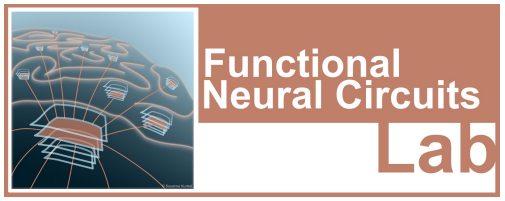


Plasticity and Learning in Neural Circuits

Learning to Play Pong from Reward (and Punishment)

Jenia Jitsev

Institute of Neuroscience and Medicine, INM-6 &
Institute for Advanced Simulation, IAS-6

Functional Neural Circuits Lab (Jülich, Germany)
Lecturers and Tutors : Phillipp Weidel, Susanne Kunkel

Plasticity and Learning in Neural Circuits

Institute for Neuroscience and Medicine (INM-6): Computational and Systems Neuroscience, Functional Neural Circuits Lab (Soon : Computations in Neural Circuits, CiNC)

Adaptation and Learning in Biology and Machines

We currently don't understand how autonomous learning from experience goes in biological organisms.

Lack of insight into fundamental closed-loop : Sense, predict, act, adapt, sense, predict, act, adapt, … → iterative, life-long optimization of behavior

→ That is why we do not understand the brain
→ That is why we cannot build autonomous machines

Adaptive, self-sustaining, autonomous

Engineered, supervised, non-autonomous

Adaptation and Learning in biological organisms

Neural circuits that implement functional behavior

Adaptation and Learning in biological organisms

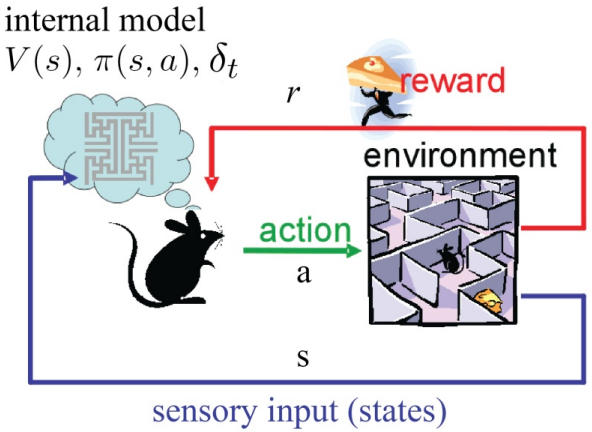
Maintaining long-term system's integrity and well-being

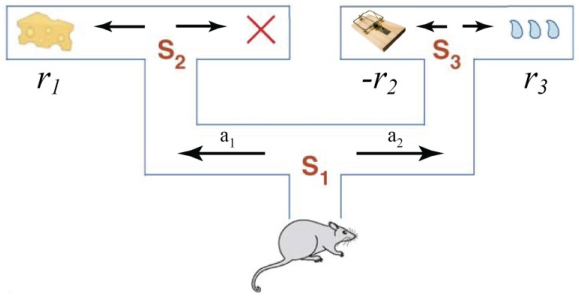
Adaptation and Learning in biological organisms

"What is painful is avoided and what is pleasant is pursued."
(Aristotle, De Motu Animalium, 400 B.C.)

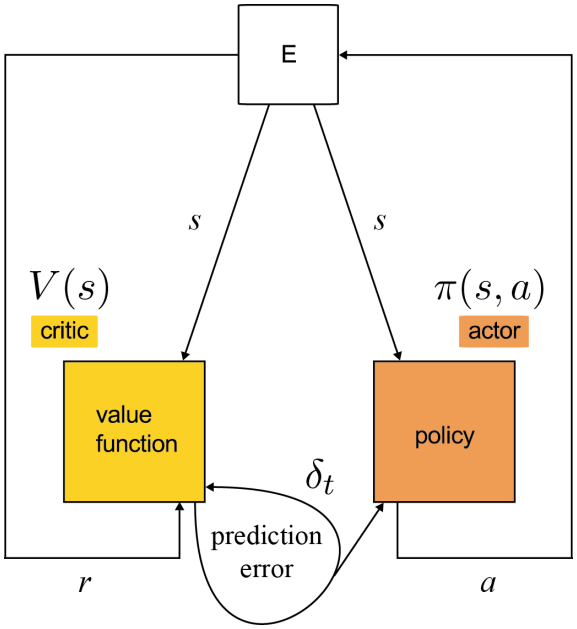
Neural Circuits for Autonomous Learning

Problem : optimal control





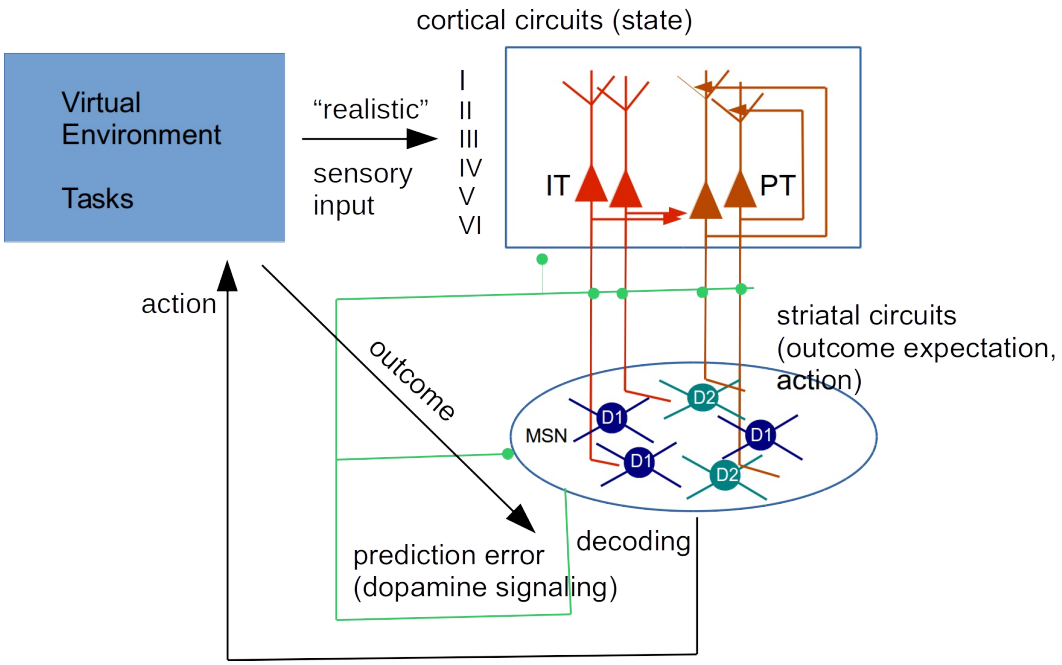
A solution : algorithm, computations utilized (e.g., temporal-difference learning, prediction error computation, ...)



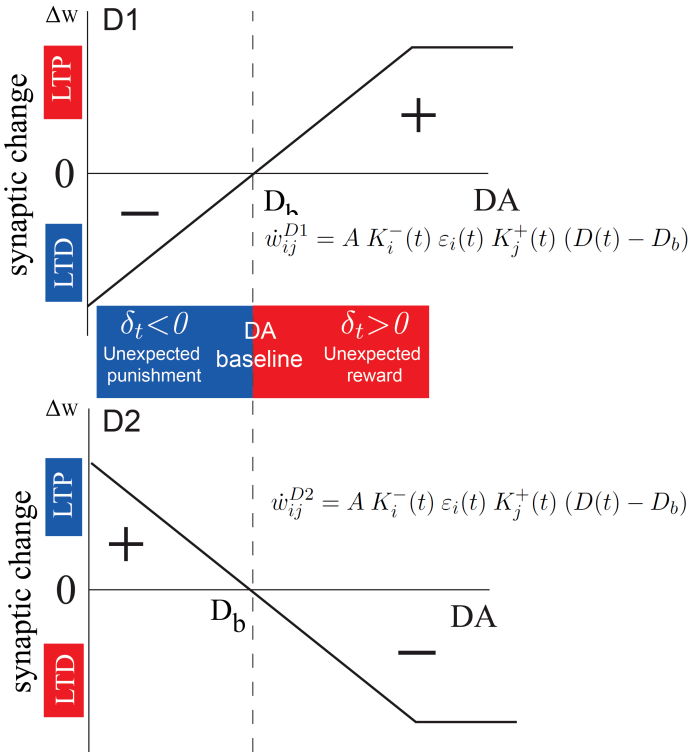
$$\delta_t = r_{t+1} + \gamma V(s_{t+1}) - V(s_t),$$
$$V(s_t) \leftarrow V(s_t) + \alpha\delta_t,$$
$$\pi(s,a) \leftarrow \pi(s,a) + \varepsilon\delta_t,$$
$$p(a|s) = \frac{e^{-\beta\pi(s,a)}}{\sum_{a' \in \mathcal{A}(s)} e^{-\beta\pi(s,a')}}$$

Neural Circuits for Autonomous Learning

Closed loop modeling of neural circuitry
(simulate neural network learning a task)

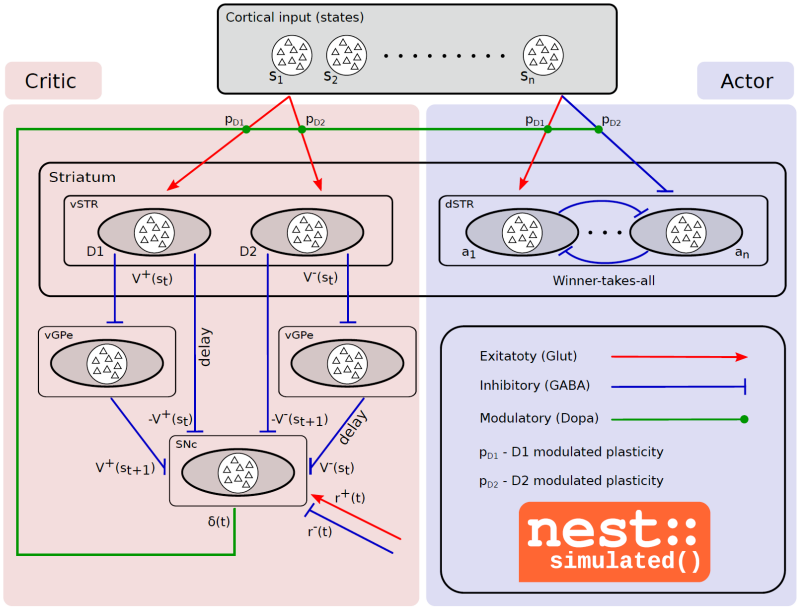


Synaptic plasticity rules
(Dopamine rulez !)

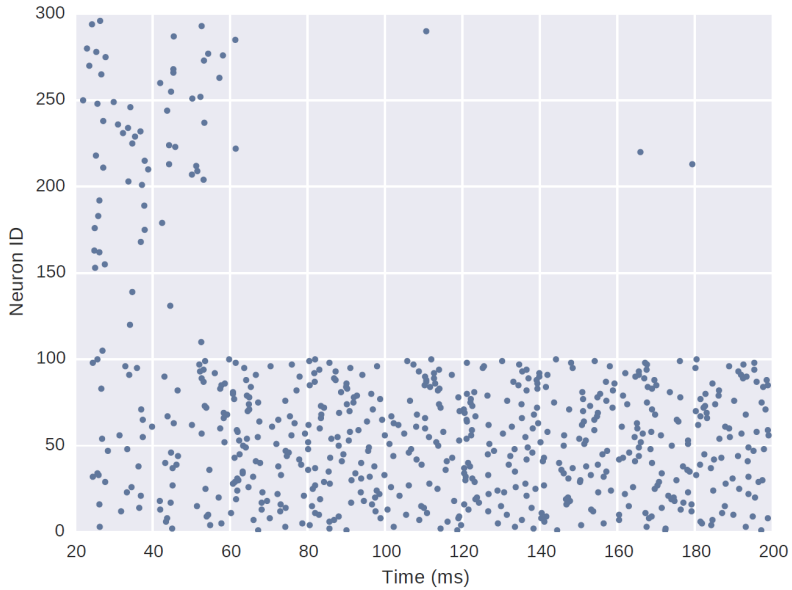


Neural Circuits for Autonomous Learning

Spiking Neural Network Model

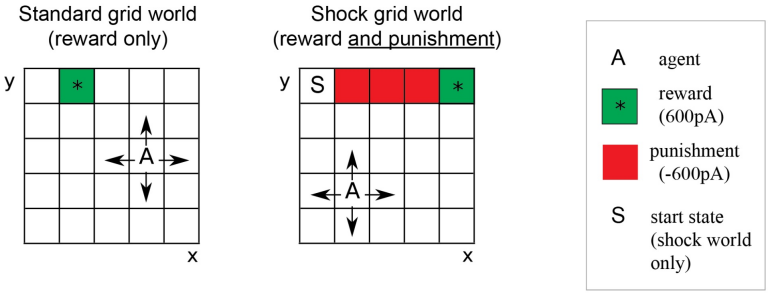


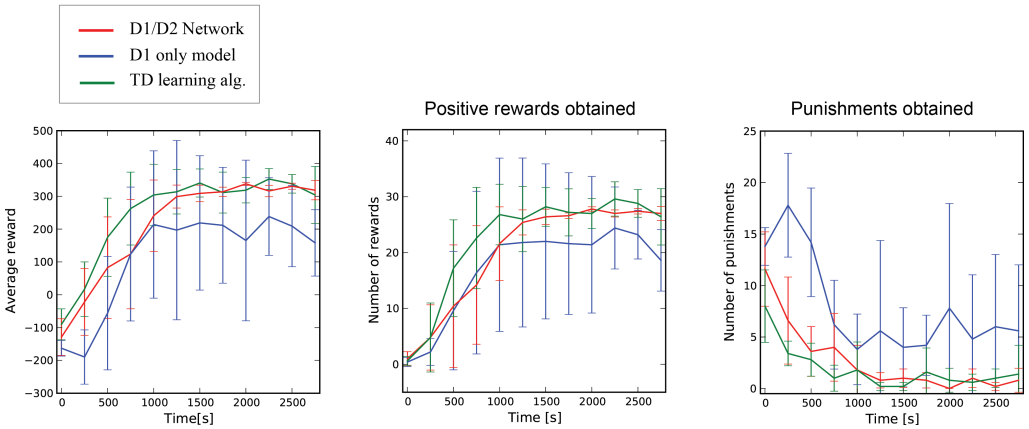
Neural activity in simulation



Neural Circuits for Autonomous Learning

Tasks involving reward and punishment



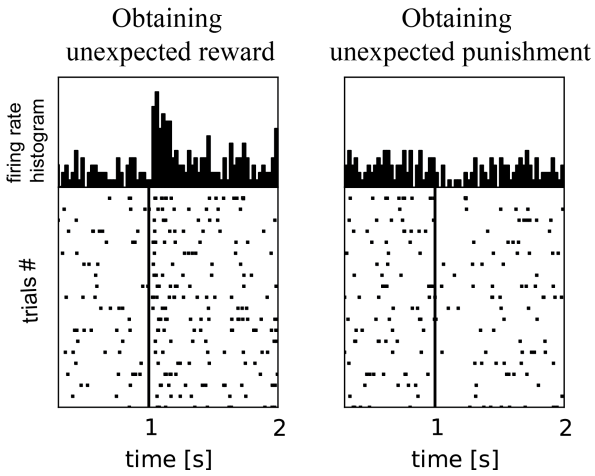


Spiking neural network circuitry model

$$\dot{\mathbf{V}}_\mathbf{m} = -\frac{1}{\tau_m}\mathbf{V}_\mathbf{m} + \frac{1}{C_m}I(t),$$

$$I_{syn}(t) = w\frac{e}{\tau_{syn}}te^{-t/\tau_{syn}}$$

DA activity (SNc/VTA, critic)
as prediction error signal

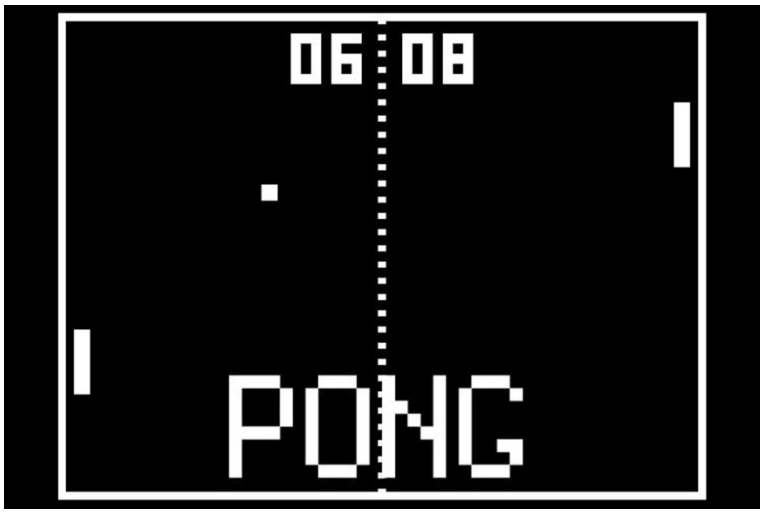


Towards a functional spiking neural architecture :

Closed loop learning from reward and punishment in diverse tasks

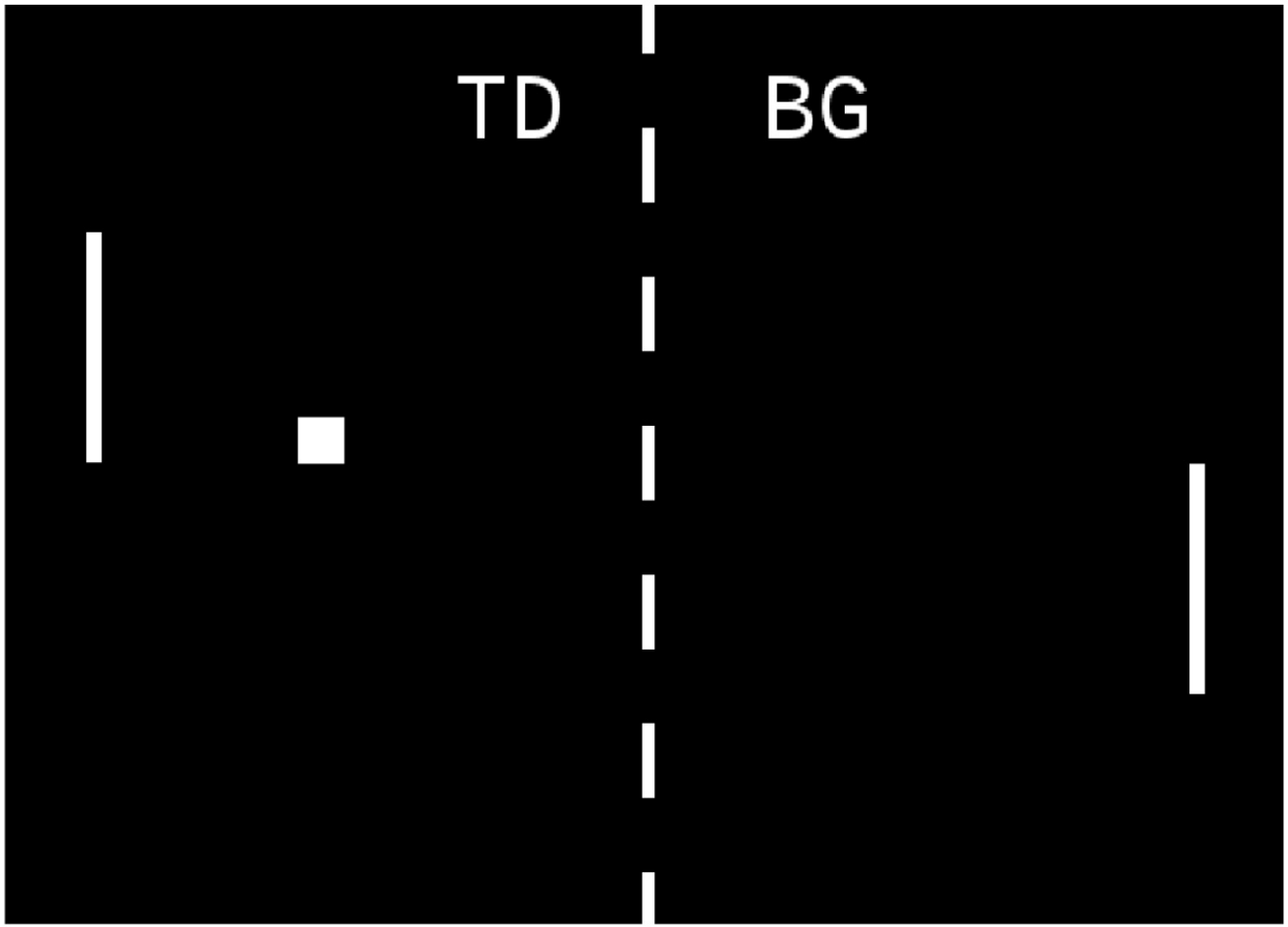
Neural Pong

Learn from reward and punishment experienced in the game



Neural Pong

Olympic pong games : different neural networks playing against each other



Neural Pong

Requirenments:

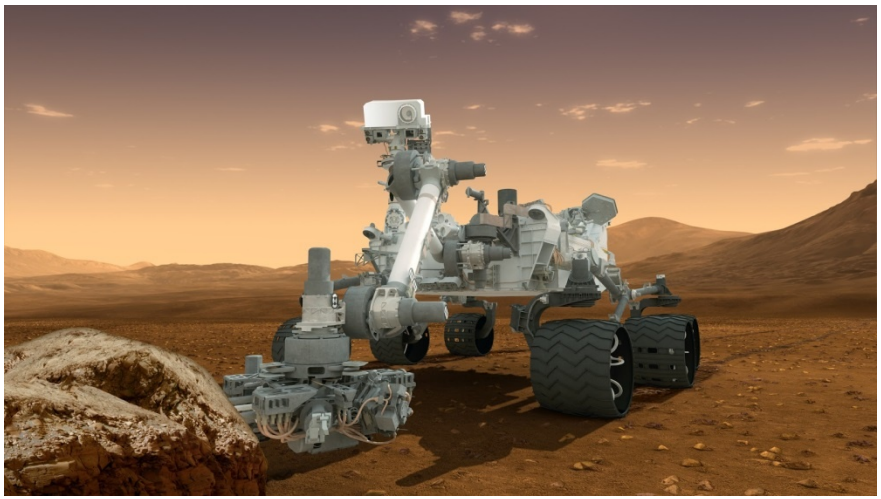
- A vivid and curious brain
- Basic Python skills
- Basic knowledge of neurobiology, basic skills in neural network
- modeling (all provided by preceding lectures, e.g. “Plasticity in Neural Circuits and Neurobiology of Learning”)
- Solid math background and reasoning definitely very helpful

Adaptation and Learning in Biology and Machines

Next step : build machines that do not need us anymore

Adaptive, self-sustaining, autonomous

Assisted, engineered, non-autonomous

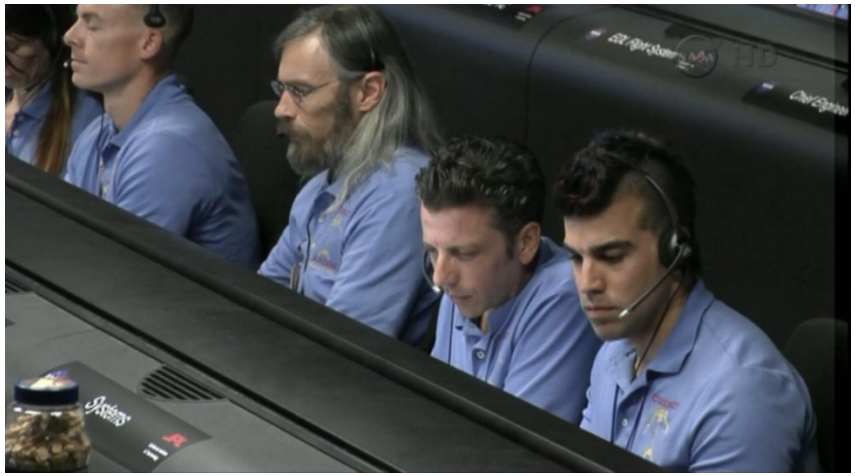


Adaptation and Learning in Biology and Machines

Next step : build machines that do not need us anymore (more time for more thrilling activities!)

Adaptive, self-sustaining, autonomous

Assisted, engineered, non-autonomous




Thanks
for
your
Attention

Neural Circuits for Autonomous Learning

Plasticity and Learning in Neural Circuits

Location : Germany, Jülich (proximity to Köln, Aachen, Düsseldorf)

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Adaptation and Learning in biological organisms

Predict the environment, act to gain benefit and avoid harm, adapt behavior from experience.

Loop forever and optimize.

Neural Circuits for Autonomous Learning

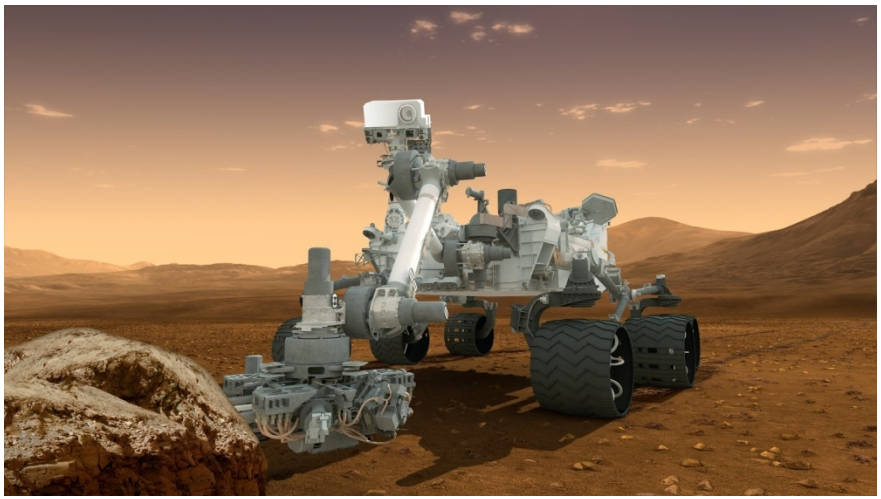
A functional neural architecture that optimizes itself :

- **Predict : internal outcome expectations given sensory input**
- **Act : (near) optimal decision making (based on expectations)**
- **Adapt : learn to get more reward and less punishment**

Adaptation and Learning in Biology and Machines

Adaptive, self-sustaining, autonomous

Assisted, engineered, non-autonomous



Adaptation and Learning in Biology and Machines

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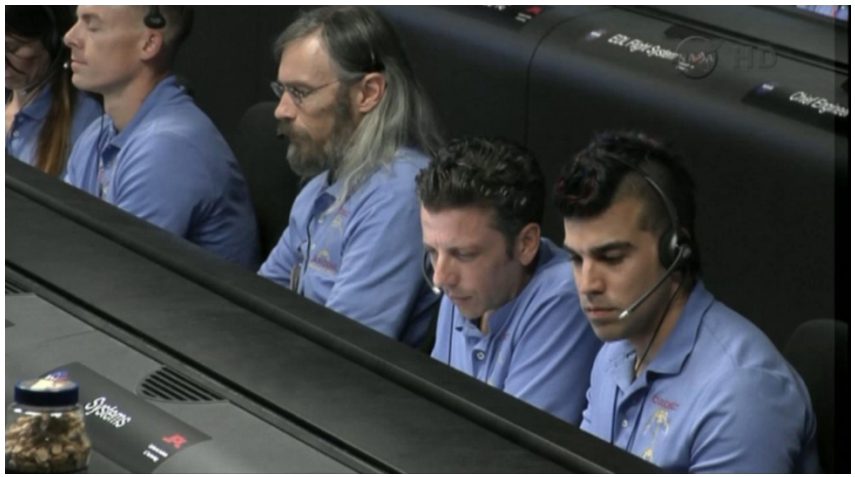
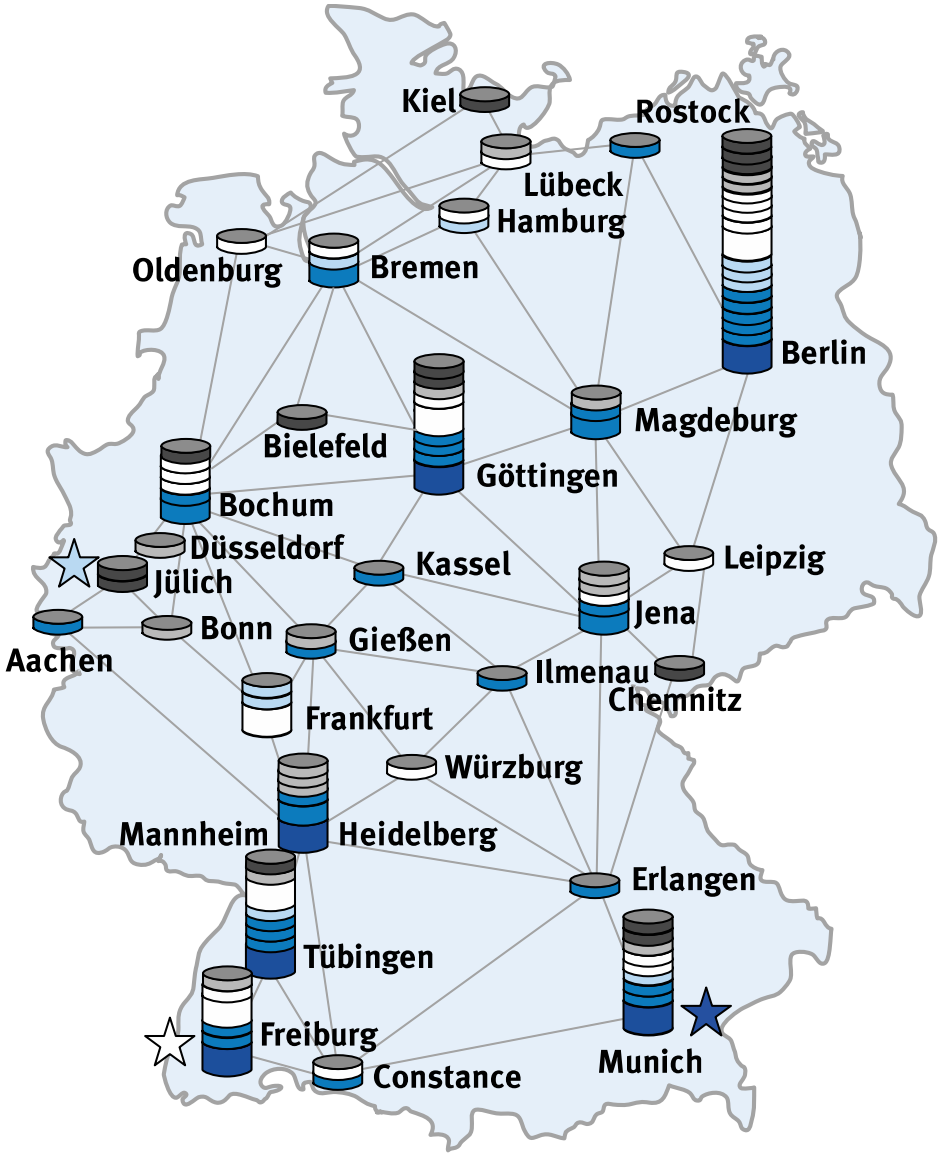
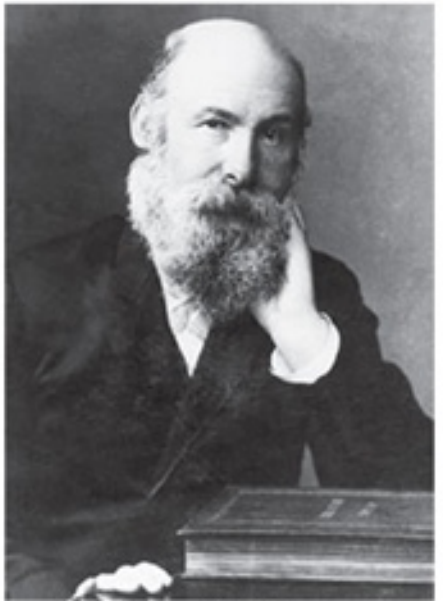


Education and Cooperation in Science

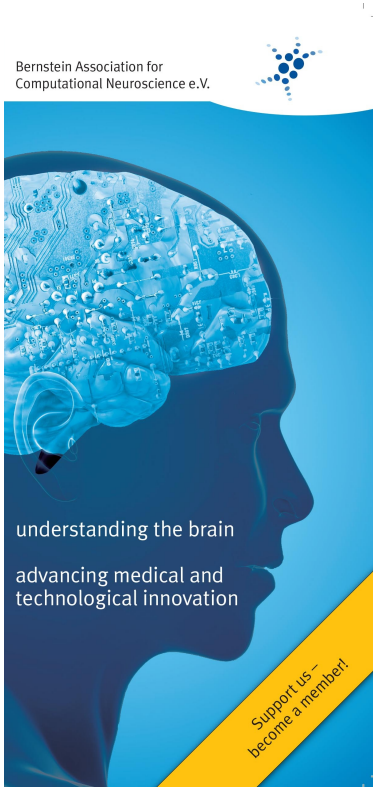
The Bernstein Network

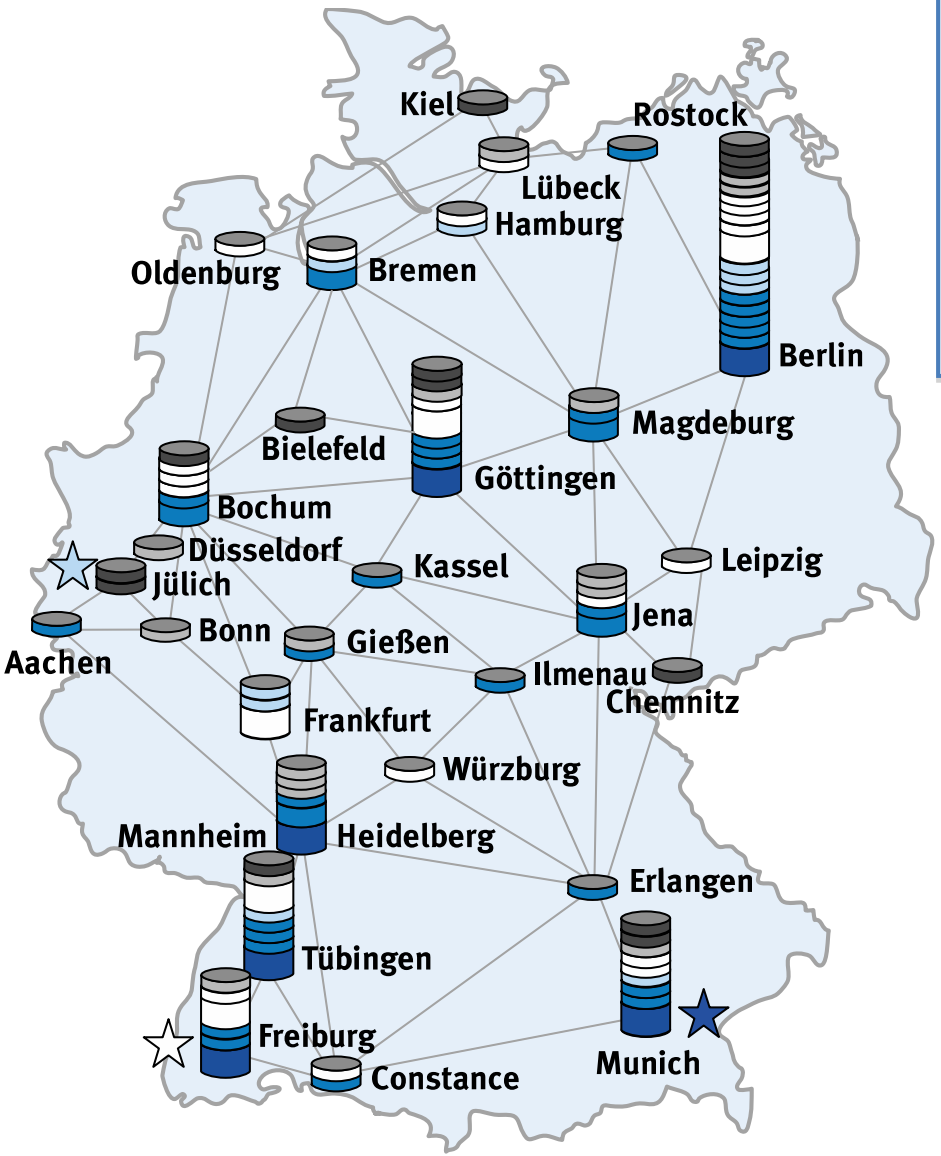




Julius Bernstein (1839-1917)

Bernstein Network for Computational Neuroscience





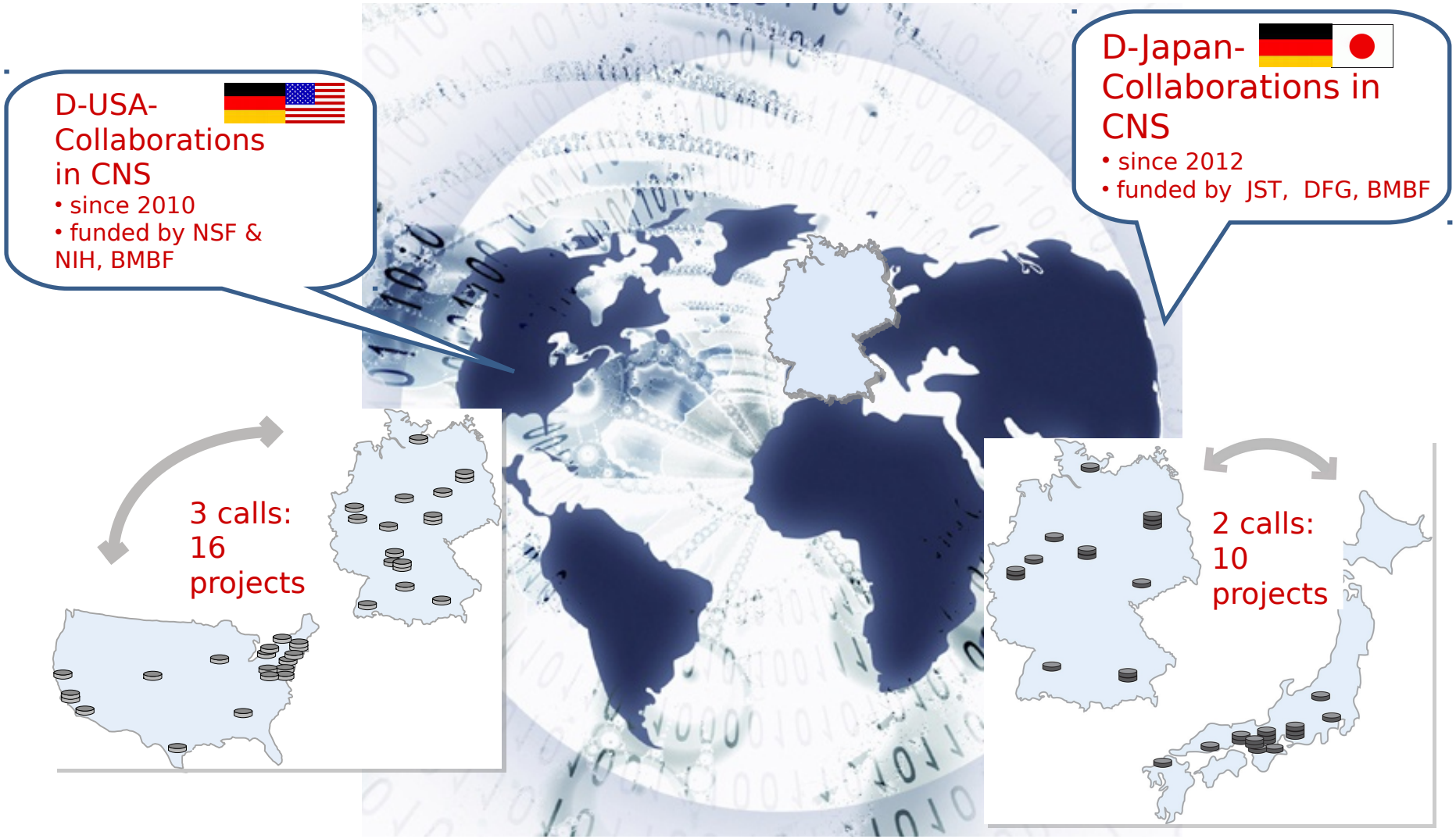
> 250 Research Groups
30 Cities / Regions

- **Universities**
- **Max Planck Institutes**
- **Fraunhofer Institutes**
- **Leibniz Institutes**
- **Helmholtz Centers**

Total Funding Volume (up to now):
> 180 Mio. €

Bernstein Network for Computational Neuroscience

Upcoming initiative : Science without borders (East Europe, ...)



Bernstein Network for Computational Neuroscience

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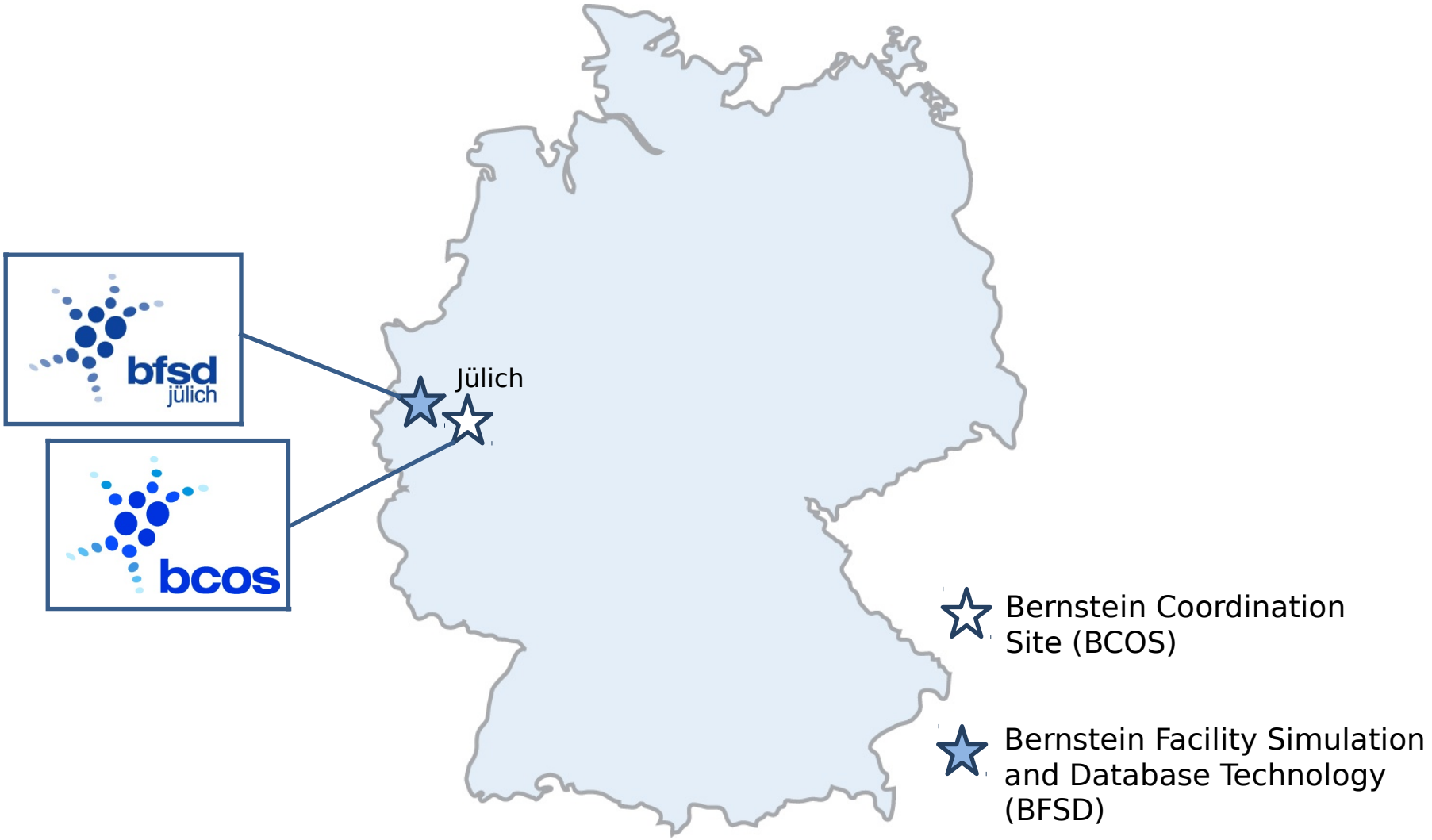


Thanks
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Adaptation and Learning in Biology

A functional, biological neural architecture :
Prediction, decision making, action and learning

→ Closed-loop : observe, act, observe, adapt, observe, act …
→ Autonomous, life-long learning and adaptation

What is the computational nature and objective of this loop?
Can we formalize it? Can we disassemble its neural substrate?

→ Can we both make predictions about function and structure?
(Given structure, predict computations; given computations, predict structure)

Adaptation and Learning in Biology

Combine :

- **Top-down: computational framework - what computations are employed by neural systems?** (e.g, temporal-difference learning)
- **Bottom-up: neurophysiology – how is the computation implemented in neural substrate?** (e.g, form of synaptic plasticity observed in experiments)

Functional Neural Circuits

Functional Neural Circuits

Text