Bayes from Cell to Chip

Pierre Bessière

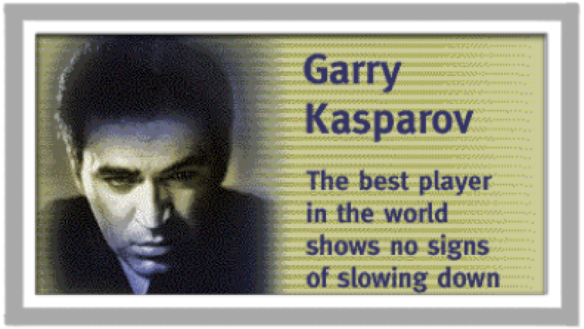
Pierre.Bessiere@sorbonne-universite.fr - Pierre.Bessiere@HawAI.tech

Topics

- Logic or probability as a paradigm of rationality ?
- Bayesian programming ?
- Is Brain Bayesian ? Is Cell Bayesian ?
- Probabilistic hardware for AI ?

Close and open problems

Who is the cleverest ?



Close and open problems
Examples

Close

- Accounting
- SQL request
- Text, image, and video compression

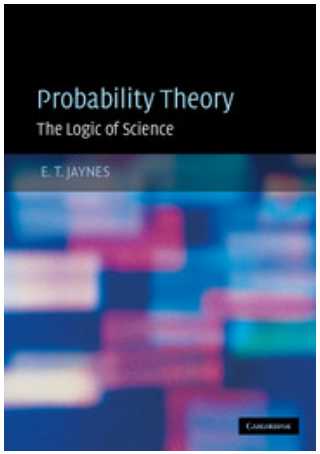
Open

- Financial decision
- Web search
- Text, image and video classification
- Sensors acquisition, fusion and classification
- Medical, mechanical and electronic diagnostic
- Fraud and malevolent behaviours detection
- Financial, natural and industrial risk prevision
- Robots, drones and cars control and autonomy

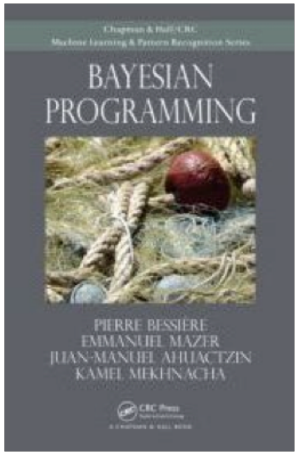
Close problems have been solved by past computer science

Open problems have to be solved by future computer science

To go further: Probability as an extension of logic



Jaynes, E. T. (2003). *Probability Theory: the Logic of Science*. Cambridge University Press.



Bessière, P., Mazer, E., Ahuactzin, J.-M., and Mekhnacha, K. (2013). *Bayesian Programming*. Chapman and Hall/CRC.

- Dedieu, E. (1995). La représentation contingente. PhD thesis, Inst. Nat. Polytechnique de Grenoble.
- Bessière, P., Dedieu, E., Lebeltel, O., Mazer, E., and Mekhnacha, K. (1998). Interprétation ou description (i) : Proposition pour une théorie probabiliste des systèmes cognitifs sensori-moteurs. Intellectica, 26:257–311.
- Bessière, P., Dedieu, E., Lebeltel, O., Mazer, E., and Mekhnacha, K. (1998). Interprétation ou description (ii) : Fondements mathzmatiques de l'approche f+d. Intellectica, 26:313–336.
- Colas, F., Diard, J., and Bessière, P. (2010). Common bayesian models for common cognitive issues. Acta Biotheoretica, 58(2-3):191–216.

Bayesian Programming

Program

Description

Specification

- Variables

$$S^0, \ldots\ldots, S^t, O^0, \ldots\ldots, O^t$$

- Decomposition (Conditional Independance Hypotheses)

$$\mathbf{P}(S^0 \wedge \ldots\ldots \wedge S^t \wedge O^0 \wedge \ldots\ldots \wedge O^t) = \mathbf{P}(S^0) \times \mathbf{P}(O^0 \mid S^0) \times \prod_{i=2}^{t} [\mathbf{P}(S^i \mid S^{i-1}) \times \mathbf{P}(O^i \mid S^i)]$$

- Parametric Forms

$$\mathbf{P}(S^0) \equiv \mathbf{G}(S^0, \mu, \sigma)$$
$$\mathbf{P}(S^i \mid S^{i-1}) \equiv \mathbf{G}(S^i, A \bullet S^{i-1}, Q)$$
$$\mathbf{P}(O^i \mid S^i) \equiv \mathbf{G}(O^i, H \bullet S^i, R)$$

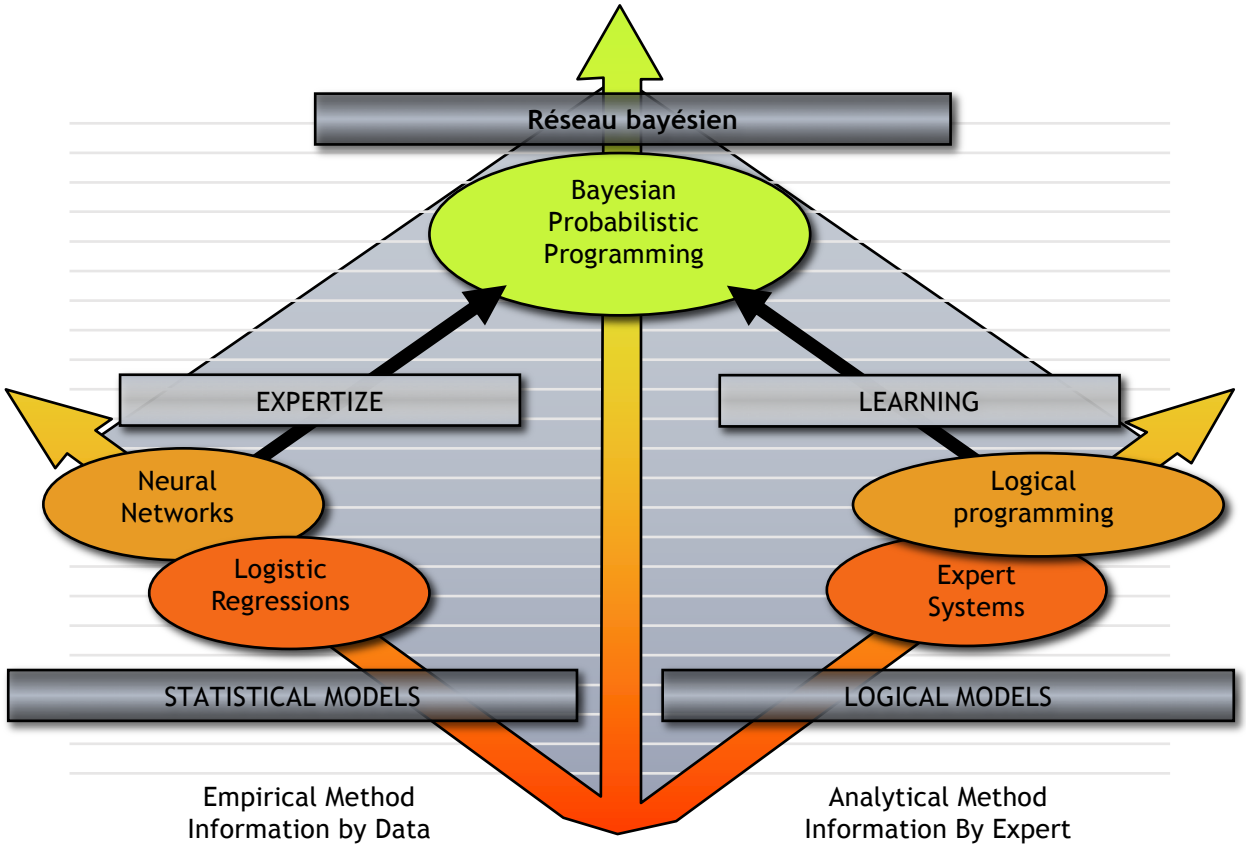
Identification

- Learning from instances

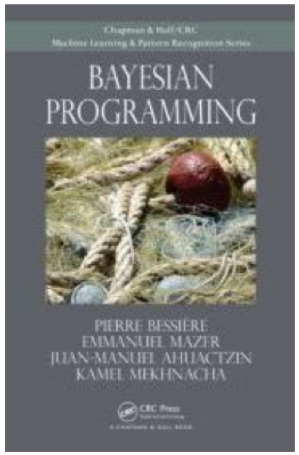
Question

$$\mathbf{P}(S^t \mid O^0 \wedge \ldots\ldots \wedge O^t)$$

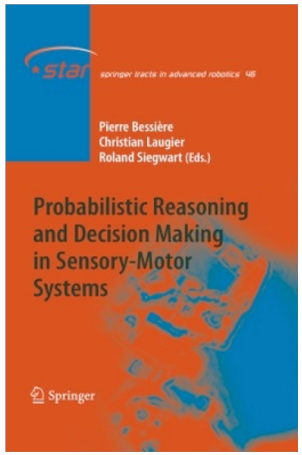
BP in between learning and programming



To go further: Bayesian programming methodology and applications



Bessière, P., Mazer, E., Ahuactzin, J.-M., and Mekhnacha, K. (2013). *Bayesian Programming*. Chapman and Hall/CRC.

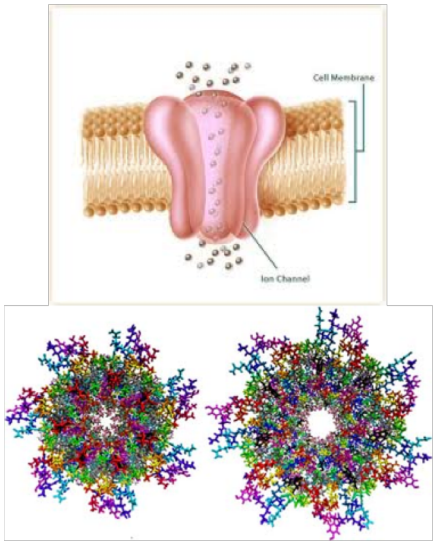


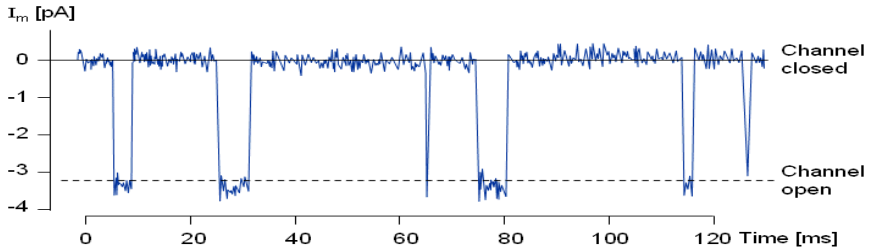
Bessière, P., Laugier, C., and Siegwart, R. (2008). Probabilistic Reasoning and Decision Making in Sensory-Motor Systems. Springer.

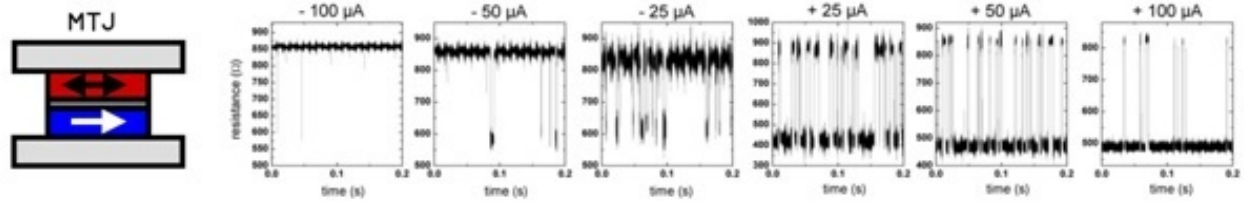
- Lebeltel, O., Bessière, P., Diard, J., and Mazer, E. (2004). Bayesian robot program- ming. *Advanced Robotics*, 16(1):49–79.
- Le Hy, R., Arrigoni, A., Bessière, P., and Lebeltel, O. (2004). Teaching Bayesian Behaviours to Video Game Characters. *Robotics and Autonomous Systems*, 47:177–185.
- Pradalier, C., Hermosillo, J., Koike, C., Braillon, C., Bessière, P., and Laugier, C. (2005). The CyCab: a car-like robot navigating autonomously and safely among pedestrians. *Robotics and Autonomous Systems*, 50(1):51–68.
- Coué, C., Pradalier, C., Laugier, C., Fraichard, T., and Bessière, P. (2006). Bayesian Occupancy Filtering for Multitarget Tracking: an Automotive Application. *International Journal of Robotics Research*, 25(1):19–30.
- Diard, J., Gilet, E., Simonin, E., and Bessière, P. (2010). Incremental learning of Bayesian sensorimotor models: from low-level behaviours to large-scale structure of the environment. *Connection Science*, 22(4):291–312.
- Balaniuk, R., Bessière, P., Mazer, E., and Cobbe, P. (2013). Corruption risk analysis using semi-supervised naïve Bayes classifiers. *International Journal of Reasoning-based Intelligent Systems*, 5(4):237–245.
- Synnaeve, G. and Bessière, P. (2015). Multi-scale bayesian modeling for rts games: an application to starcraft ai. *IEEE Transactions on Computational Intelligence and AI in Games*.
- Coninx, A., Bessière, P., and Droulez, J. (2016). Quick and energy-efficient bayesian computing of binocular disparity using stochastic digital signals. *International Journal of Approximate Reasoning*

ProbaYes.com

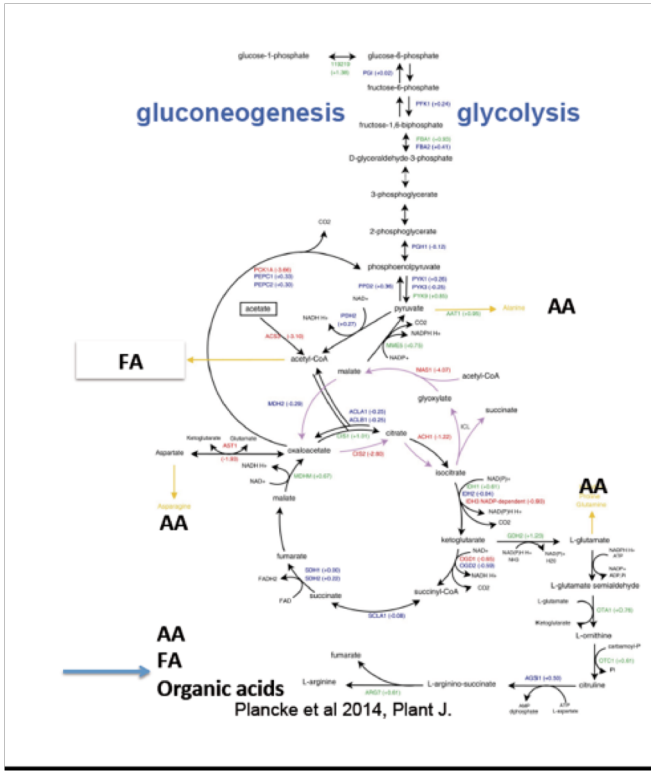
Stochastic bit generation



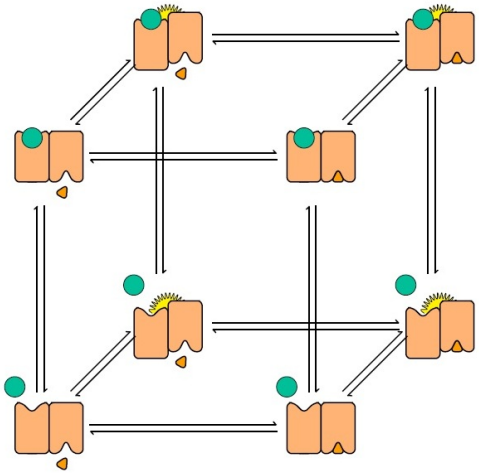




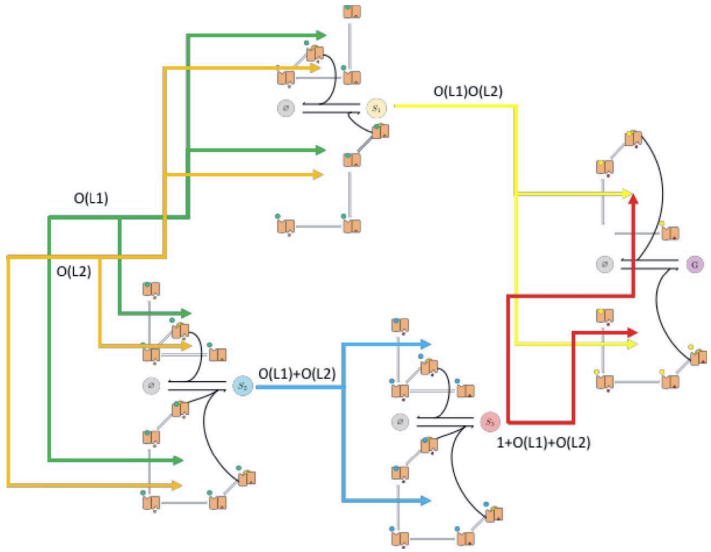
A Bayesian vision on cell signaling



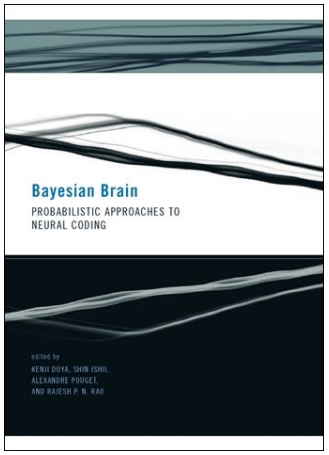
Markov Chain model of macromolecular configuration dynamics:
Equilibrium state = RFNC = Result of Prob. Inference



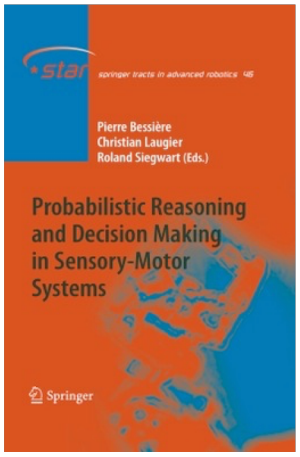
Cascade of macromolecules and messengers to perform a phototactic behavior (Colliaux et al, 2017)



To go further: Bayesian biology and psychology



Kenji Doya, Shin Ishii, Alexandre Pouget and Rajesh Rao (2006). *Bayesian Brain: Probabilistic approach to neural coding*. MIT Press.



Bessière, P., Laugier, C., and Siegwart, R. (2008). Probabilistic Reasoning and Decision Making in Sensory-Motor Systems. Springer.

Stanislas Dehaene :

[Le cerveau statisticien : la revolution bayésienne en science cognitive]

[Le bébé statistician : les theories bayésiennes de l'apprentissage]

- Serkhane, J., Schwartz, J.-L., and Bessière, P. (2005). Building a talking baby robot A contribution to the study of speech acquisition and evolution. *Interaction Studies*, 6(2):253–286.
- Laurens, J. and Droulez, J. (2007). Bayesian processing of vestibular information. *Biological Cybernetics*, 96:389–404
- Colas, F., Droulez, J., Wexler, M., and Bessière, P. (2008). A unified probabilistic model of the perception of three-dimensional structure from optic flow. *Biological Cybernetics*, pages 132–154.
- Colas, F., Flacher, F., Tanner, T., Bessière, P., and Girard, B. (2009). Bayesian models of eye movement selection with retinotopic maps. *Biological Cybernetics*, 100(3):203–14.
- Houillon, A., Bessière, P., and Droulez, J. (2010). The probabilistic cell: implementation of a probabilistic inference by the biochemical mechanisms of phototransduction. Acta Biotheoretica, 58(2-3):103–120.
- Gilet, E., Diard, J., and Bessière, P. (2011). Bayesian action–perception computational model: Interaction of production and recognition of cursive letters. *PLoS ONE*, 6(6):e20387.
- Moulin-Frier, C., Laurent, R., Bessière, P., Schwartz, J.-L., and Diard, J. (2012). Adverse conditions improve distinguishability of auditory, motor and percep-tuo-motor theories of speech perception: an exploratory Bayesian modeling study. *Language and Cognitive Processes*, 27(7-8 Special Issue: Speech Recognition in Adverse Conditions):1240–1263.
- Diard, J., Bessière, P., and Berthoz, A. (2013). Spatial memory of paths using circular probability distributions: Theoretical properties, navigation strategies and orientation cue combination. *Spatial cognition and computation*, 13(3):219–257.
- Laurent, R., Moulin-Frier, C., Bessière, P., Schwartz, J.-L., and Diard, J. (2013). Integrate, yes, but what and how? a computational approach of perceptuo-motor fusion in speech perception. *Behavioral and Brain Sciences (BBS)*, 36(4):36–37.
- Colliaux, D., Bessière, P., and Droulez, J. (2016). Cell signaling as a probabilistic computer. *International Journal of Approximate Reasoning*
- Schwartz, J.-L., Barnaud, M.-L., Bessière, P., Diard, J., and Moulin-Frier, C. (2016). Phonology in the mirror. *Physics of Life Reviews*, 16:93–95.
- Laurent, R., Barnaud, M.-L., Schwartz, J.-L., Bessière, P., and Diard, J. (2017). The complementary roles of auditory and motor information evaluated in a Bayesian perceptuo-motor model of speech perception. *Psychological Review*.

HawAI.tech

Hardware for AI

Born : January 2nd 2019

V I S I O N

Logic

Von Neumann

Rebooting computing

- Quantum Computing
- Neural Net Computing
- Probabilistic Computing
- Bio Computing
- …

Bayesian ASIC

(B)ASIC

Perceive & Synthetize

Bayesian Processing Unit

(B)PU

Predict & Decide

Bayesian Learning

(B)LEARN

Adapt & Learn

HawAI.tech credo

Develop and promote

Mathematical methods, algorithms

Electronic components, circuits

Integrated electronic devices and machines

For

Probabilistic Artificial Intelligence

Intel and Probabilistic Hardware

« We plan to develop technology that integrates probabilistic models and Monte Carlo inference into programming languages, compilers, runtime systems, and microarchitectures »

Mike Mayberry, Intel CTO, 10 may 2018

Probabilistic hardware for AI

- Acceleration of existing MCMC algorithms on FPGA (now)
- ★ (B)ASIC : Ultra-low power consumption stochastic ASIC for IoT (3 years - IP cores)
- ★ (B)PU : Very high throughput MCMC coprocessors for simulation and prediction (5 years – IP cores)
- (B)Learn : Circuits with online learning and adaptation capabilities (7 years)

VISION

(B)ASIC

(B)ASIC : Ultra-low power consumption

stochastic ASIC for IoT (3 years - IP cores)

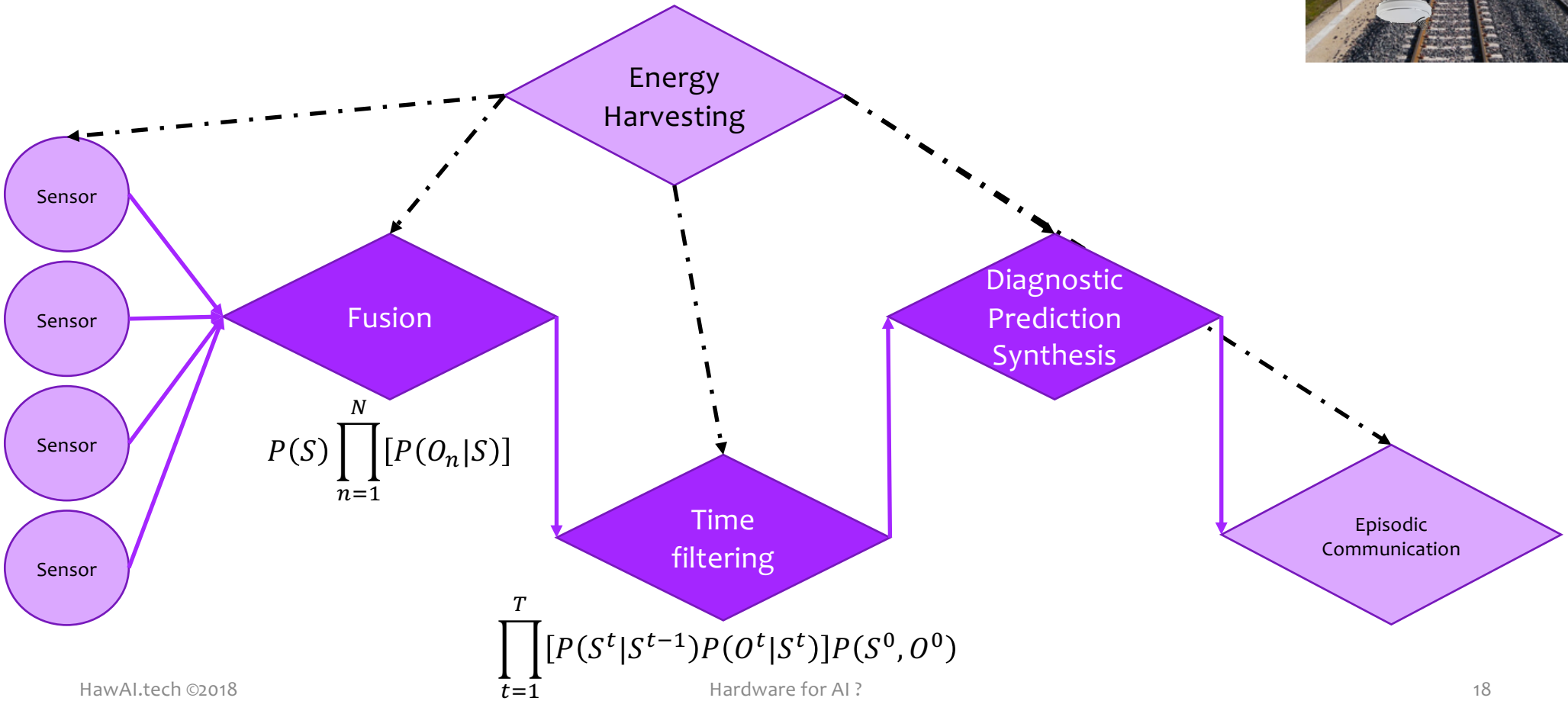
Constellation of sensors

Large industrial equipment monitoring

Natural risk monitoring

Building and objects monitoring

Constellation of sensors

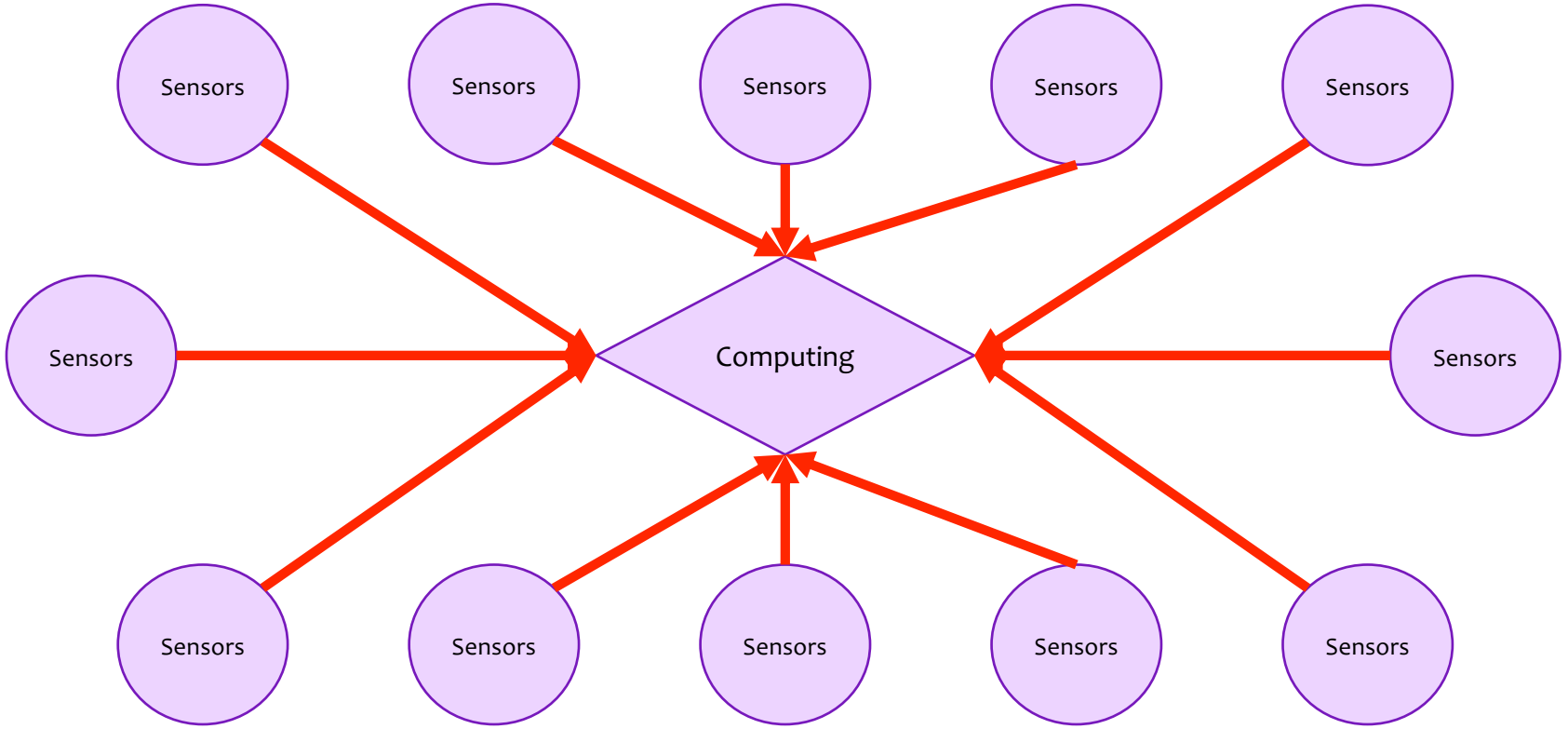


Constellation of sensors
Examples

- Large industrial equipment monitoring
  - Railways
  - Electrical grids
  - Nuclear plants
  - Water and sewer networks
  - Bridges
  - …
- Natural risk monitoring
  - Landslide
  - Floods
  - Forest fires
  - Agricultural monitoring
  - Hurricanes watch
  - …
- Building and objects monitoring
  - Elder safety
  - Energy savings
  - Robbery prevention
  - …

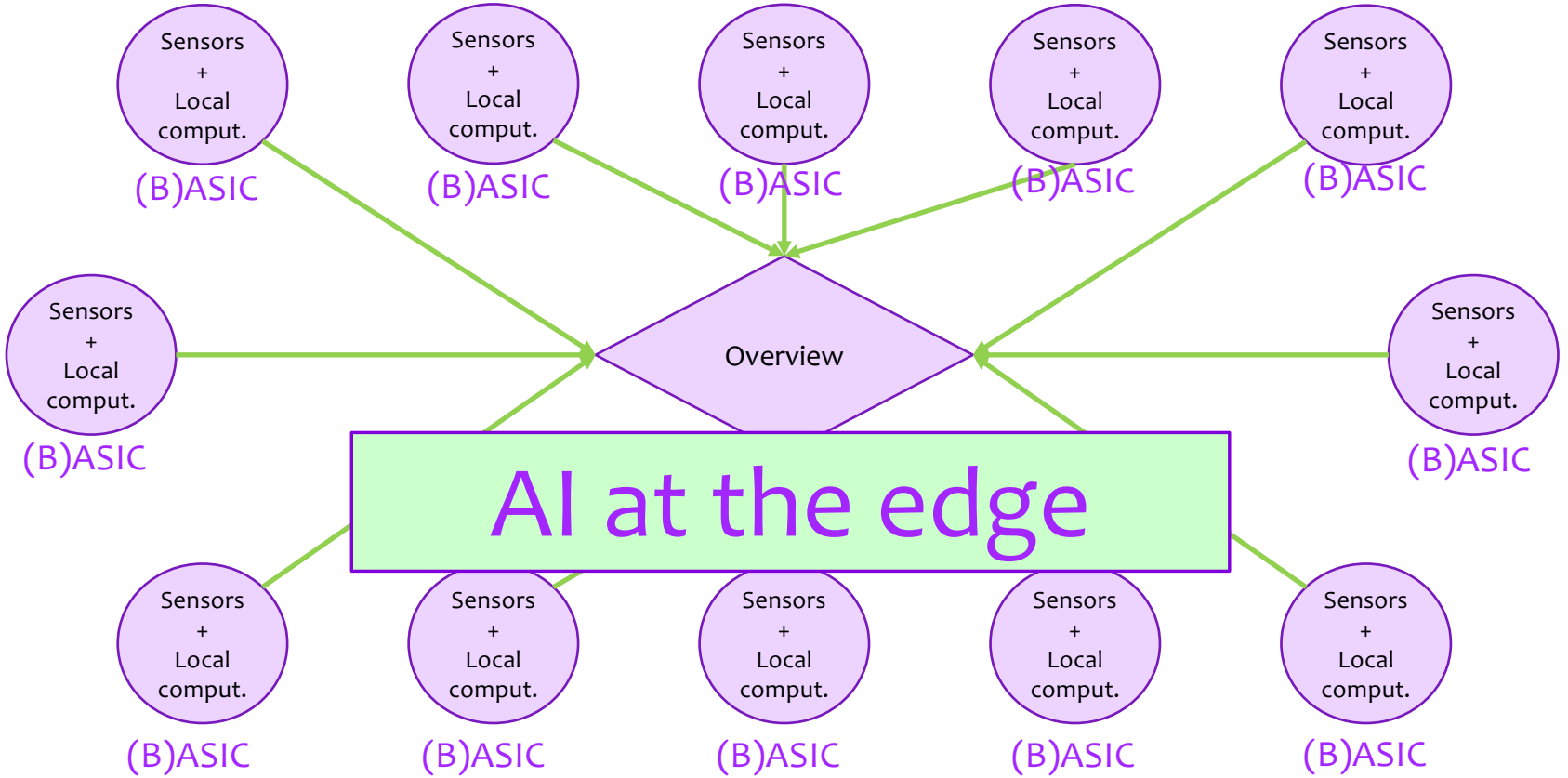
Edge computing

- High bandwidth
- High energy
- Complicated maintenance



Edge computing

- low bandwidth
- low energy
- simple maintenance

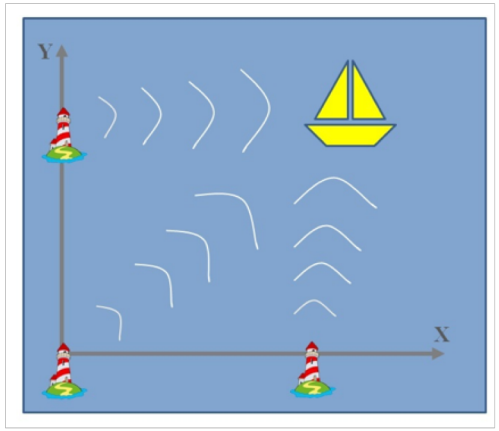


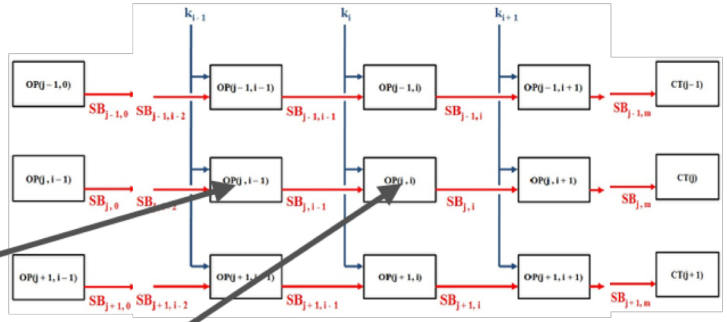
Probabilistic fusion and time filtering

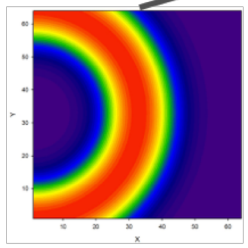
$$P(S, O_1, \cdots, O_N) = P(S) \prod_{n=1}^{N} [P(O_n|S)]$$

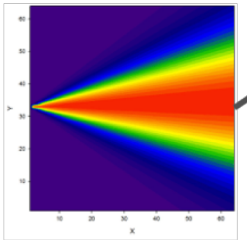
$$P(S^{0\to T}, O^{0\to T}) = \prod_{t=1}^{T} [P(S^t|S^{t-1}) P(O^t|S^t)] P(S^0, O^0)$$

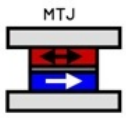
(B)ASIC stochastic architecture

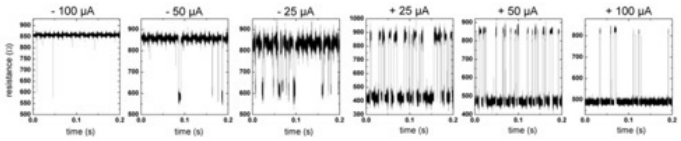


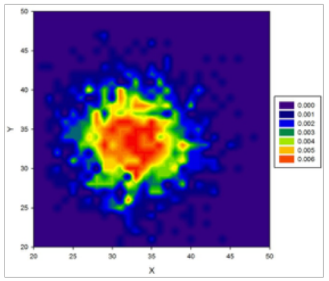




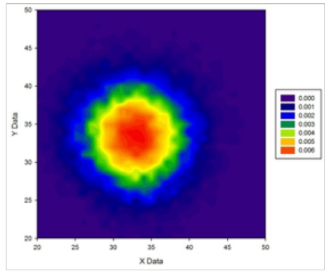




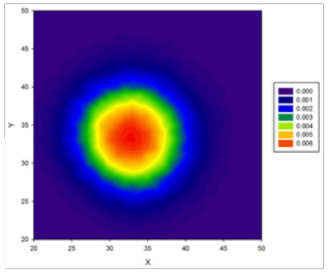




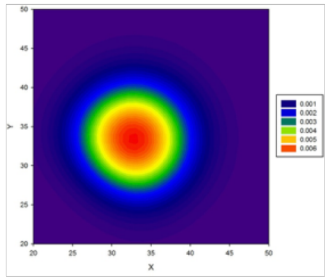
7 clock cycles



100 clock cycles



1000 clock cycles



Exact inference

Bayesian ASIC for IoT

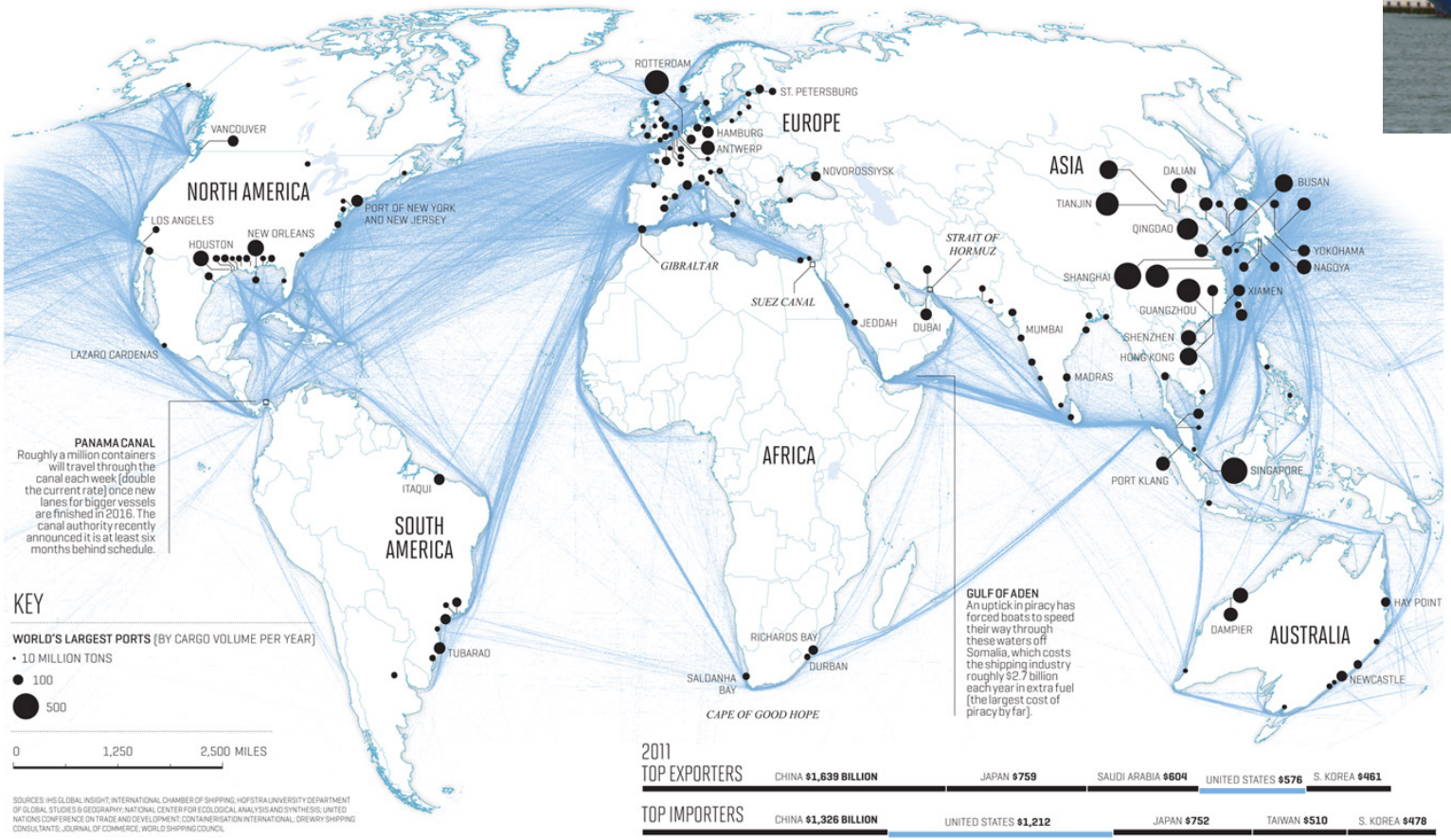
- Continuous or as needed monitoring of signals
- Synthesis for episodic transmission
- Very low power consumption for sensor fusion and time filtering
- IP cores for specific applications
- AI at the edge

(B)ASIC

(B)PU

(B)PU : Very high throughput MCMC programmable coprocessors for simulation and prediction (5 years – IP cores)

Supply chains simulation



Supply chains simulation

Where and when will the empty containers
be returned to be filled again?

- 10^6 Containers
- 10^2 Hubs
- 10^3 Harbours
- 10^4 Repositories
- 10^7 Clients

→ 24 hours of computation once a week

↓ (B)PU

10 minutes twice a day
with 10 times more samples

Probabilistic inference -> MCMC

$$P(S|k) \propto \sum_{F} [P(S,k,F)]$$

(B)PU architecture

Patents

MCMC
Examples

- ★ Price prediction
- ★ Risk analysis and management
- ★ Logistic prediction
- Physical simulation
- Meteorology and climate prediction
- ★ Supply chain simulation and management
- Project management
- Computer graphics
- ★ Predictive maintenance
- ★ Video games AI
- Localization of victims for rescue
- …

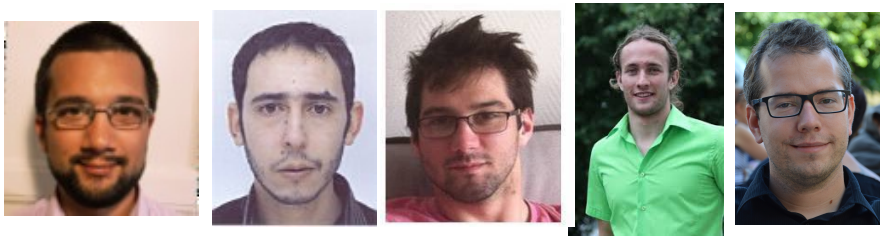
Bayesian Processing Unit

- Coprocessor to simulate, predict and decide
- MCMC hardware accelerator
- Inferring with incomplete and uncertain knowledge

Team

5 young PhD for the core team:

- Jean Simatic (CEO)
- Karim Cherkaoui
- Marvin Faix
- Raphael Frisch
- Raphael Laurent



4 experienced CNRS scientific advisers:

- Pierre Bessière
- Jacques Droulez
- Damien Querlioz
- Emmanuel Mazer

1 Business developer:

- Jean-François Miribel

2 serial start-up creators:

- Jean-François Miribel
- Emmanuel Mazer

3 Business angels:

- Pierre Bessière
- Emmanuel Mazer
- Jean-François Miribel

1 Industrial associate

Looking for clients with real applications

Looking for Corporate VCs for series A