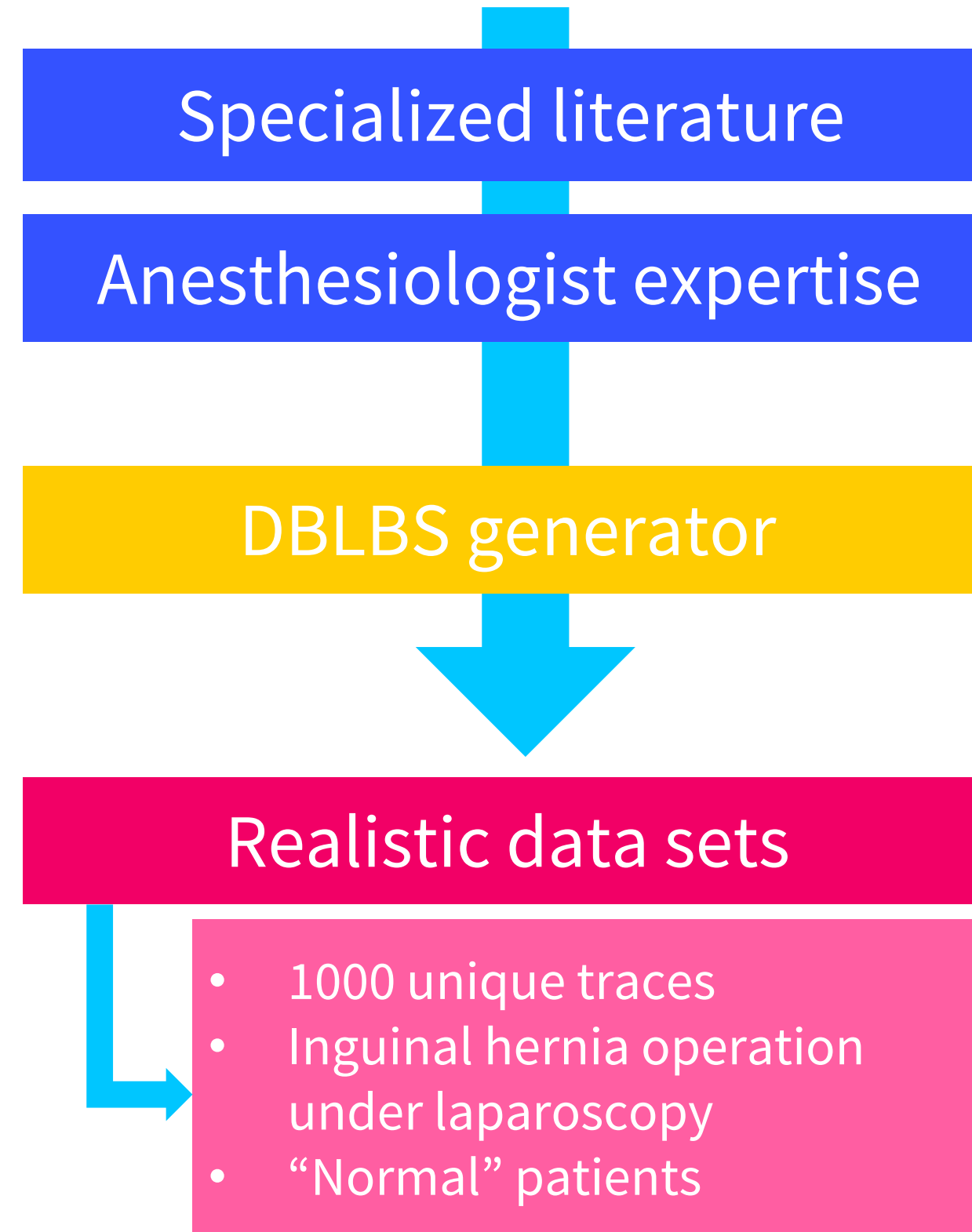TS Fresh

Feature selection

Matrix Profile

MP Dist

Fourier Transform

DFT

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Choice of dissimilarity measure and benchmark

- Benchmark methodology
  - DBLBS Dataset
  - Perturbations

Specialized literature

Anesthesiologist expertise

DBLBS generator

Realistic data sets

- 1000 unique traces
- Inguinal hernia operation under laparoscopy
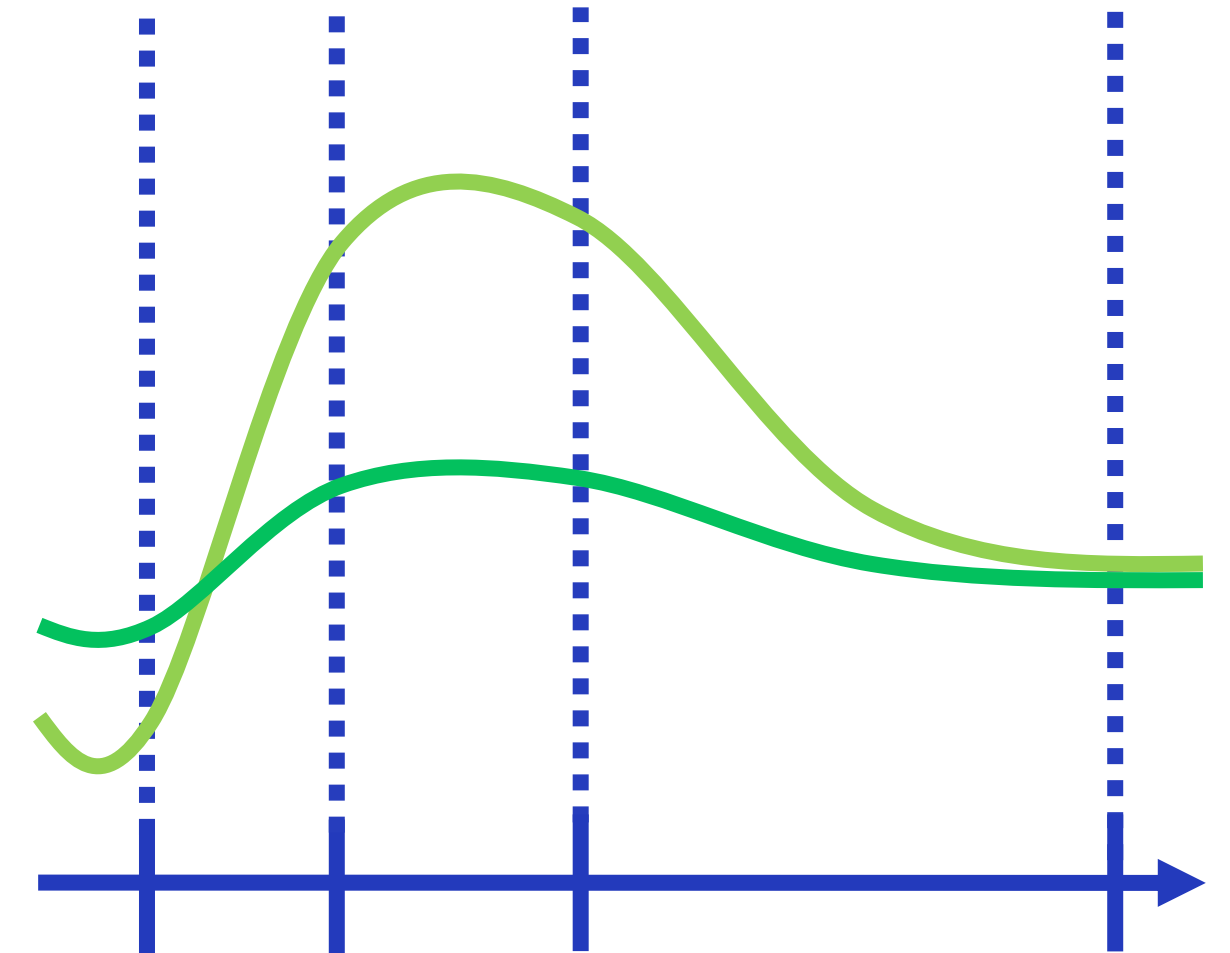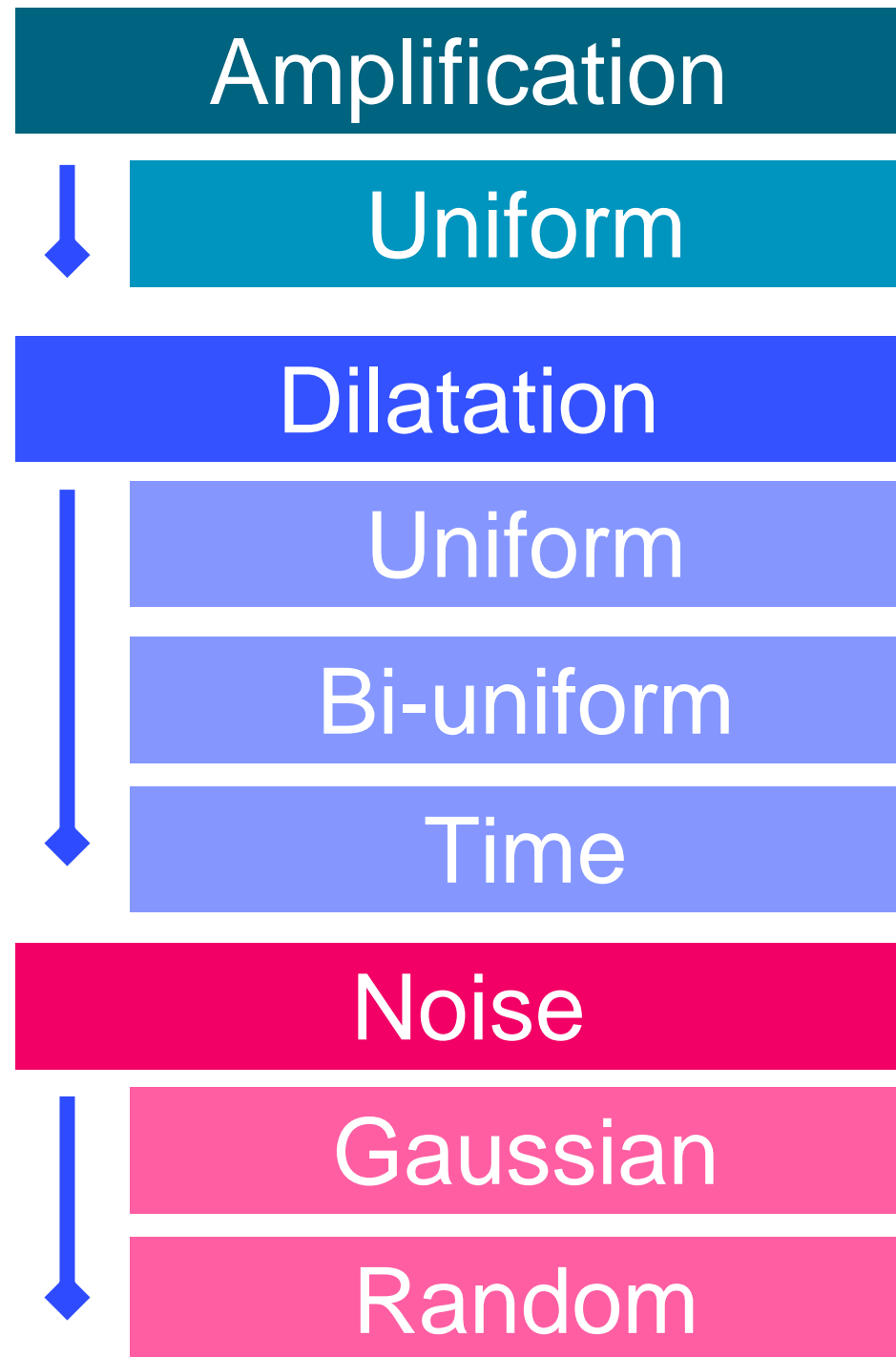- "Normal" patients

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Choice of dissimilarity measure and benchmark

- Benchmark methodology
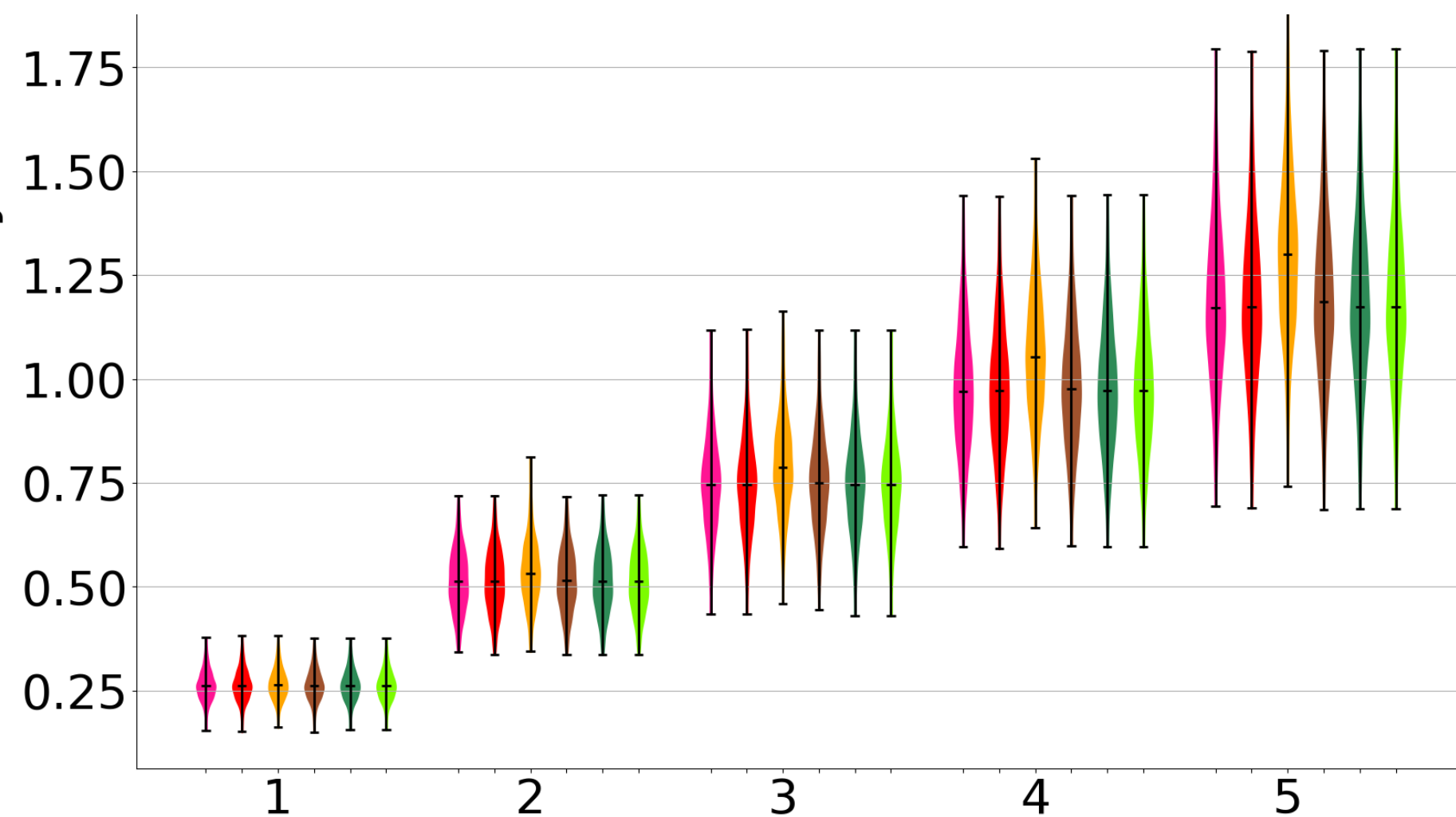 - DBLBS Dataset
  - Perturbations

Time series transformation

| Amplification |
| Uniform |
| Dilatation |
| Uniform |
| Bi-uniform |
| Time |
| Noise |
| Gaussian |
| Random |

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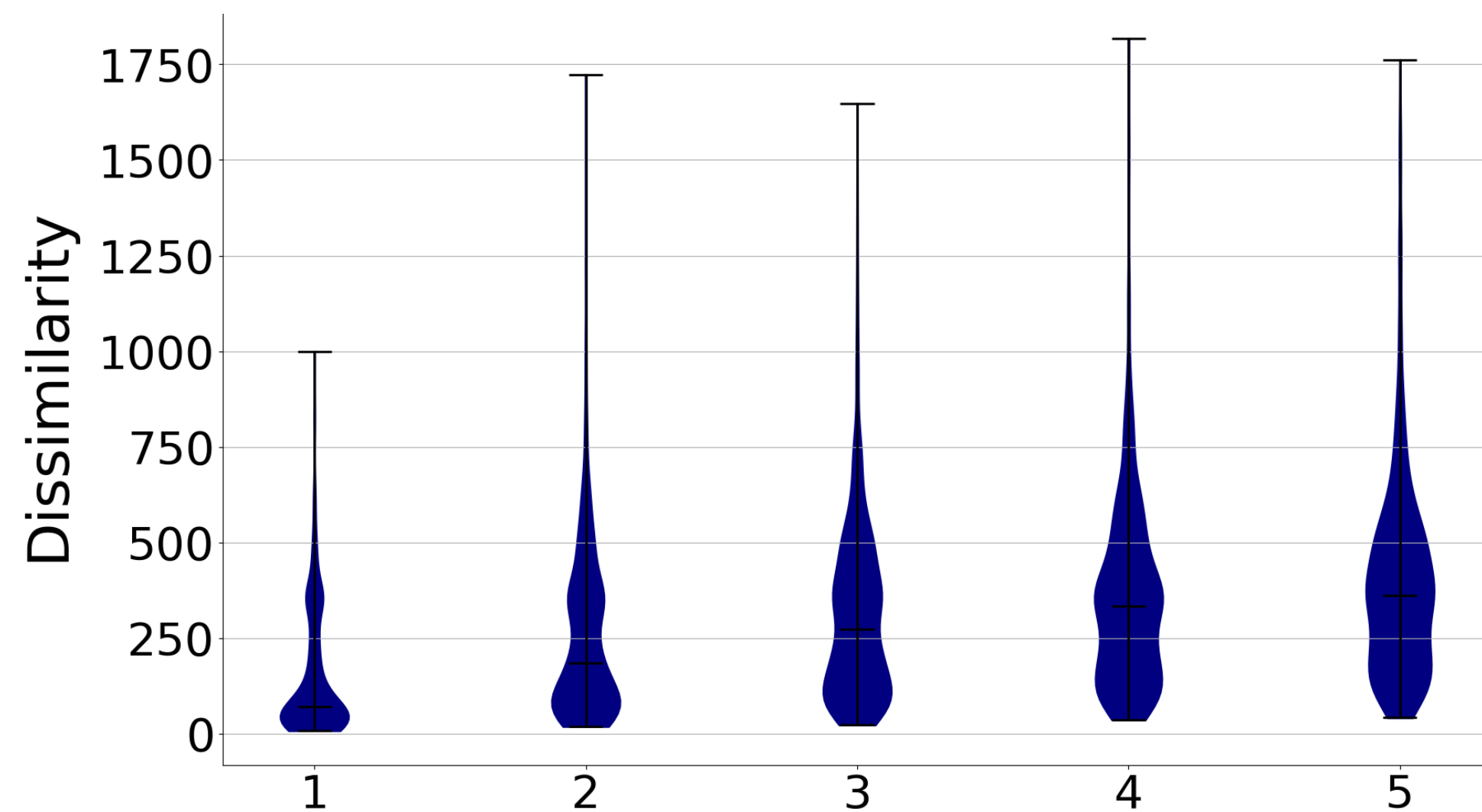# Choice of dissimilarity measure and benchmark

- Results
  - Discard methods
  - Choice of DTW implementation

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DTW

MPdist

TSfresh