Projet FOOD3SA

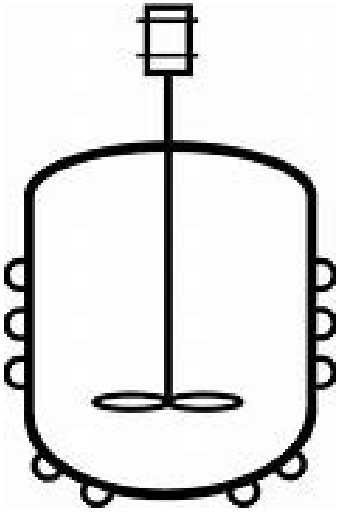
A bioreactor's Digital Twin

By LE ROUX Luka

P4S/Shaker/FHOOX

Introduction

What's a bioreactor?



"A bioreactor is a device or a system that supports a biologically active environment."
- Wikipedia

In our case : an aerobic biological process is carried out which involves growing organisms.

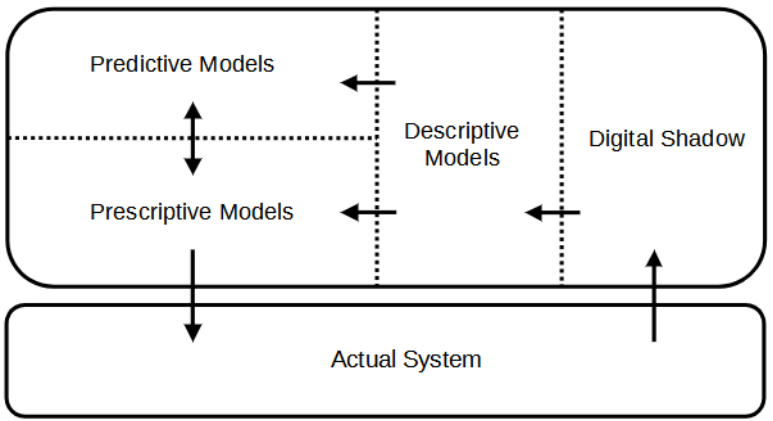
Introduction

What's a digital twin?

contextual data and their aggregation and abstraction

A Digital Twin of a system consists of
- a set of models of the system and
- a set of digital shadows,
  - both of which are purposefully updated on a regular basis, and
- provides a set of services to use both purposefully with respect to the original system.

- The digital twin interacts with the original system by
  - providing useful information about the system's context and
  - sending it control commands.



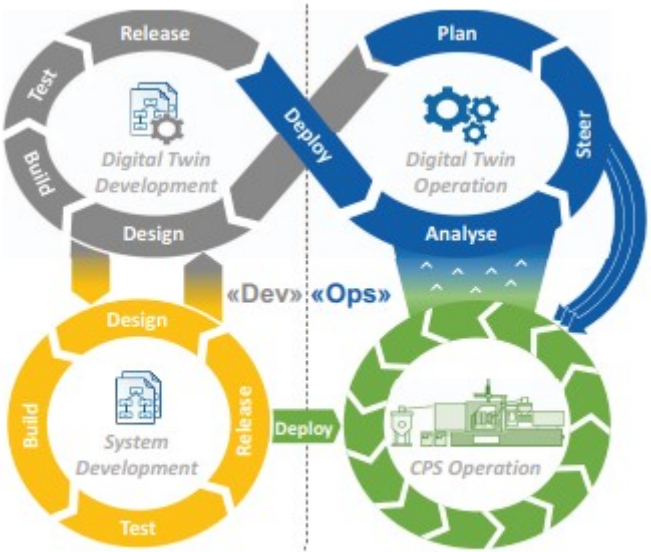
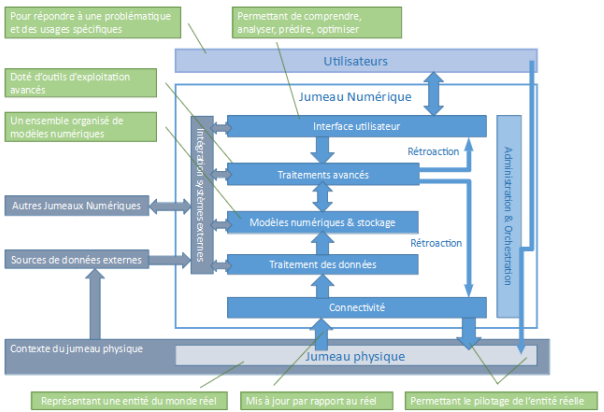
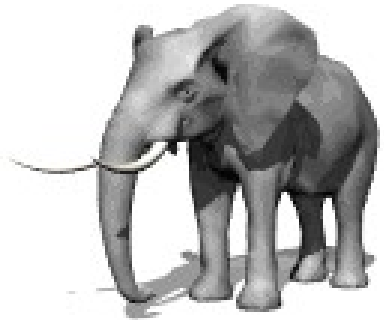


Figure 2: Envisioned impact of MBDO on system development and CPS operation.

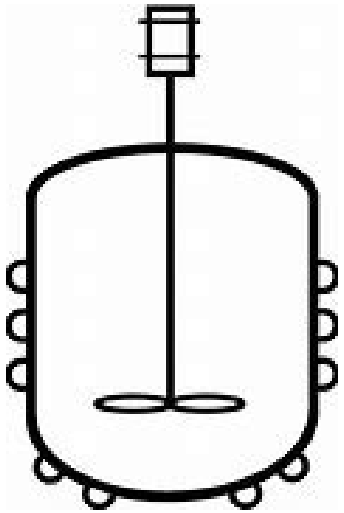


Introduction

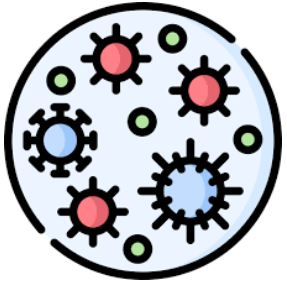
What's a digital twin?



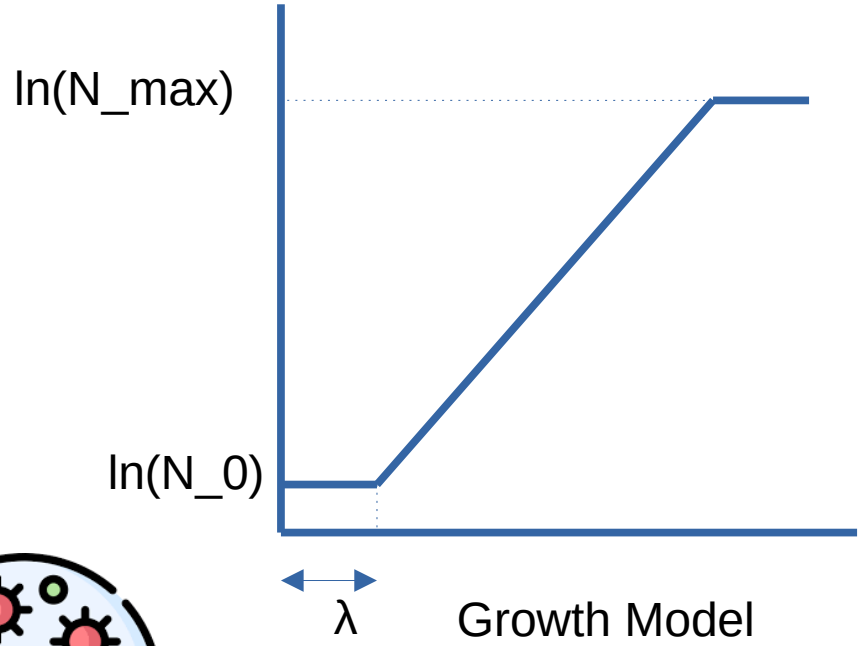
Starting point



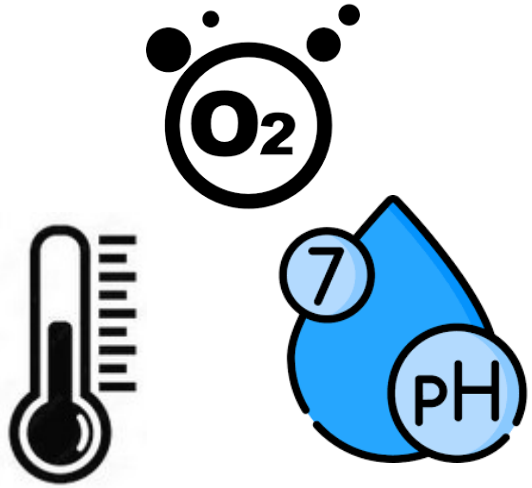
Equipment



Starting conditions



Growth Model



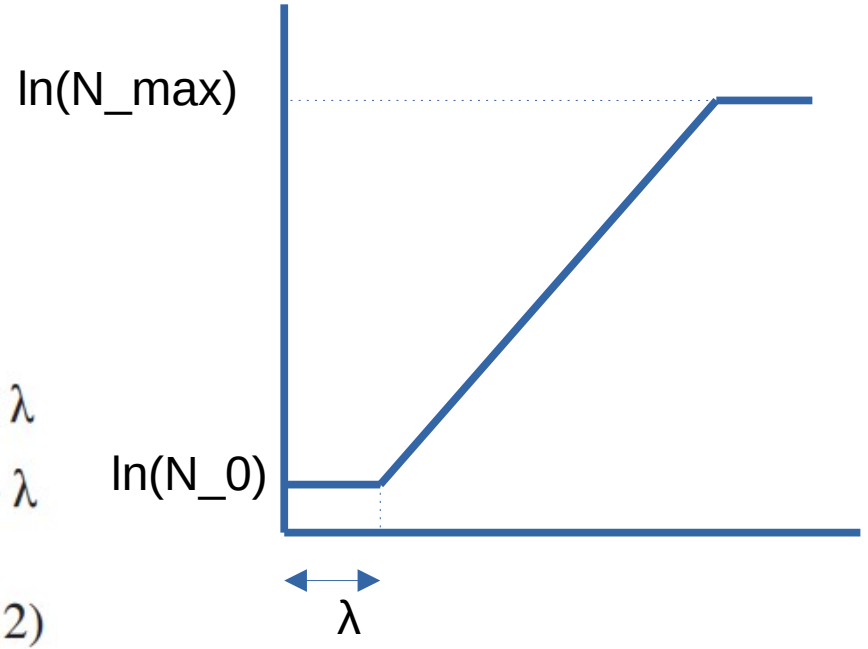
Environmental factors

Exponential Growth

$$\ln[N(t)] = \begin{cases} \ln(N_0) & \text{si } t \le \lambda \\ \ln(N_0) + \mu(t-\lambda) & \text{si } t > \lambda \\ \ln(N_{max}) & \text{si } N(t) \ge N_{max} \end{cases} \quad \text{(Éq. 1)}$$

$$\ln[N(t)] = \begin{cases} \ln(N_0) & \text{si } t \le \lambda \\ \ln(N_{max}) - \ln\left[1 + \left(\frac{N_{max}}{N_0} - 1\right) e^{[-\mu(t-\lambda)]}\right] & \text{si } t > \lambda \end{cases}$$

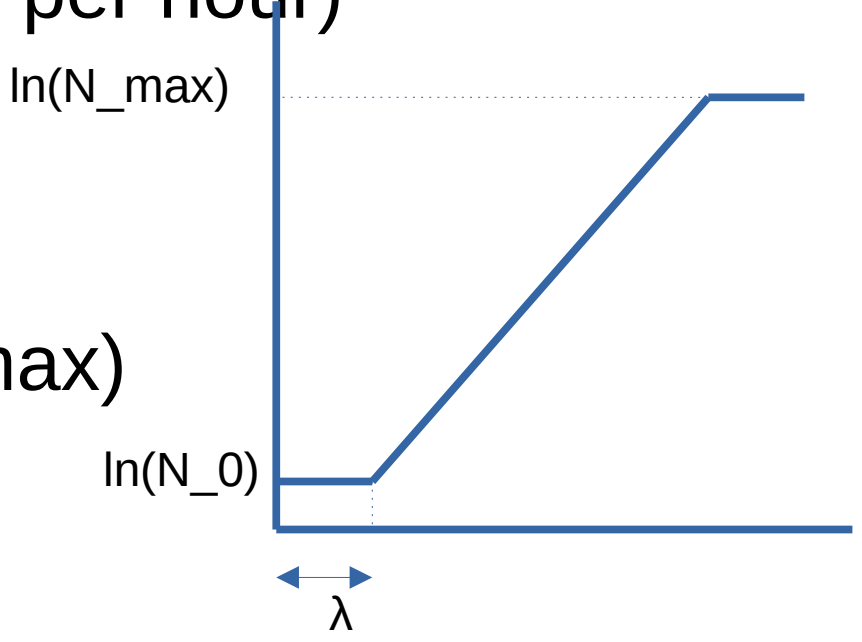
(Éq. 2)



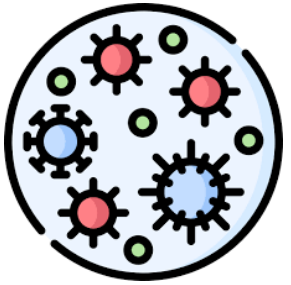
Exponential Growth

With μ the rate of growth (ln per hour)

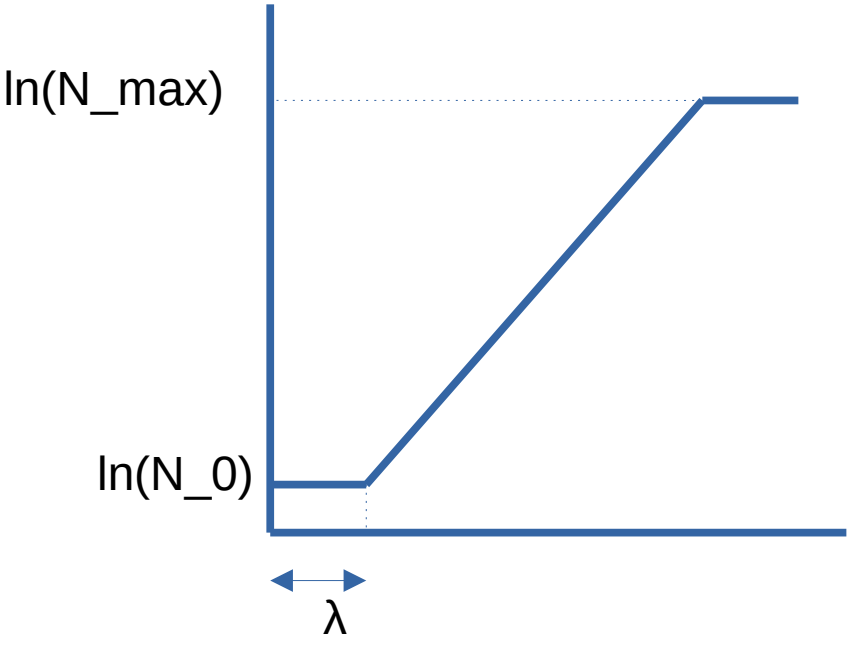
- Latency phase (μ = 0)
- Acceleration phase
- Exponential phase (μ = μ_max)
- Deceleration phase
- Stationary phase (μ = 0)



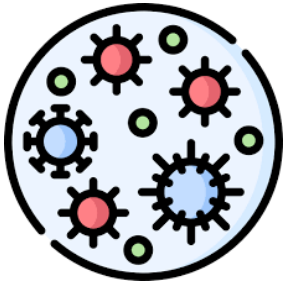
Biomass parameters



- Population
  - Initial & maximum
  - Bactery per gram or ml
- Latency (λ, in hours)
- Growth rate (μ, ln per hour)
  - Optimal and/or maximal
- Constant k (μ_max * λ)

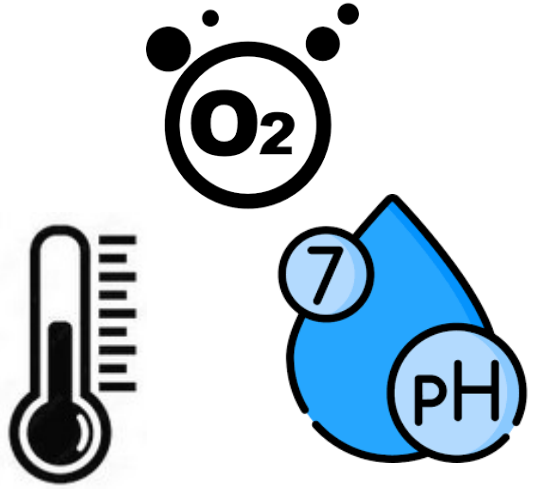


Biomass parameters



For each environmental factor (acidity, temperature, oxygen, …) :

- Minimal value for growth
- Maximal value for growth
- Optimal value for growth



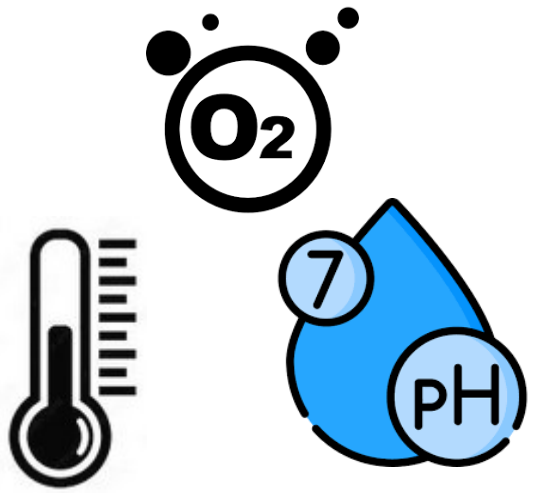
“Gamma” formulae

$$\mu_{max} = \mu_{opt}\gamma(T)\gamma(pH)\gamma(a_w) \qquad \text{(Éq. 8)}$$

$$\gamma(T) = \left[\frac{T - T_{min}}{T_{opt} - T_{min}}\right]^2 \qquad \text{(Éq. 9)}$$

$$\gamma(pH) = \frac{(pH - pH_{min})(pH_{max} - pH)}{(pH_{opt} - pH_{min})(pH_{max} - pH_{opt})} \qquad \text{(Éq. 10)}$$

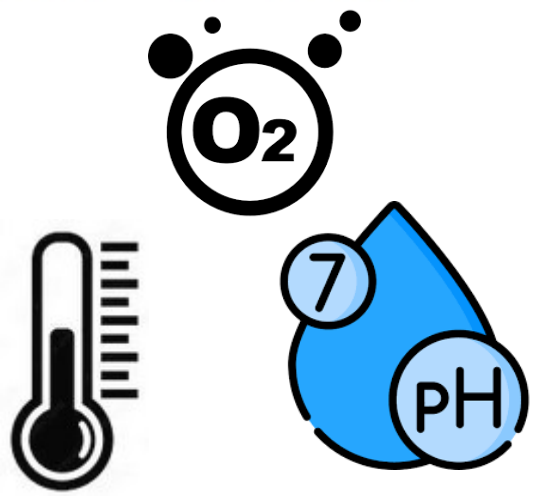
$$\gamma(a_w) = \frac{a_w - a_{wmin}}{1 - a_{wmin}} \qquad \text{(Éq.11)}$$

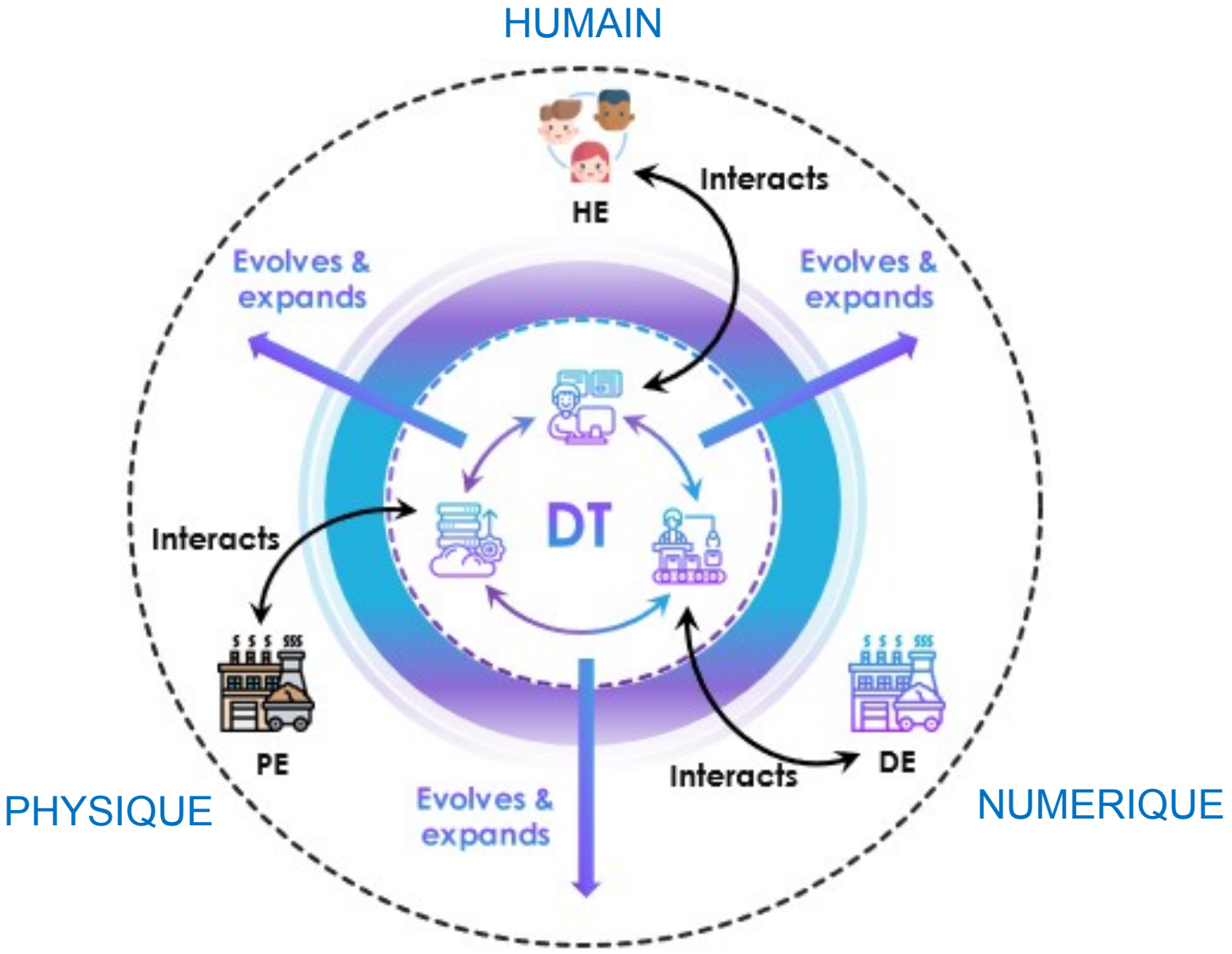


“Gamma” generic formula

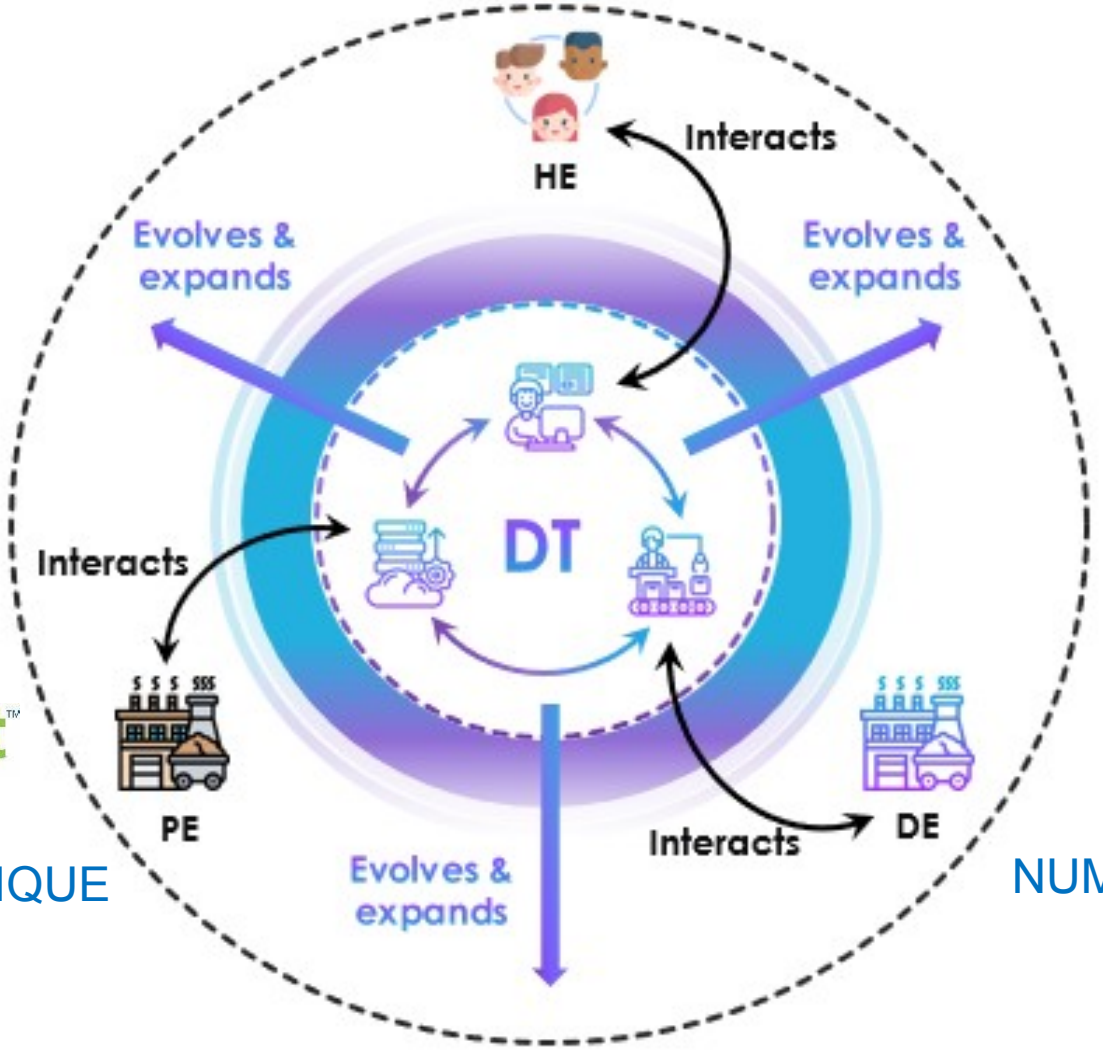
$$CM_n(X) = \begin{cases} 0, & X \le X_{min} \\ \dfrac{(X - X_{max})(X - X_{min})^n}{(X_{opt} - X_{min})^{n-1}[(X_{opt} - X_{min})(X - X_{opt}) - (X_{opt} - X_{max})((n-1)X_{opt} + X_{min} - nX)]} & X_{min} < X < X_{max} \\ 0, & X \ge X_{max} \end{cases} \quad \text{(Éq. 13)}$$

$$\mu_{max} = \mu_{opt} CM_2(T) CM_1(pH) CM_2(a_w) \prod_{i=1}^{n} \gamma(c_i) \prod_{j=1}^{p} k_j \quad \text{(Éq. 14)}$$




HUMAIN
HE
Interacts
Evolves & expands
Evolves & expands
DT
Interacts
PE
PHYSIQUE
Evolves & expands
Interacts
DE
NUMERIQUE

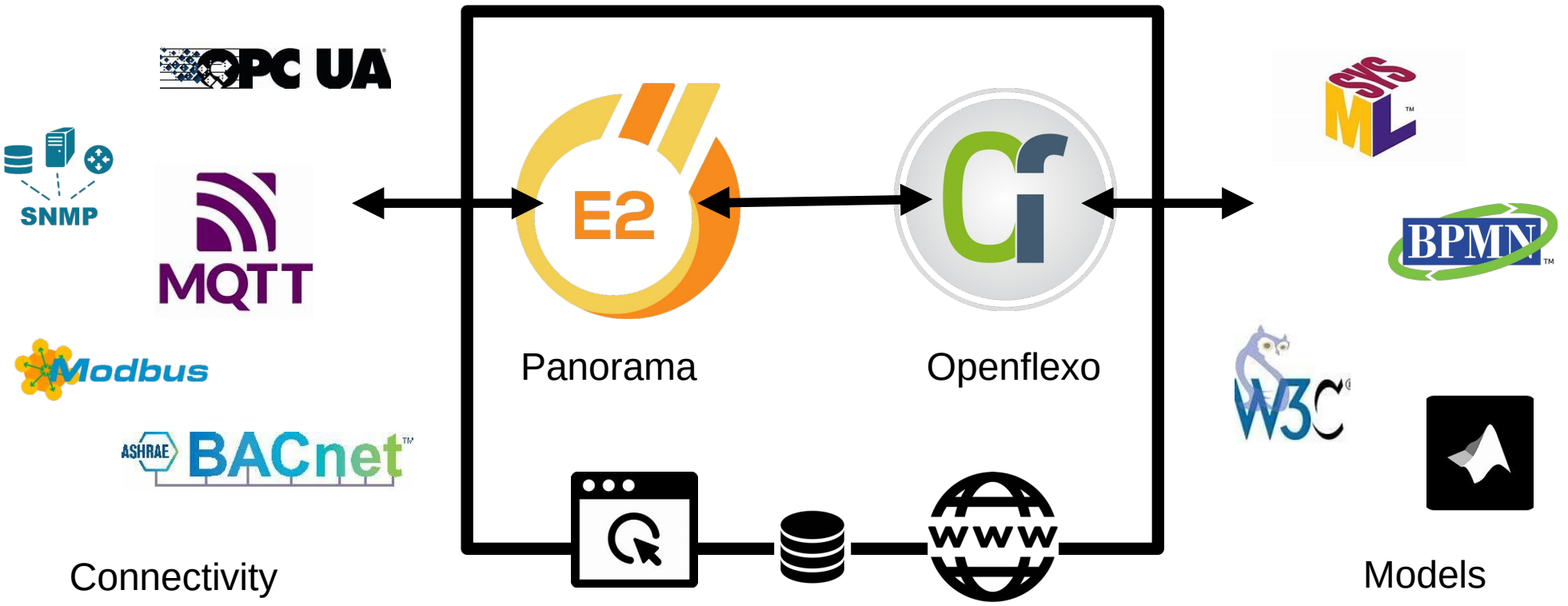
HUMAIN



PHYSIQUE

NUMERIQUE

Technological overview

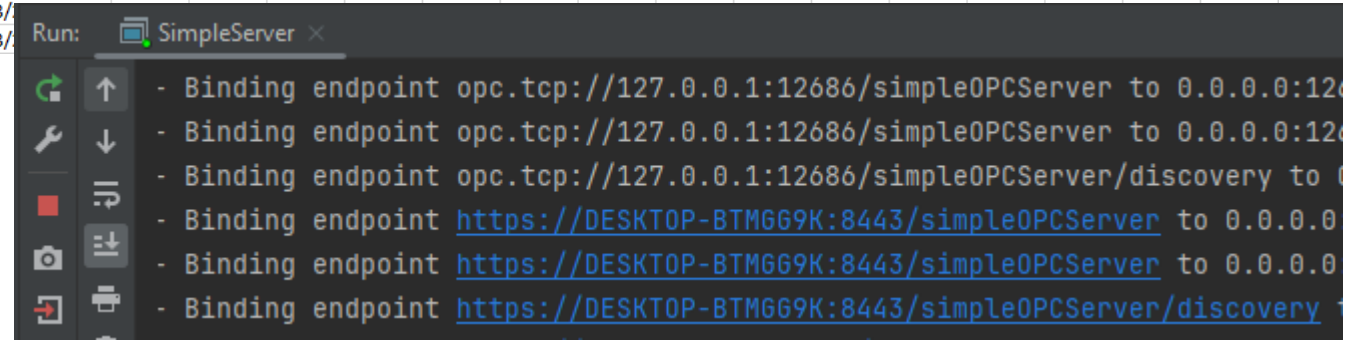


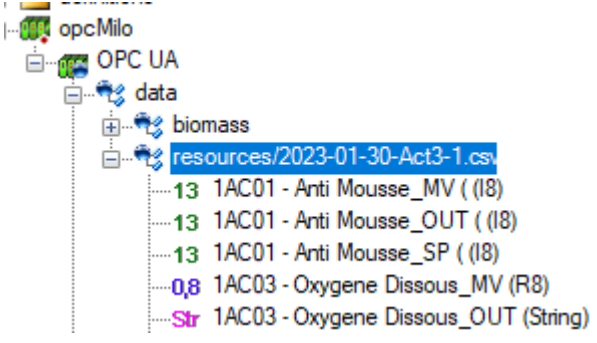
Bioreactor + DT : usages

- V1
  - Emulation, replay (parameters tuning, diagnostic)
  - Monitoring (visualization, alarms, over already existing control)
- V2
  - Prediction, Inference
  - Mitigation (on top of monitoring)
- V3
  - “Full control” ???

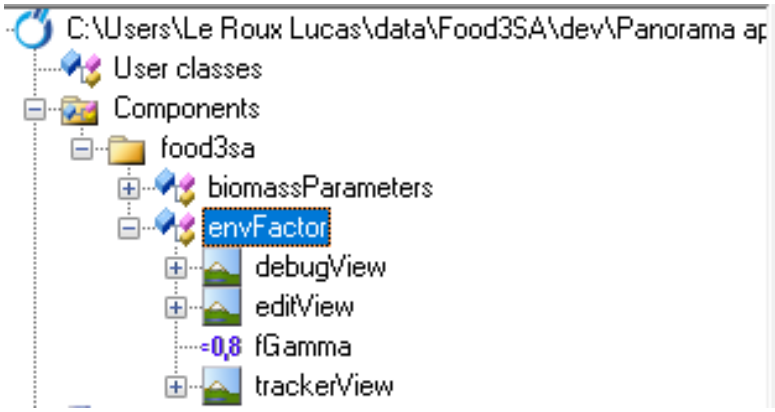
Emulation / Replay / Monitoring

Date	1TE01 -	1AE02 -	1AE03 -	1AE05 -	1AE06 -	1MT01 -	1PP23 -	1AE01 -	1FV50 -	1SC01 -	1SC01 -	1SC01 -	1TC01 -	1TC01 -	1TC01 -
06/03/2023 18:04	29,3152	85,899	6,94105	-0,2698	-109,18	400	8	0	0,49785	400	400	40	29,3152	30	13,1118
06/03/2023 18:05	29,3482	85,9656	6,96772	-0,2097	-109,18	400	8	0	0,49985	400	400	40	29,3482	30	12,8299
06/03/2023 18:05	29,1265	85,879	6,96678	-0,2698	-109,18	400	8	0	0,49986	400	400	40	29,1265	30	15,3666
06/03/2023 18:06	29,1445	85,8856	6,96304	-0,2498	-109,18	400	8	0	0,49993	400	400	40	29,1445	30	14,662
06/03/2023 18:06	29,1834	87,1385	6,96538	-0,3099	-109,18	400	8	0	0,50008	400	400	40	29,1894	30	14,3519
06/03/2023 18:07	29,2164	89,2043	6,9621	-0,2698	-109,18	400	8	0	0,49984	400	400	40	29,2164	30	14,0701
06/03/2023 18:07	29,2463	90,6238	6,97006	-0,2698	-109,18	400	8	0	0,50006	400	400	40	29,2463	30	13,8164
06/03/2023 18:08	29,3152	91,71	6,98784	-0,2498	-109,18	400	8	0	0,50019	400	400	40	29,3152	30	13,1118
06/03/															
06/03/															

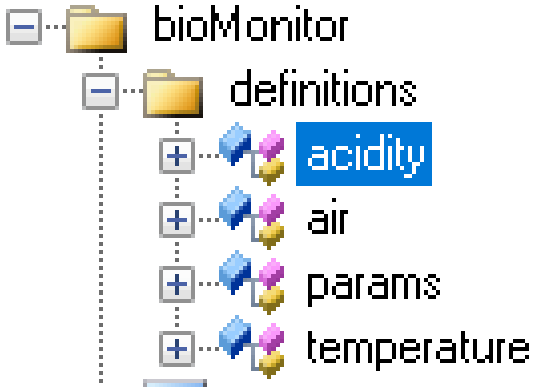




Emulation / Replay / Monitoring

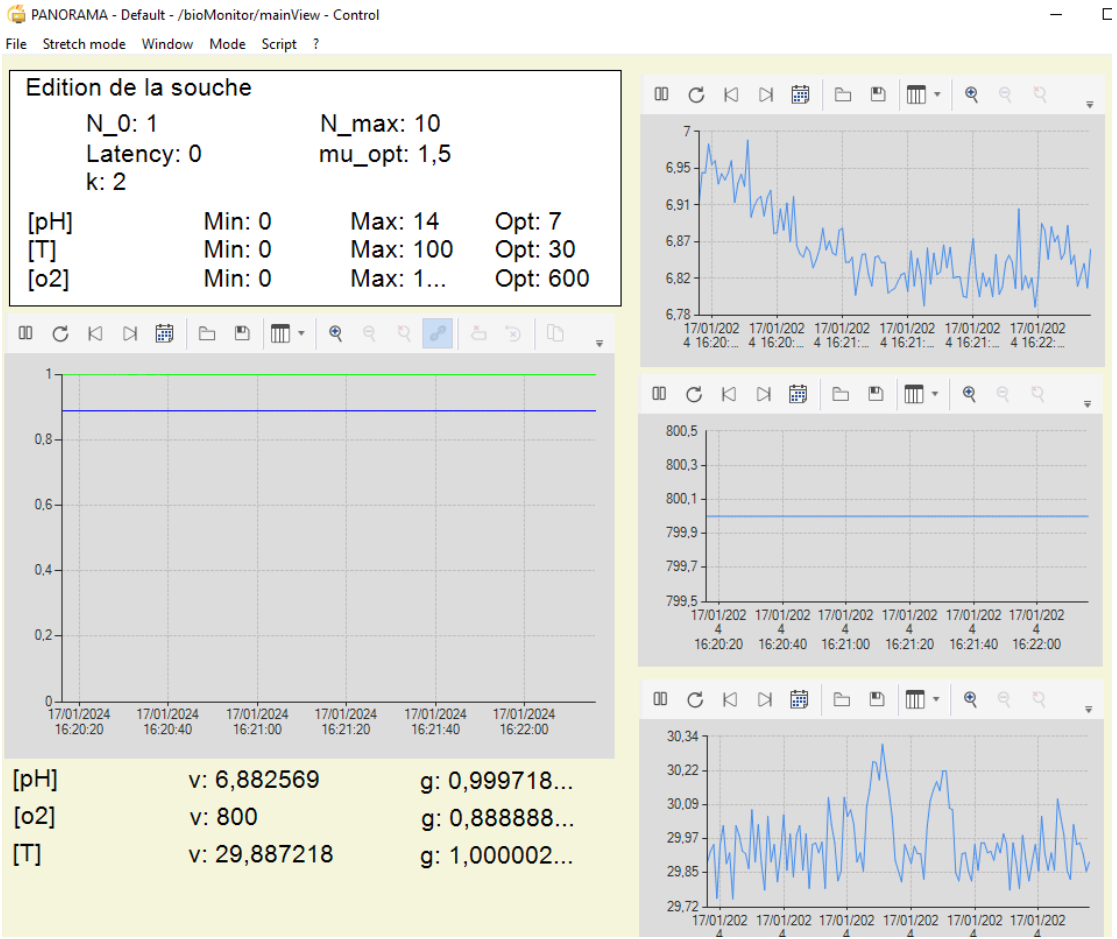


Name	Type	Kind
fCurrent	Real	Value
fMax	Real	Adjustable
fMin	Real	Adjustable
fN	Integer	Configuration
fName	String	Configuration
fOpt	Real	Adjustable
fUnit	String	Configuration

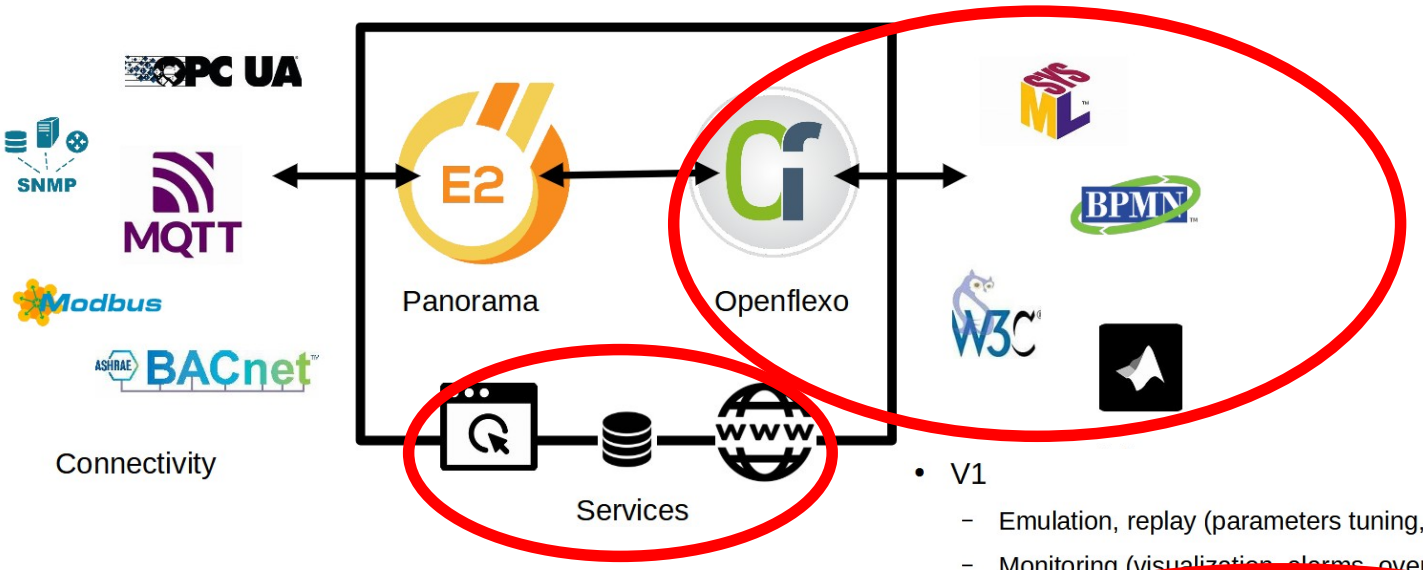


Name	Value	Link
fName	**pH**	
fUnit		
fN	**1**	
fMax	**14**	
fMin	0	
fOpt	**7**	
fCurrent	**0**	**OPC:../opcMilo,...**

Emulation / Replay / Monitoring



What’s next?



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