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The Human Brain Project

The Human Brain Project

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EUROPEAN COMMISSION

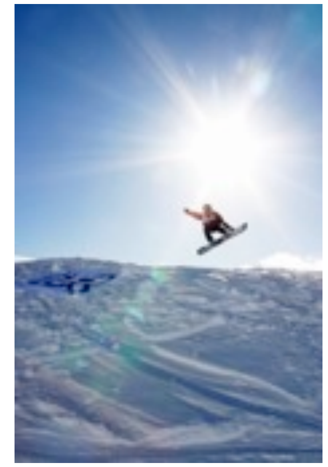
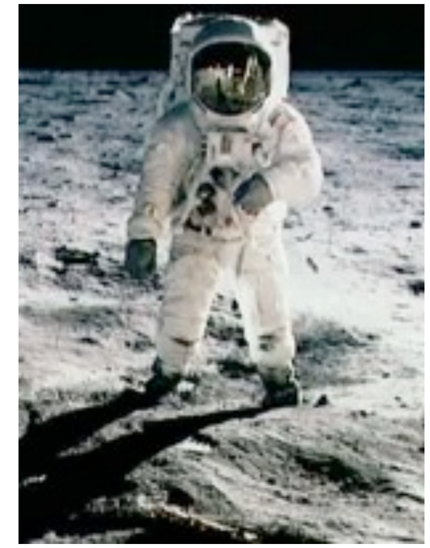
FET FLAGSHIPS

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Upon this gifted age, in its dark hour,
Rains from the sky a meteoric shower
Of facts . . . they lie unquestioned, uncombined.
Wisdom enough to leech us of our ill
Is daily spun; but there exists no loom
To weave it into fabric;

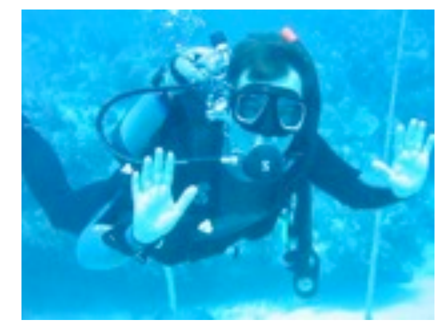
Edna St. Vincent Millay, 1939

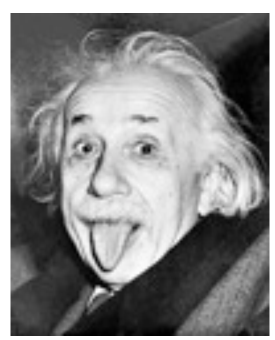


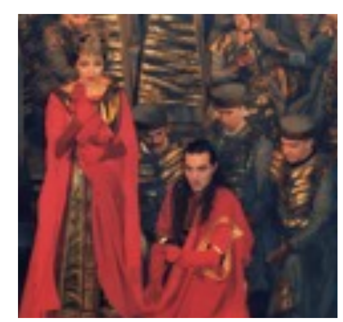














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Developmental Disorders

- Autism spectrum disorders
- ADHD
- Learning disorders, conduct disorders
- Strong genetic disorders (Fragile X, Down’s etc)

Adolescent Disorders

- Depression, Suicide
- Eating disorders
- Bipolar disorder
- Conduct disorders and violence
- Borderline syndrome
- Adjustment disorders
- Anxiety, phobias, suicide
- Tourette’s syndrome
- Epilepsy

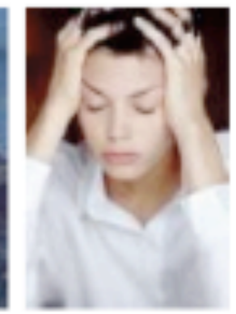
Adult Disorders

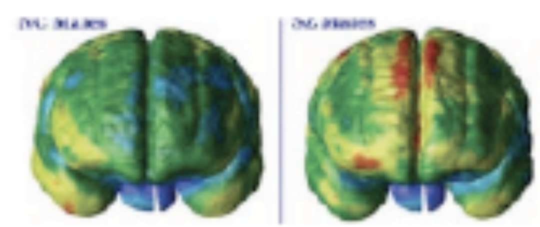
- Schizophrenia
- Epilepsy
- Mood disorders, hysterias, anxieties and phobias
- Obsessive compulsive disorders
- Eating disorders, sexual disorders
- Sleep disorders, stress disorders
- Impulse control disorders
- Substance abuse disorders
- PTSD/TBI










Aging Disorders

- Depression
- Dementia
- Neurodegenerative disorders
  - Alzheimer’s
  - Parkinson’s
  - Huntington’s
- Memory disorders

Glutamate

Nutrition

Dopamine

Genes

Sugar

GABA

Myelin

Serotonin

Metals

Dopamine

Toxins

Acetylcholine

Protein misfolding

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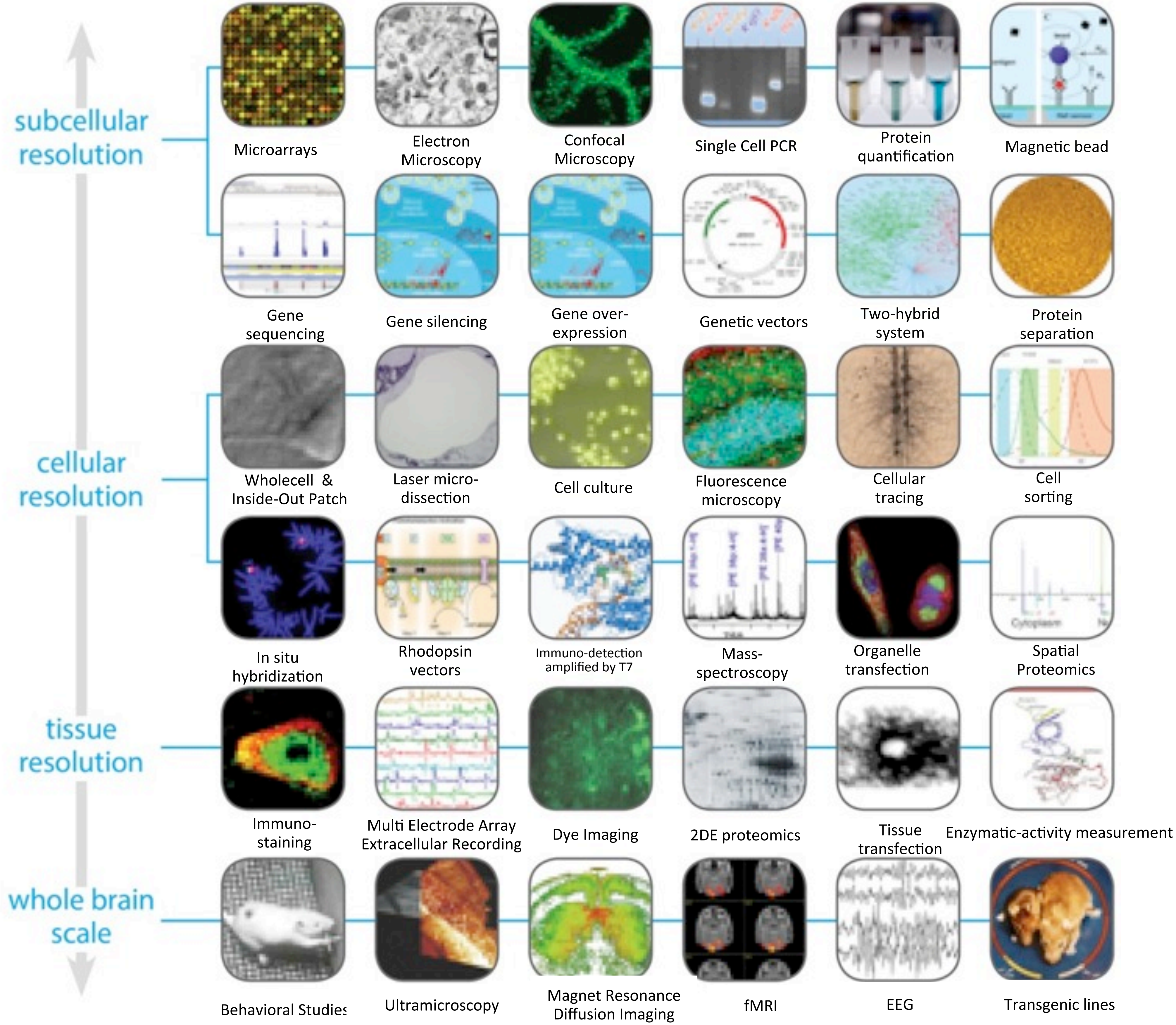

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What is the Human Brain Project?

A 10-year European initiative to launch a global, collaborative effort to understand the human brain, enabling advances in neuroscience, medicine and future computing.

One of the two final projects selected for funding as a FET Flagship from 2013.

A consortium of 256 researchers from 146 institutions, in 24 countries across Europe, in the US, Japan and China.

Will receive funding of €1 billion over 10 years - half provided by the European Commission. Funding provided in phases with regular reviews.

Figure 1: The Human Brain - one of the greatest challenges for 21st century science

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What is a FET Flagship?

Future and Emerging Technologies (FET) Flagships are ambitious large-scale, science-driven, research initiatives that aim to achieve a visionary goal.

The scientific advance should provide a strong and broad basis for future technological innovation and economic exploitation in a variety of areas, as well as novel benefits for society.

Objective is to keep Europe competitive and drive technological innovation

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FET FLAGSHIPS

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Goal

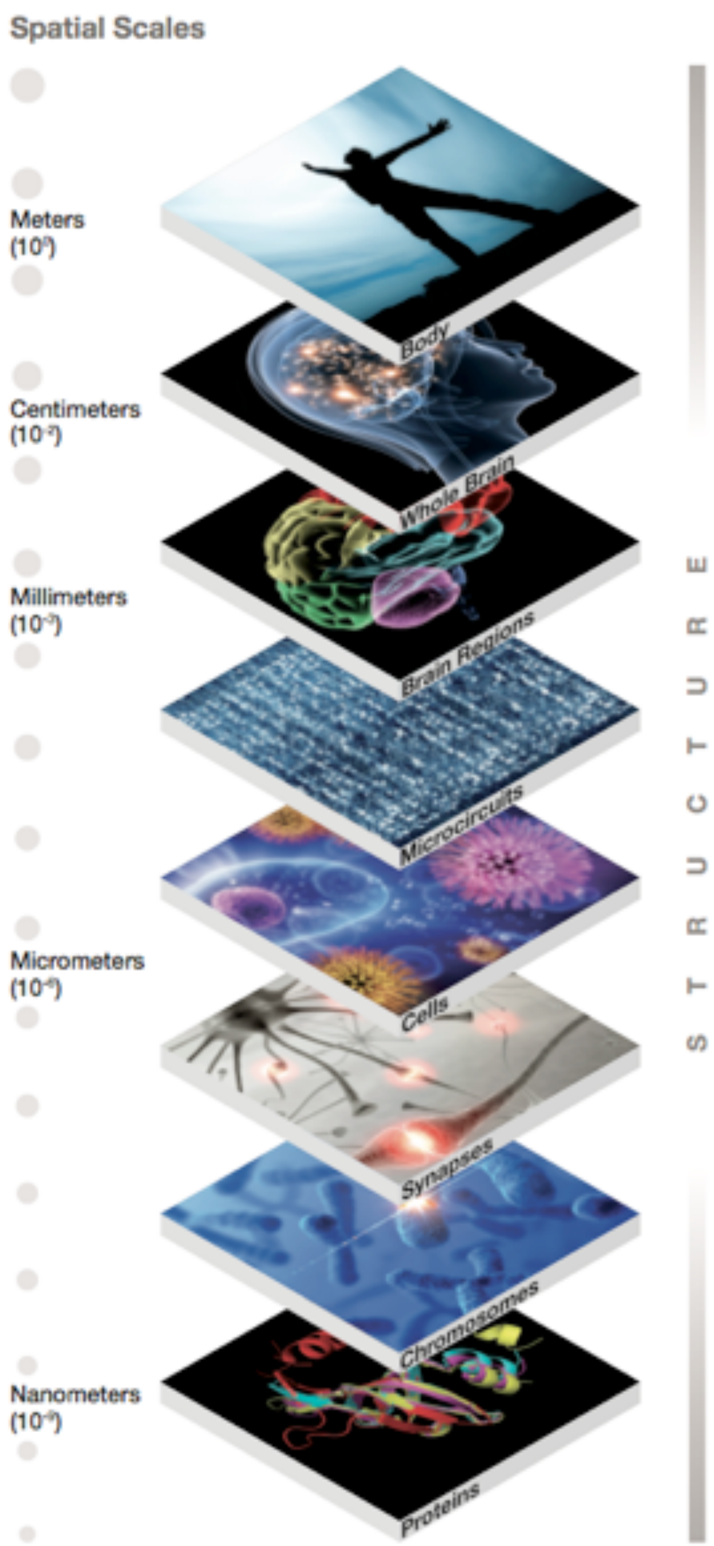


Figure 4: From molecules to the body: spatial scales for the brain's different levels of organization span nine orders of magnitude

The Human Brain Project should:

- Lay the technical foundations for a new model of ICT-based brain research

- Drive integration between data and knowledge from different disciplines

- Catalyze a community effort to achieve a new understanding of the brain, new treatments for brain disease and new brain-like computing technologies.

Research Areas

Neuroscience

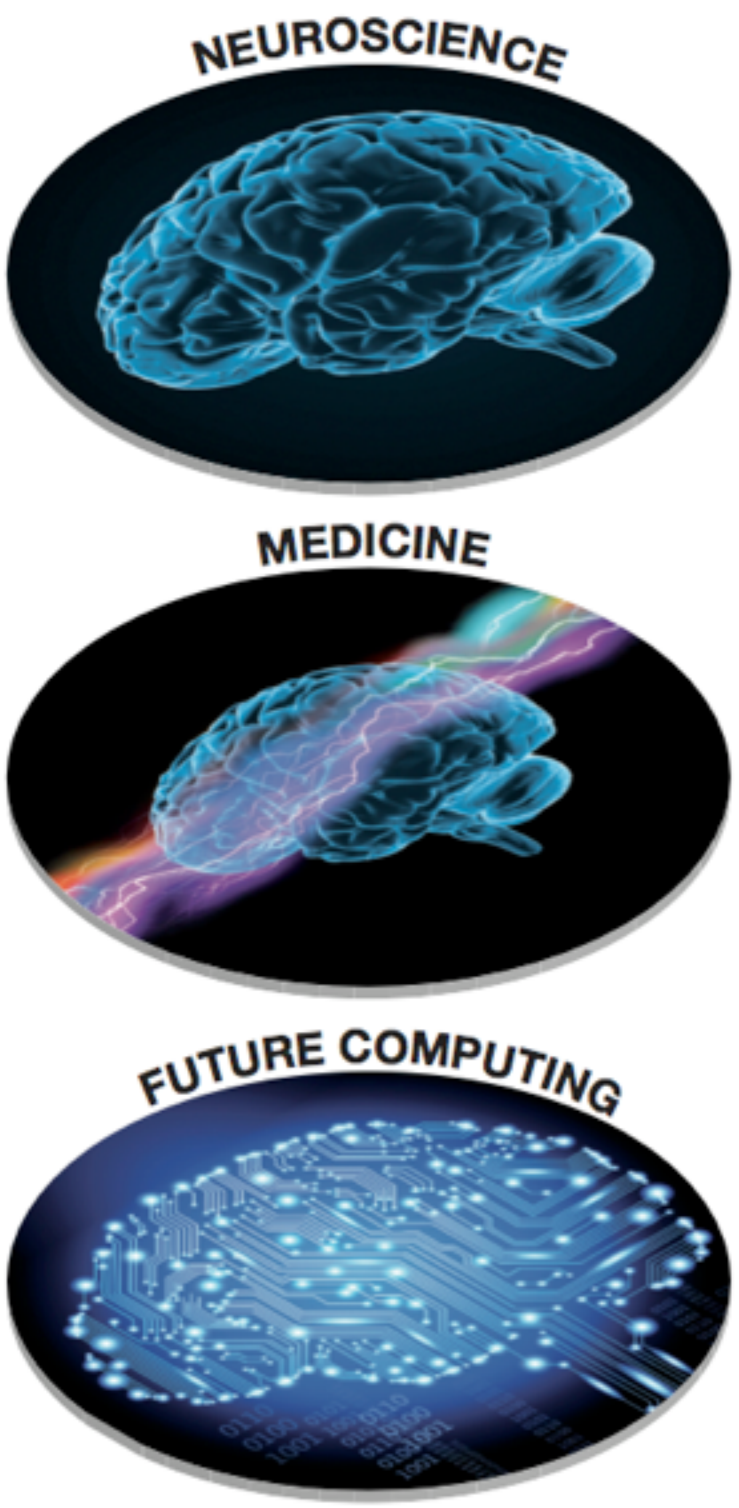
Integrate everything we know about the brain into computer models and simulations

Medicine

Contribute to **understanding, diagnosing and treating** diseases of the brain

Future Computing

Learn from the brain to build the supercomputers of tomorrow



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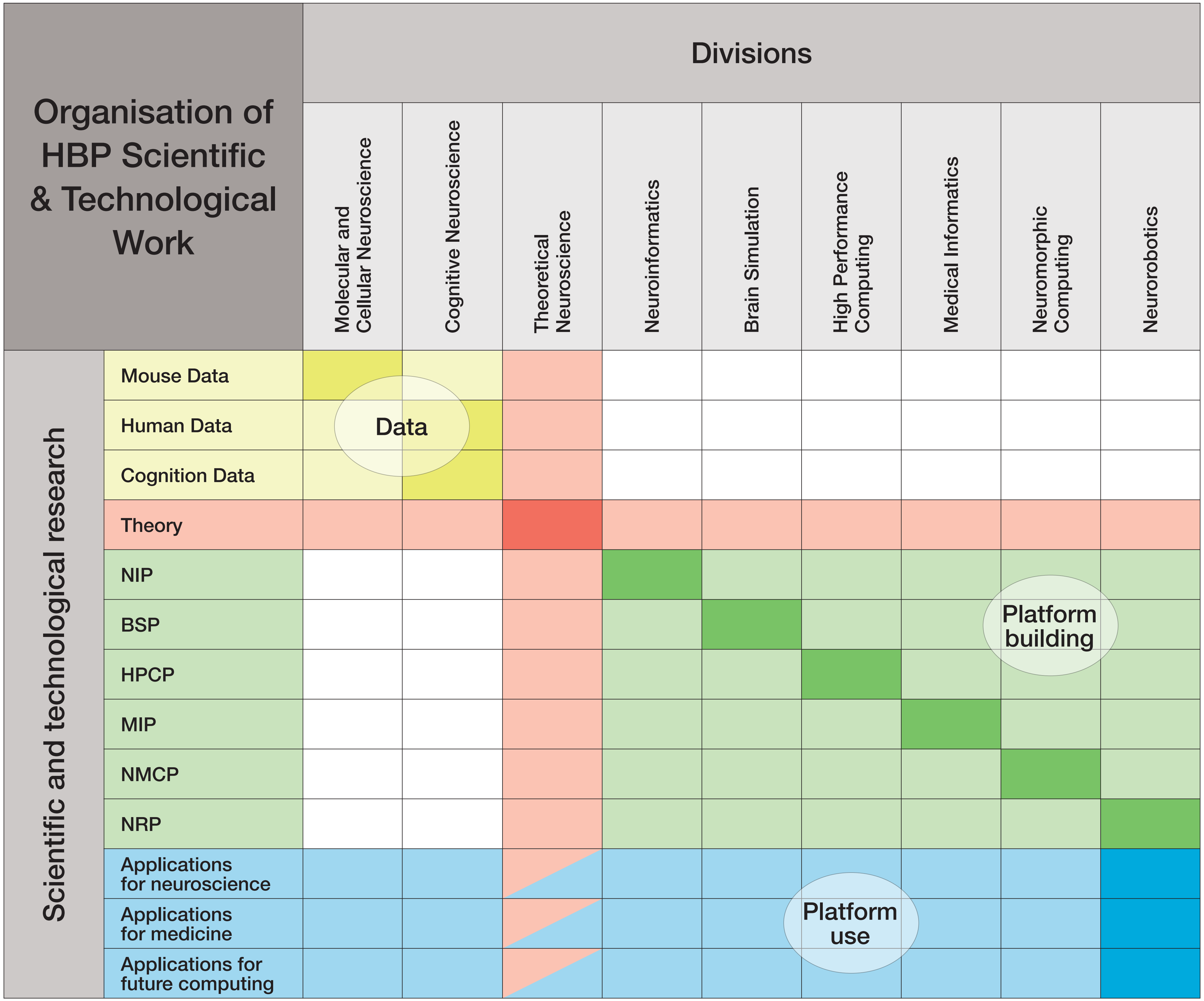
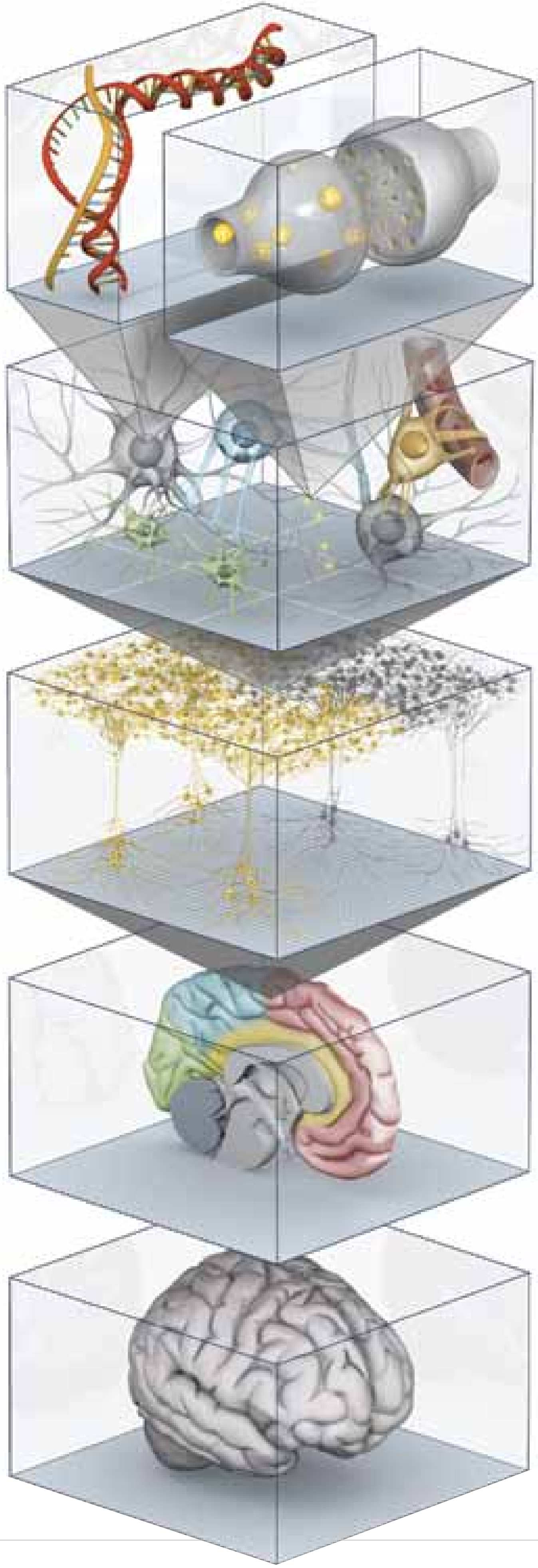
Scientific organization

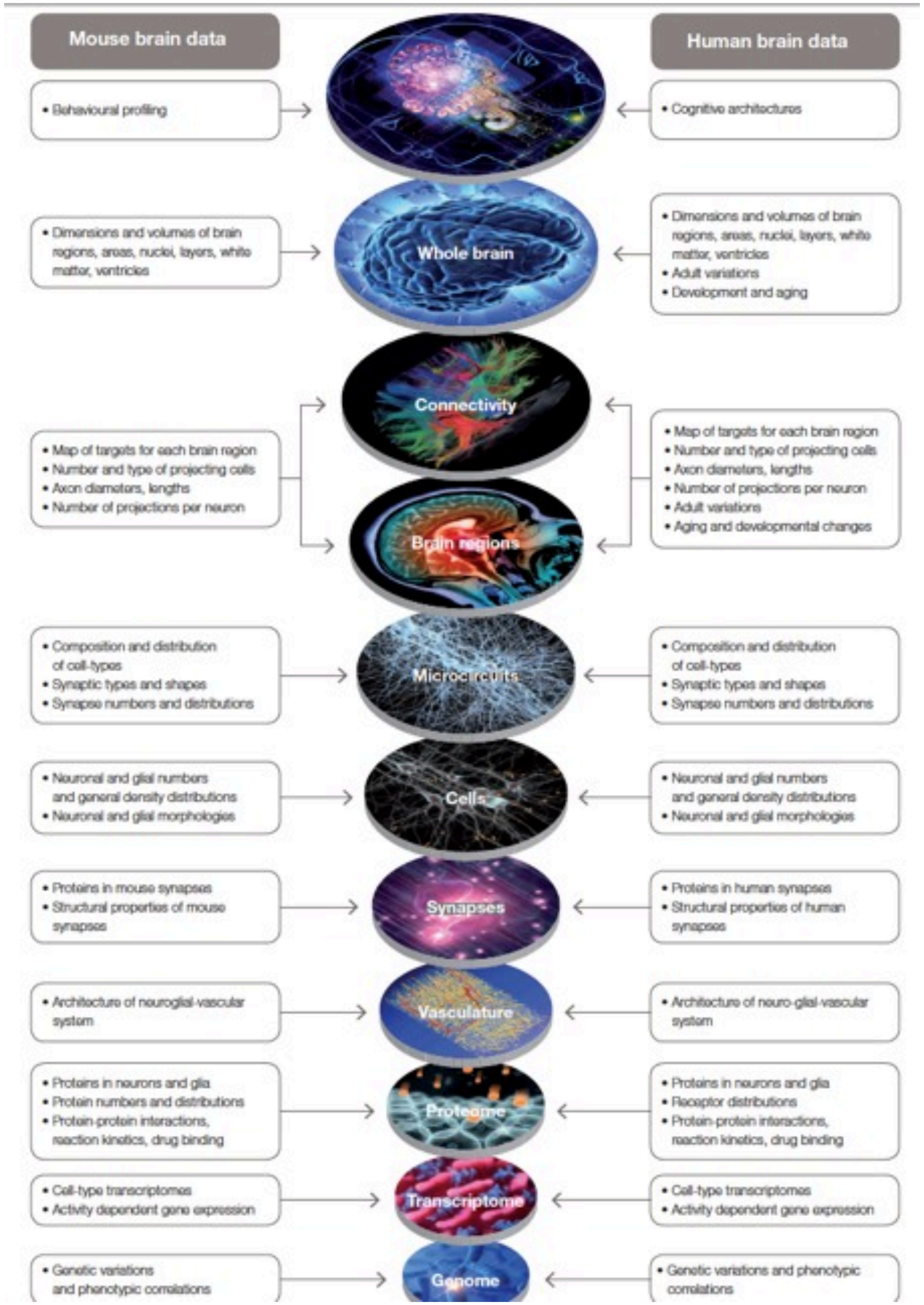




Data

Generate and interpret strategically selected data needed to build multilevel atlases and unifying models of the brain.

The Data Ladder to the Human Brain



Data

However,

HBP is NOT primarily a data generation project

It IS a data integration project.

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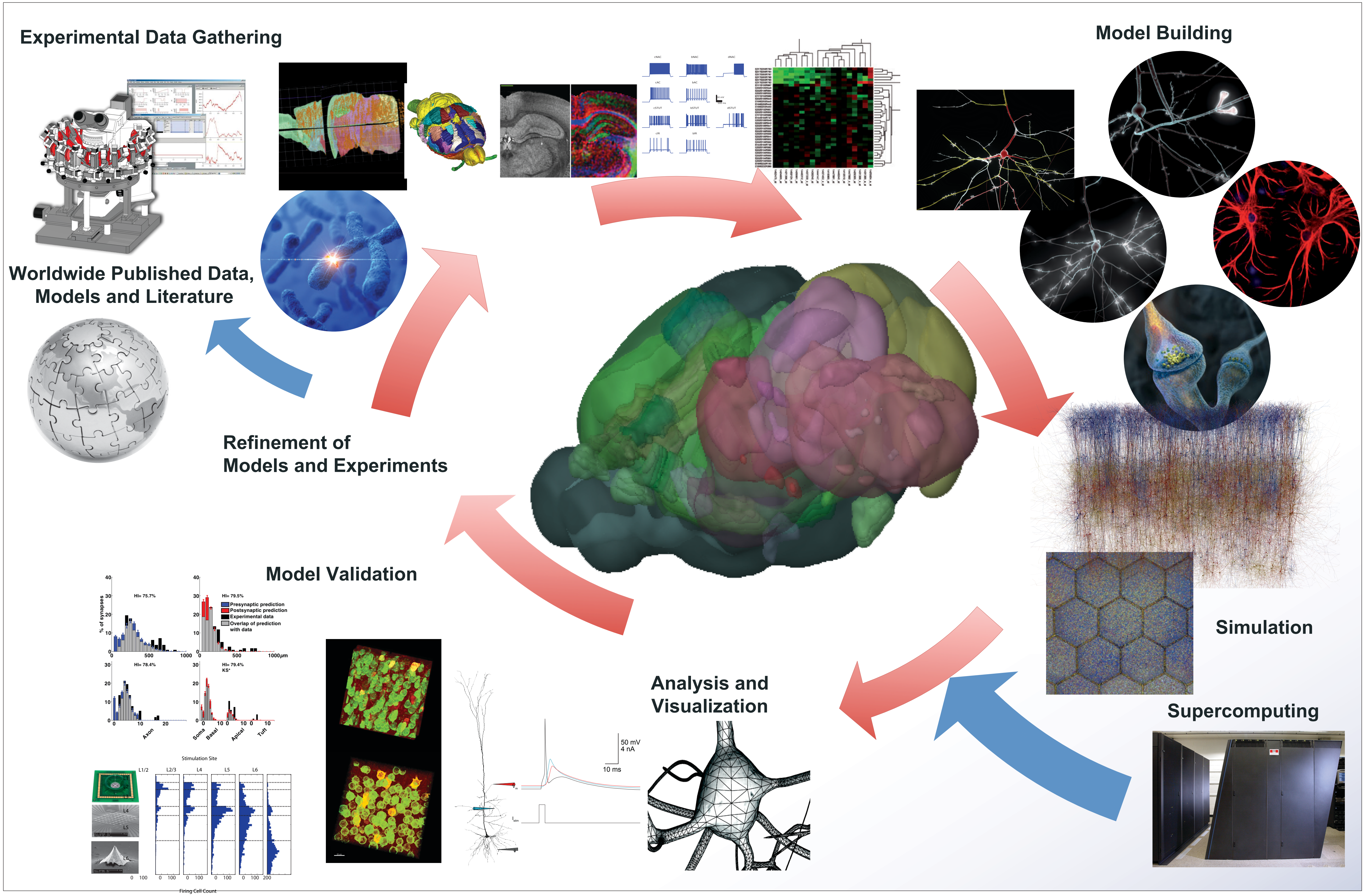
Build, Simulate and Validate Unifying Brain Models



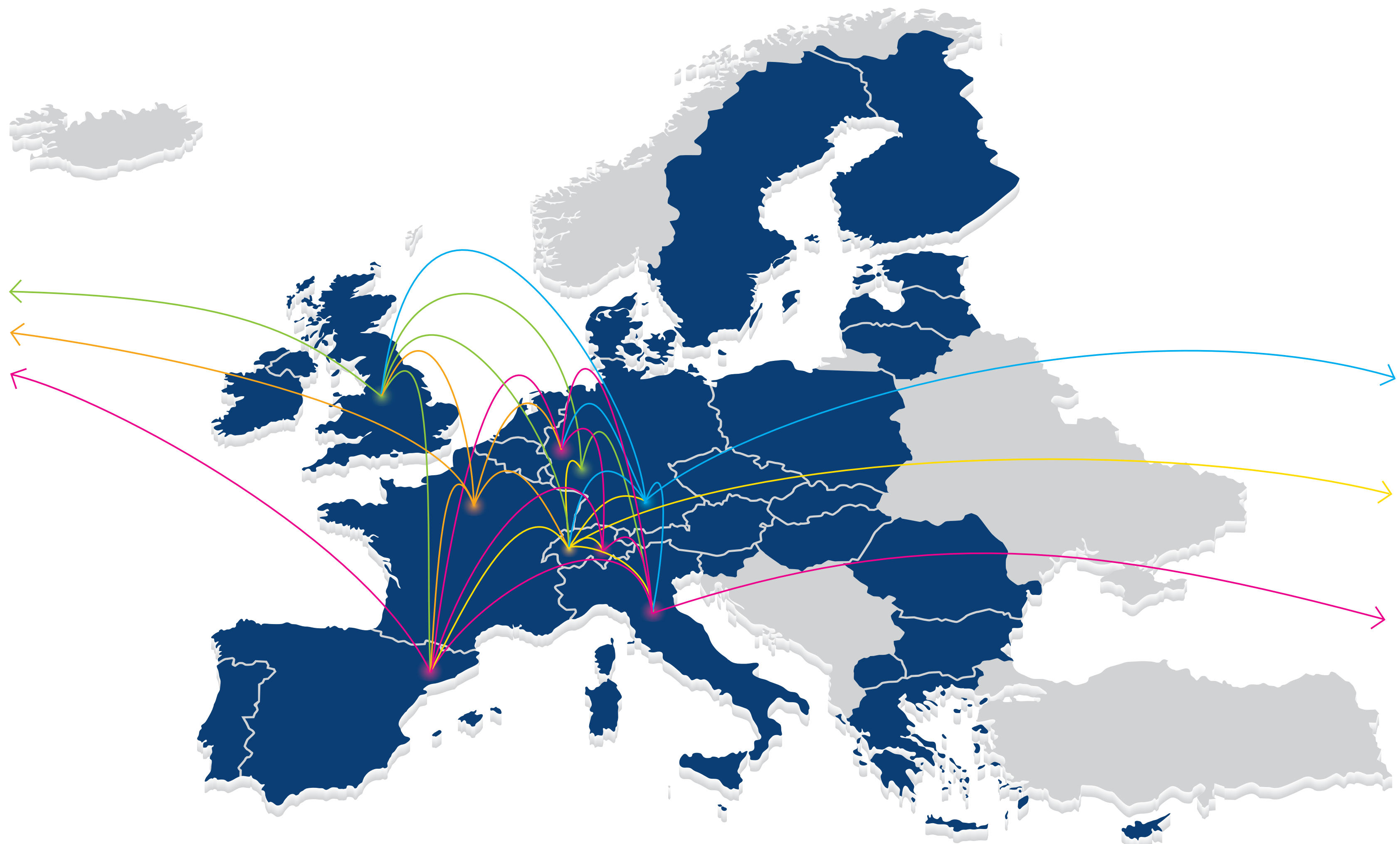
ICT Platforms

Six new ICT platforms:

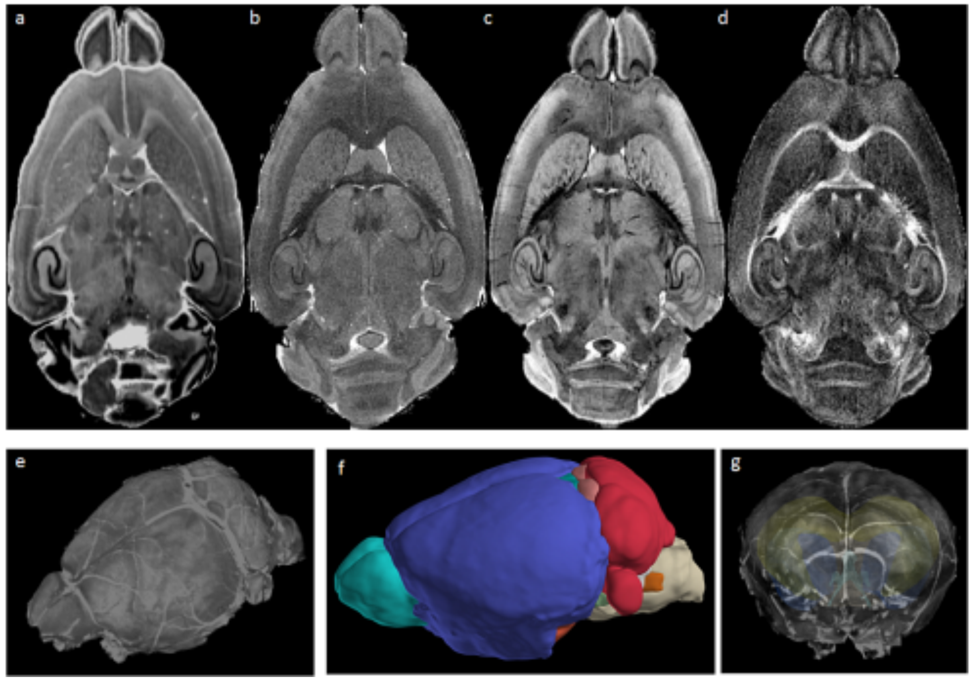
1. **Neuroinformatics**
2. **Brain Simulation**
3. **Medical Informatics**
4. **High Performance Computing**
5. **Neuromorphic Computing**
6. **Neurorobotics**

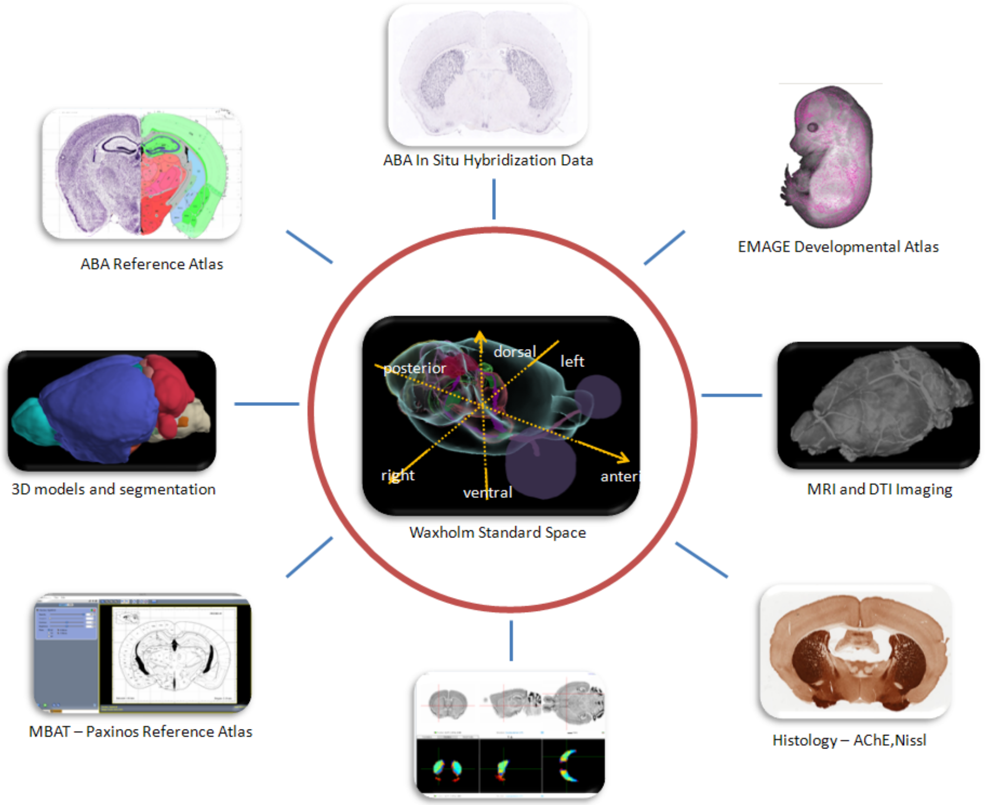
For the entire research community.

An integrated network of ICT platforms of the HBP



Neuroinformatics Platform





Provide technical capabilities to federate neuroscience data, analyze structural and functional brain data and to build and navigate multi-level brain atlases. This involves:

- spatial and temporal data registration
- ontology development and semantic annotation
- predictive neuroscience
- machine learning, data mining
- track provenance, build workflows.

Goal: enable an integrated view of the neuroscience data. Prepare data for modeling pipelines

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Data management strategy

DATASPACE

- Don't centralize - federate
- INCF Global datasharing infrastructure
- Federated data management
- Dropbox-like Ease of Use
- Big Data Capabilities
- Robust Infrastructure
- Data Replication Services
- Persistent Identifier Services
- Semantic & Linked Data Annotation Services

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NIF

Knowledge integration strategy

KNOWLEDGE
SPACE

BASIC | DETAIL | ADVANCED | FACTBOX

Name:	Neocortex pyramidal cell
Description:	Pyramidal neuron of the cerebral cortex (not including hippocampus or olfactory cortex). The pyramidal cell of the neocortex is located in layers 2-3 and 5-6, has a pyramidal-shaped cell body which gives off a number of laterally-directed basal dendrites and usually a single apical dendrite which ascends to branch and terminate in layer 1; these dendrites are covered in dendritic spines.
Synonym(s):	Neocortical pyramidal cell, Neocortical pyramidal neuron, Cortical pyramidal neuron, neocortex pyramidal neuron
Has role:	Principal neuron
Super-category:	Neuron
URL:	big pyramidal cell body, regular spiking property
Id:	sao2128417084
Defining criteria:	Apical and basal dendrites; soma in layer 5
Organism:	Mammal
Link to OWL / RDF:	Download this content as OWL/RDF

Soma Specific Properties

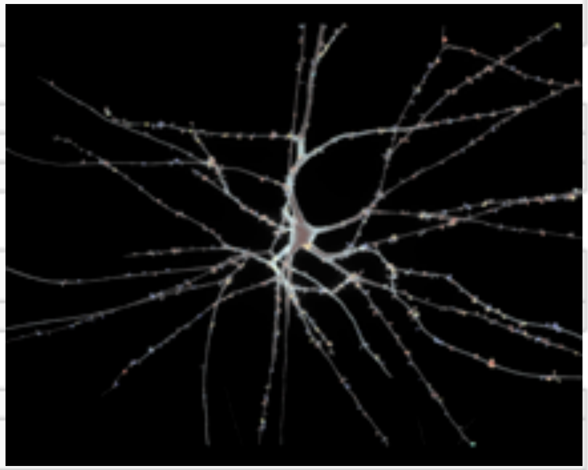
Cell Soma Shape:	Pyramidal
Cell Soma Size:	Large soma
Soma Location:	Neocortex

Dendrite Specific Properties

Spine density on dendrites:	spiny high density
Branching type:	unipolar

Axon Specific Properties

Axon myelination:	myelinated
Axon projection laterality:	ipsilateral
Origin of axon:	soma
Location of distant axon arborization:	spinal cord, superior colliculus, basal pons or the contralateral cortex
Location of local axon arborization:	Neocortex layer 6



neurolex.org

- INCF Community encyclopedia
- Living review articles
- Build and maintain working ontologies
- Links to data, models and literature
- Define all vocabulary, terms, protocols, brain structures, diseases, etc
- Semantic organization, search, analysis and integration
- Global directory of all shared vocabularies, CDEs, etc

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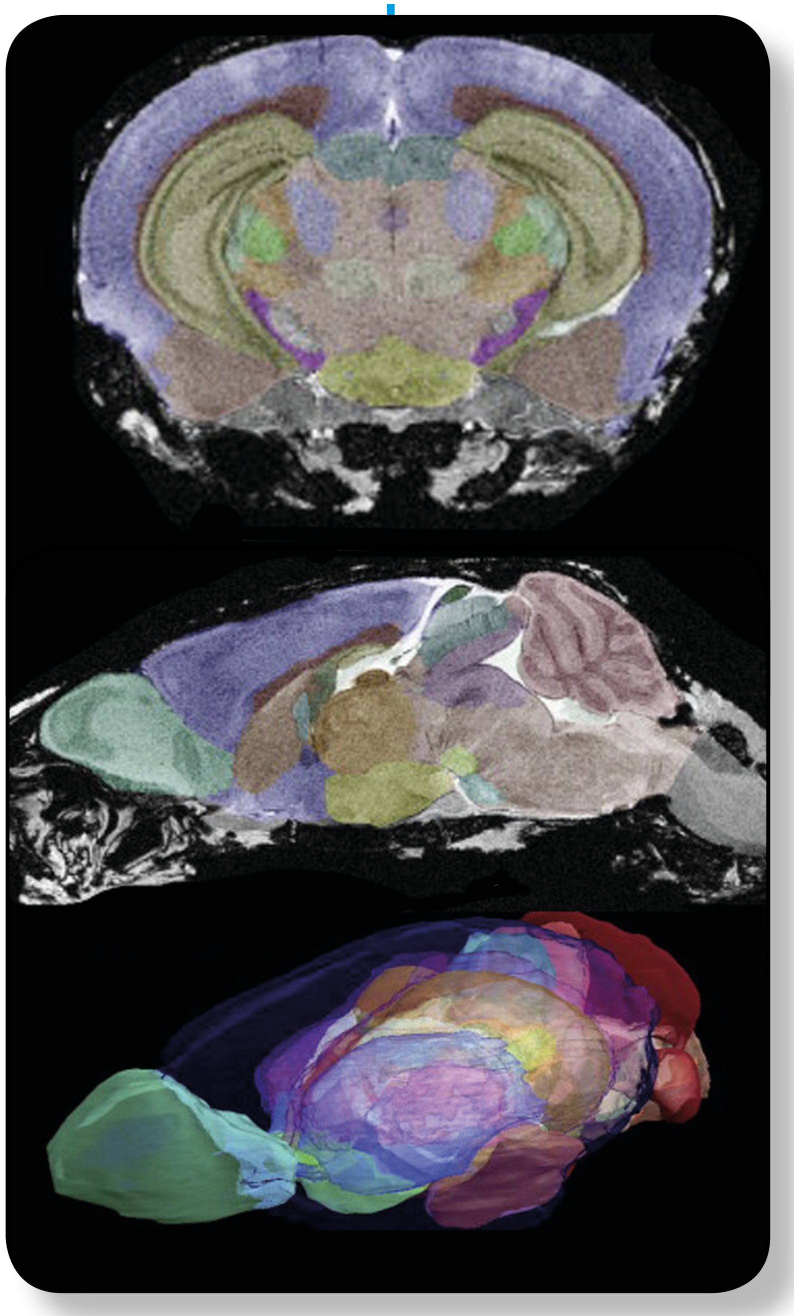
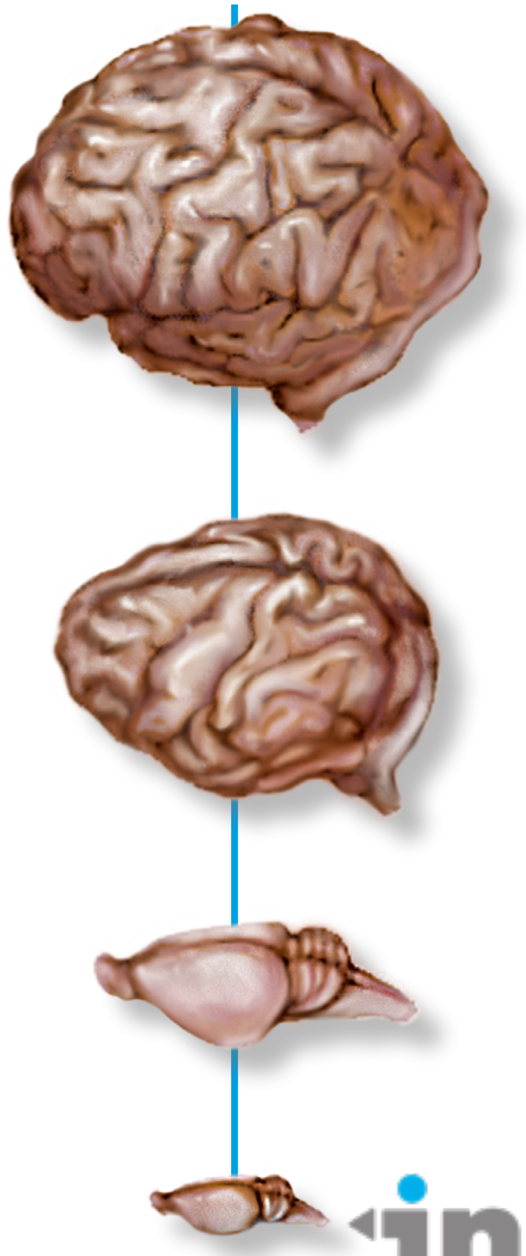
Multiscale and Multimodal Brain Atlases

Atlases - collections of spatially and semantically registered and searchable data, models and literature

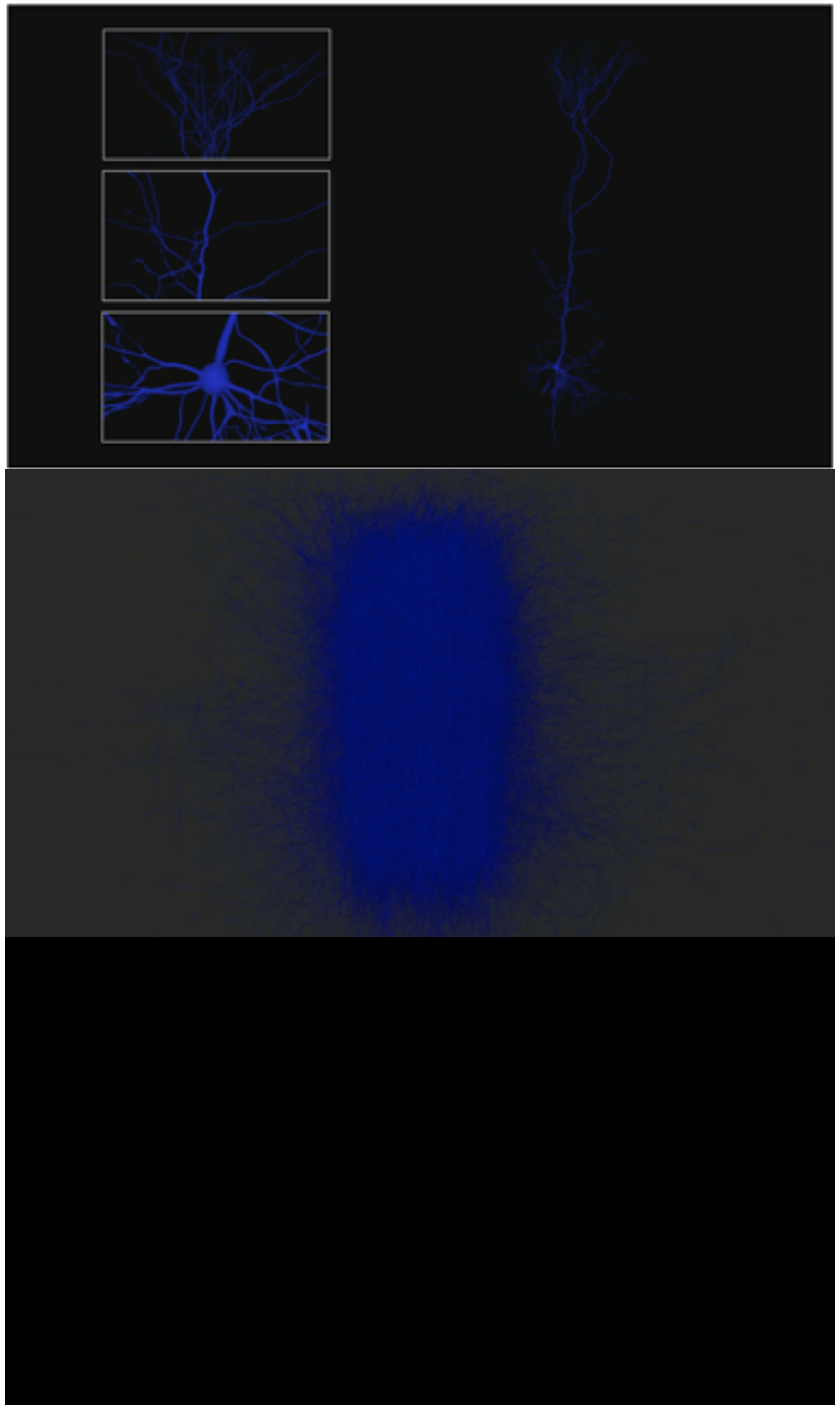
Highly controlled data for building models

Other data for validations





Brain Simulation Platform



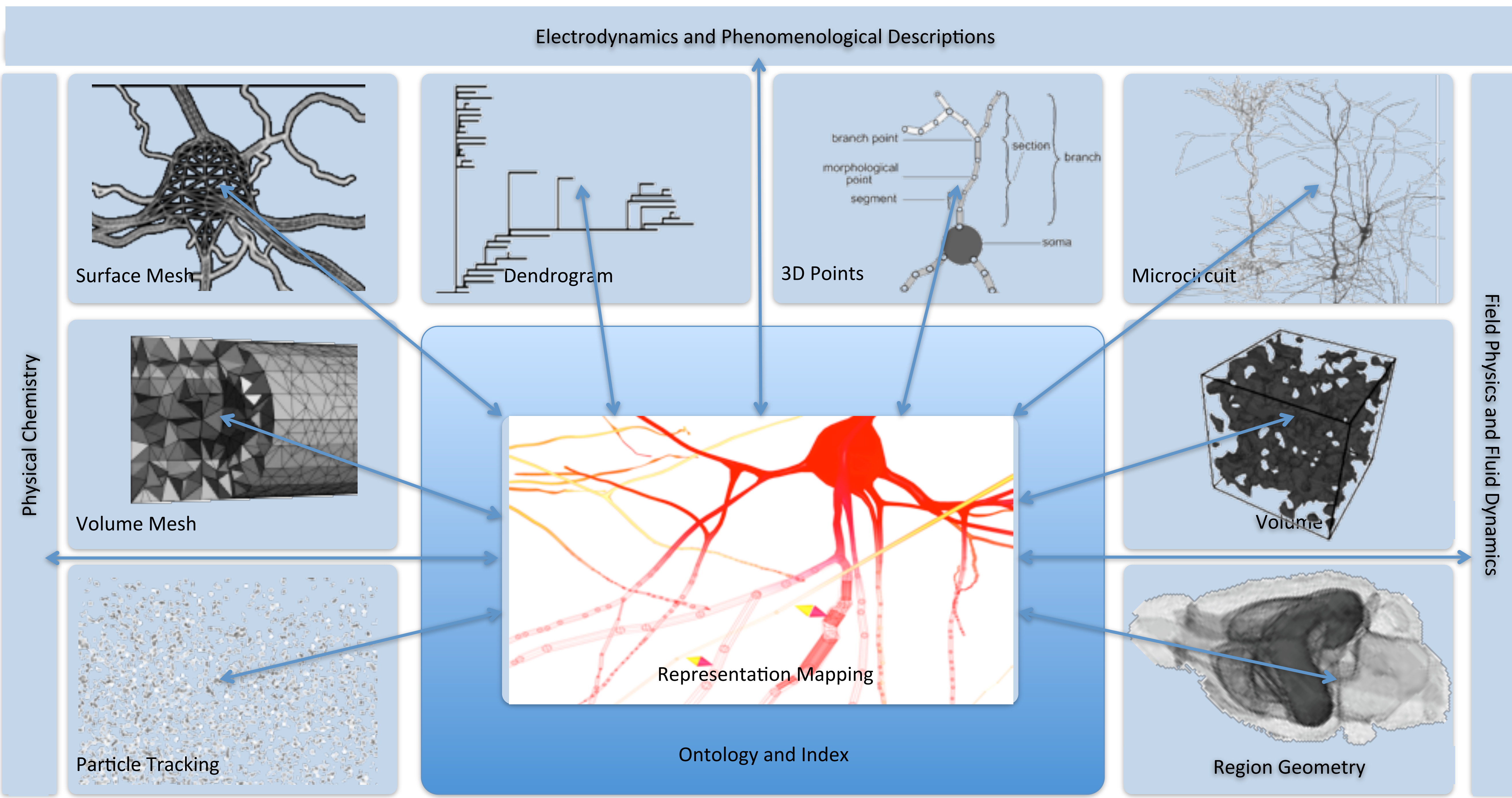
Provide technical capabilities to build and simulate multi-scale brain models at different levels of detail.

- internet portal for neuroscientists
- modeling tools
- workflows
- simulation
- virtual instruments (EM, LFP, fMRI, etc)
- link to virtual body and environment
- in silico experiments

Goal: Integrate large volumes of heterogeneous data in multi-scale models of the mouse and human brains, and to simulate their dynamics.

Enable neuroscientists to ask new questions and prioritize experiments.

Brain Simulation Platform: Multiscale representations



Brain Simulation Platform: Multiscale solvers

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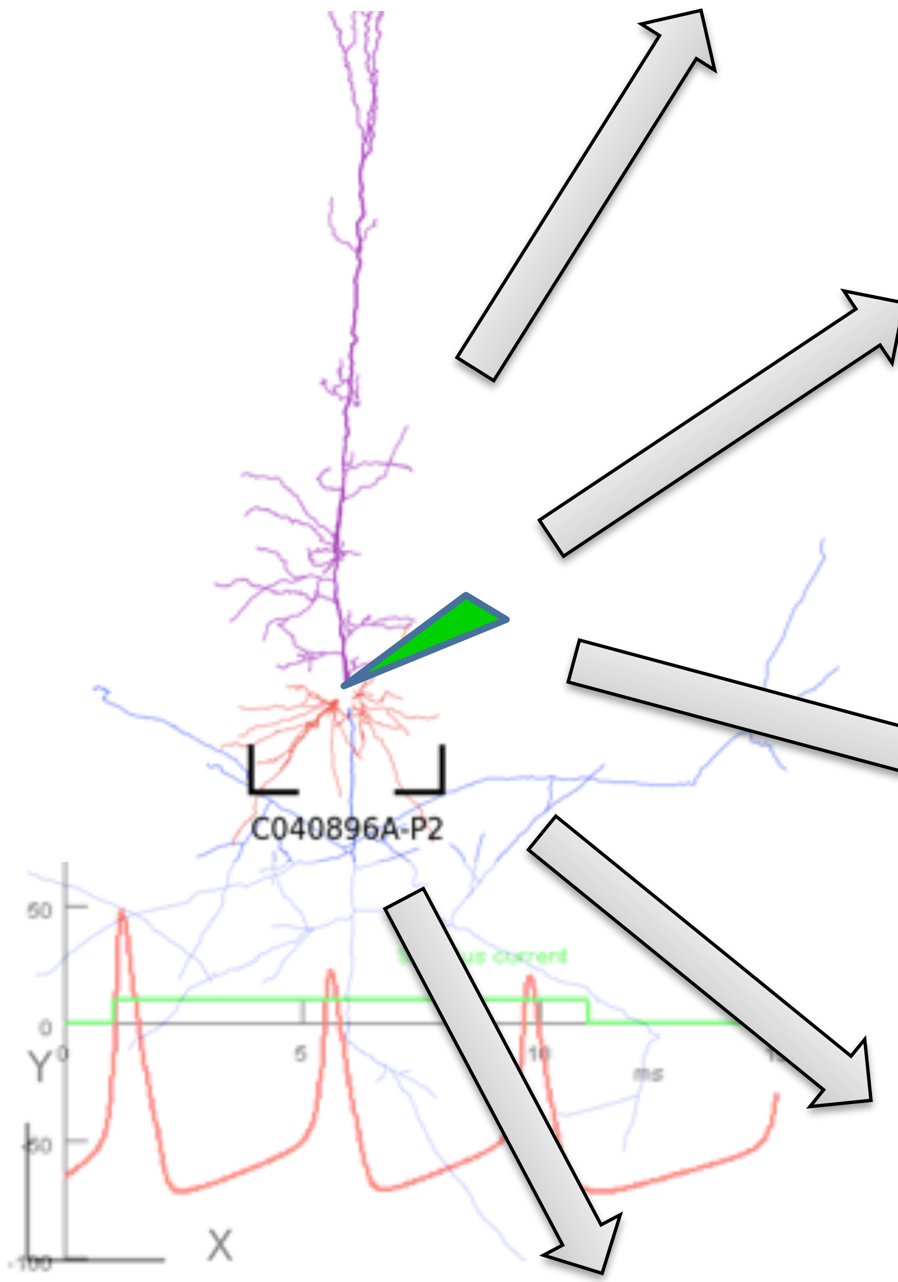
Multi-scale

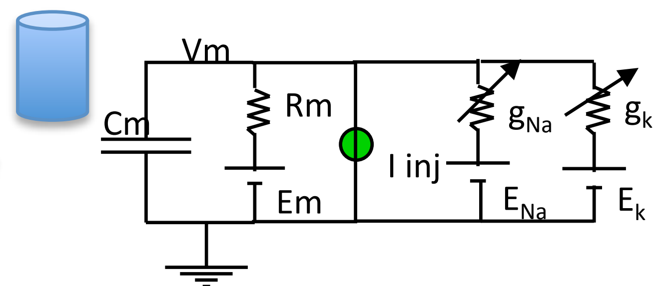


Point neuron, e.g. Izhikevich

$v' = 0.04v^2 + 5v + 140 - u + I$
$u' = a(bv - u)$

if $v = 30$ mV,
then $v \leftarrow c, \quad u \leftarrow u + d$

Single Compartment HH model



$$\frac{C_m dV_m}{dt} = \frac{E_m - V_m}{R_m} + I_{channels}$$

$$\frac{d\mathrm{m}}{dt} = \alpha_{\mathrm{m}}(V_m)(1-\mathrm{m}) - \beta_{\mathrm{m}}(V_m)\mathrm{m}$$

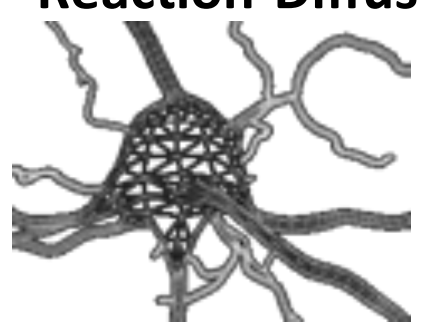
$$\frac{d\mathrm{h}}{dt} = \alpha_{\mathrm{h}}(V_m)(1-\mathrm{h}) - \beta_{\mathrm{h}}(V_m)\mathrm{h}$$

$$I_{channel} = \mathrm{m}^n \mathrm{h} g_{channel}(V_m - E_{channel})$$

Multi Compartment HH model

$$\frac{C_m dV_m}{dt} = \frac{E_m - V_m}{R_m} + I_{channels} + \frac{2(V_{m_{i+1}} - V_{m_i})}{R_{a_{i+1}} + R_a} + \frac{2(V_{m_{i-1}} - V_{m_i})}{R_{a_{i-1}} + R_a}$$

Reaction-Diffusion model



$$\dot{p}(\mathbf{x};t) = -p(\mathbf{x};t)\sum_{\mu=1}^{M} a_\mu(\mathbf{x}) + \sum_{\mu=1}^{M} p(\mathbf{x}-s_\mu;t)\,a_\mu(\mathbf{x}-s_\mu)$$

Coarse-Graining/MD

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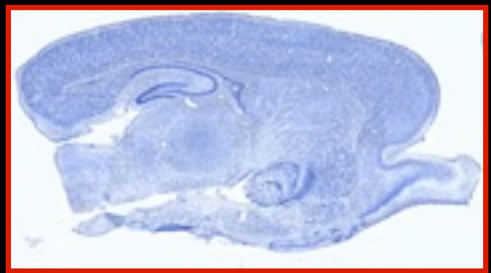
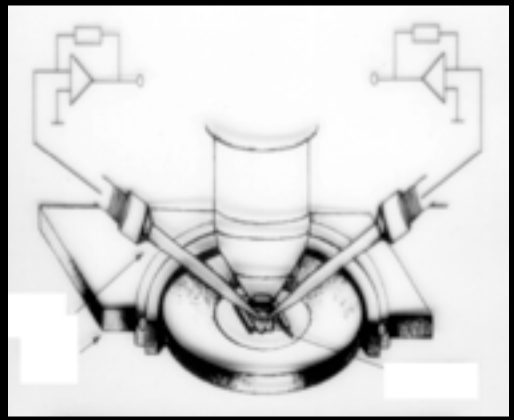
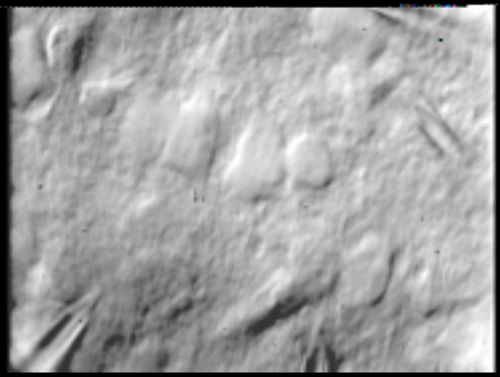
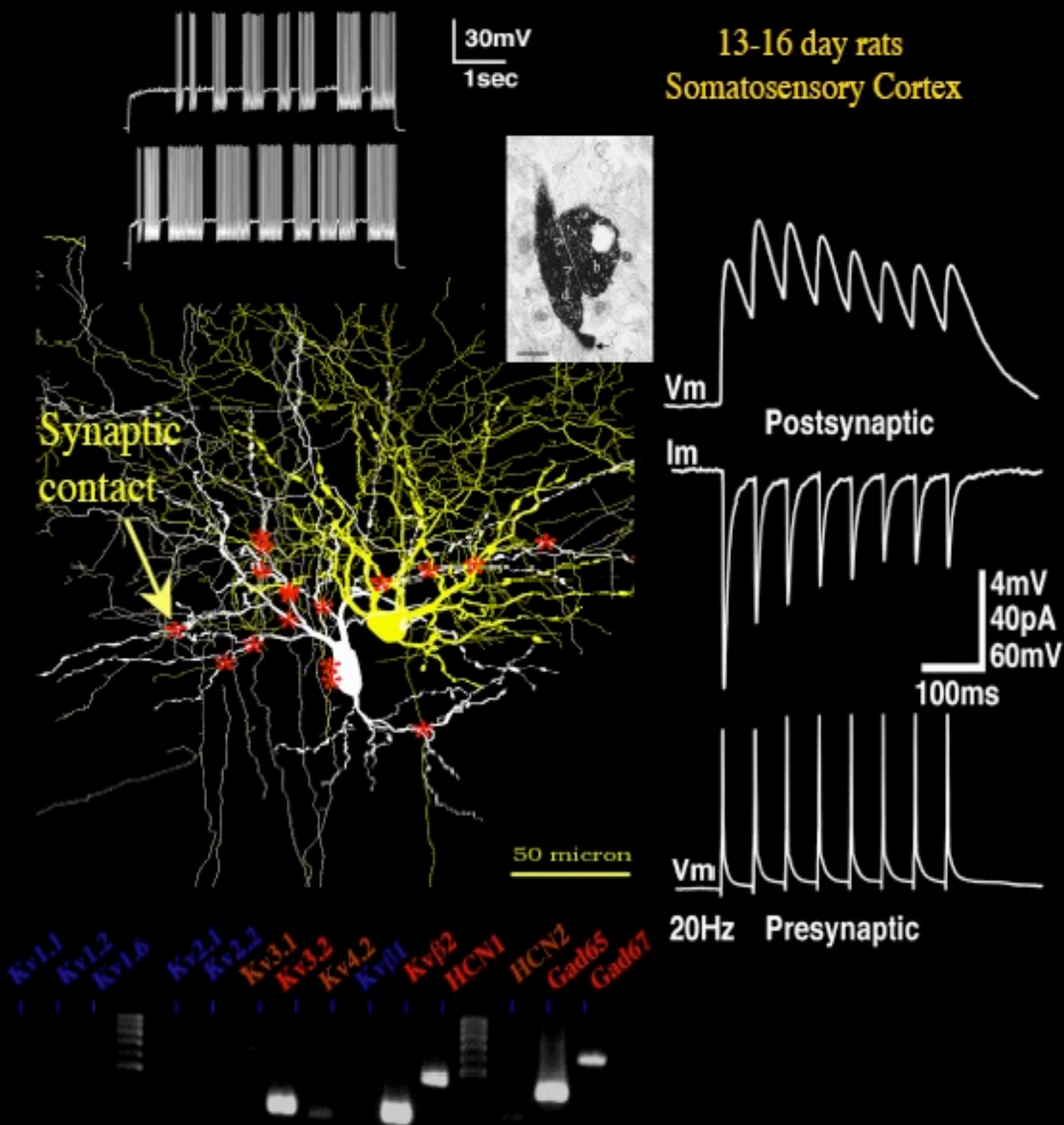
Integration of laboratory data

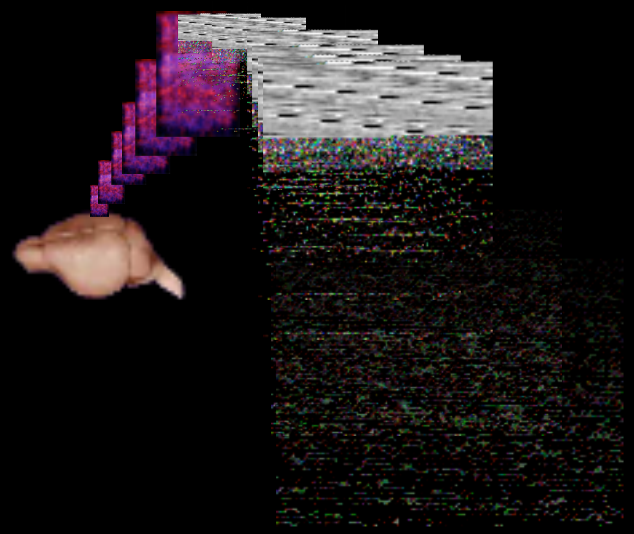








S1L1 Neocortical
Microcircuit
30’000 neurons



Gene profiles

Protein profiles

Electrical profiles

Morphology profiles

Synaptic profiles

Connectivity profiles

Circuit profiles

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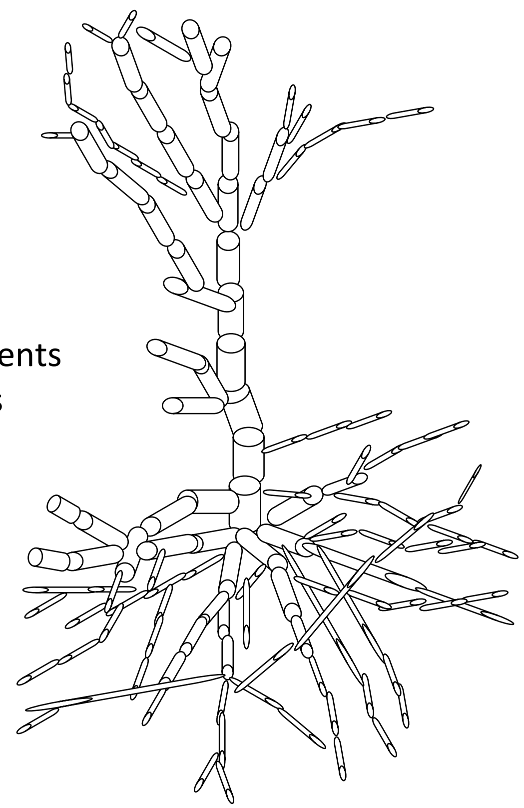
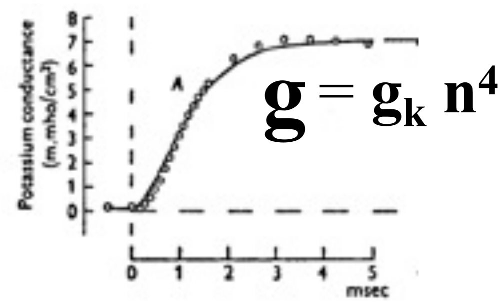
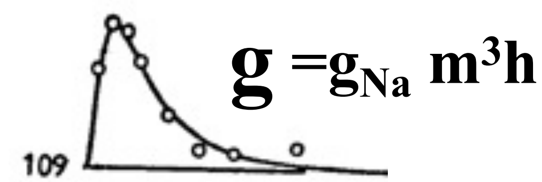
Automatically building neuron models

~400 compartments
~8000 segments





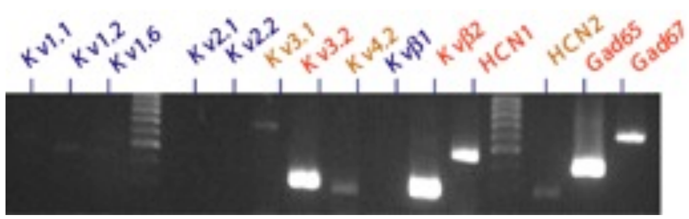
Non Inactivating K Channel



Inactivating Na Channel

Ion Channels

1. Na_p, Fast Na^+
2. Nat_t, Persistent Na^+
3. K_{fast}, Delayed Rectifier K^+
4. K_{slow}, Slow K^+
5. K_t, Transient K^+
6. LVA Ca^{2+}
7. HVA Ca^{2+}
8. I_h, H-Current
9. I_m, M-Current
10. BK, Large g, Ca^{2+} activated K^+
11. SK, Small g, Ca^{2+} activated K^+
12. Leak Current

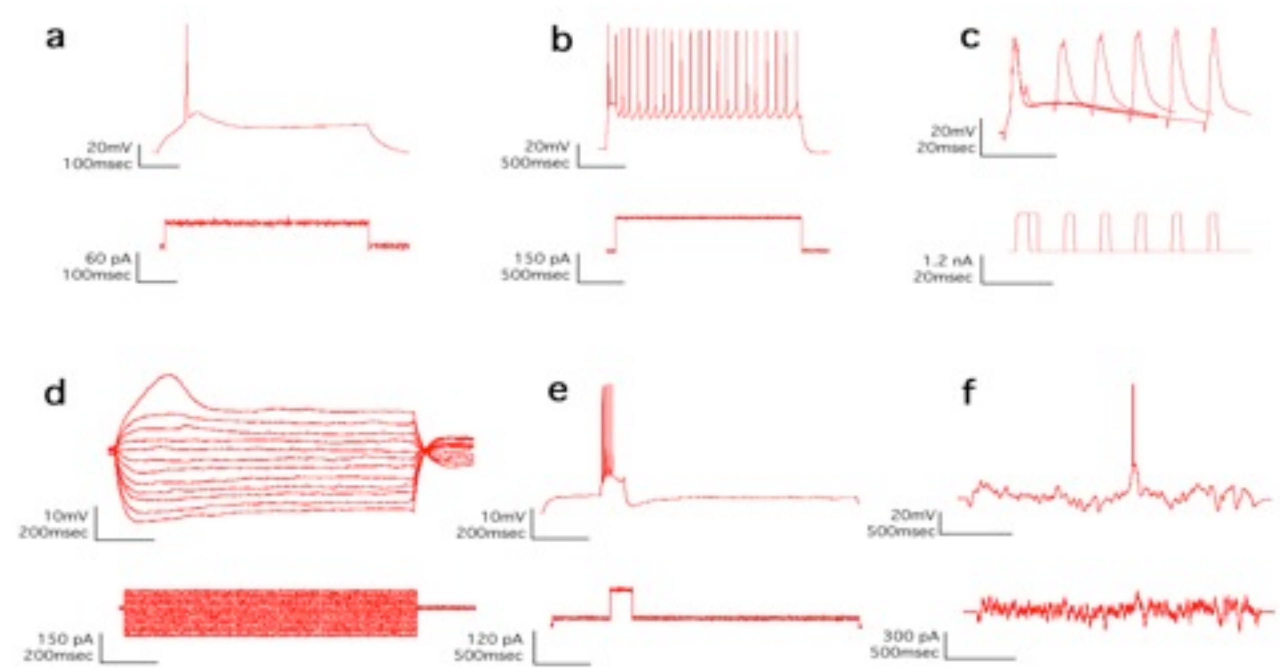


single cell rtPCR gene expression profile

?

Relative Density

- Data constrained
- Generic algorithm



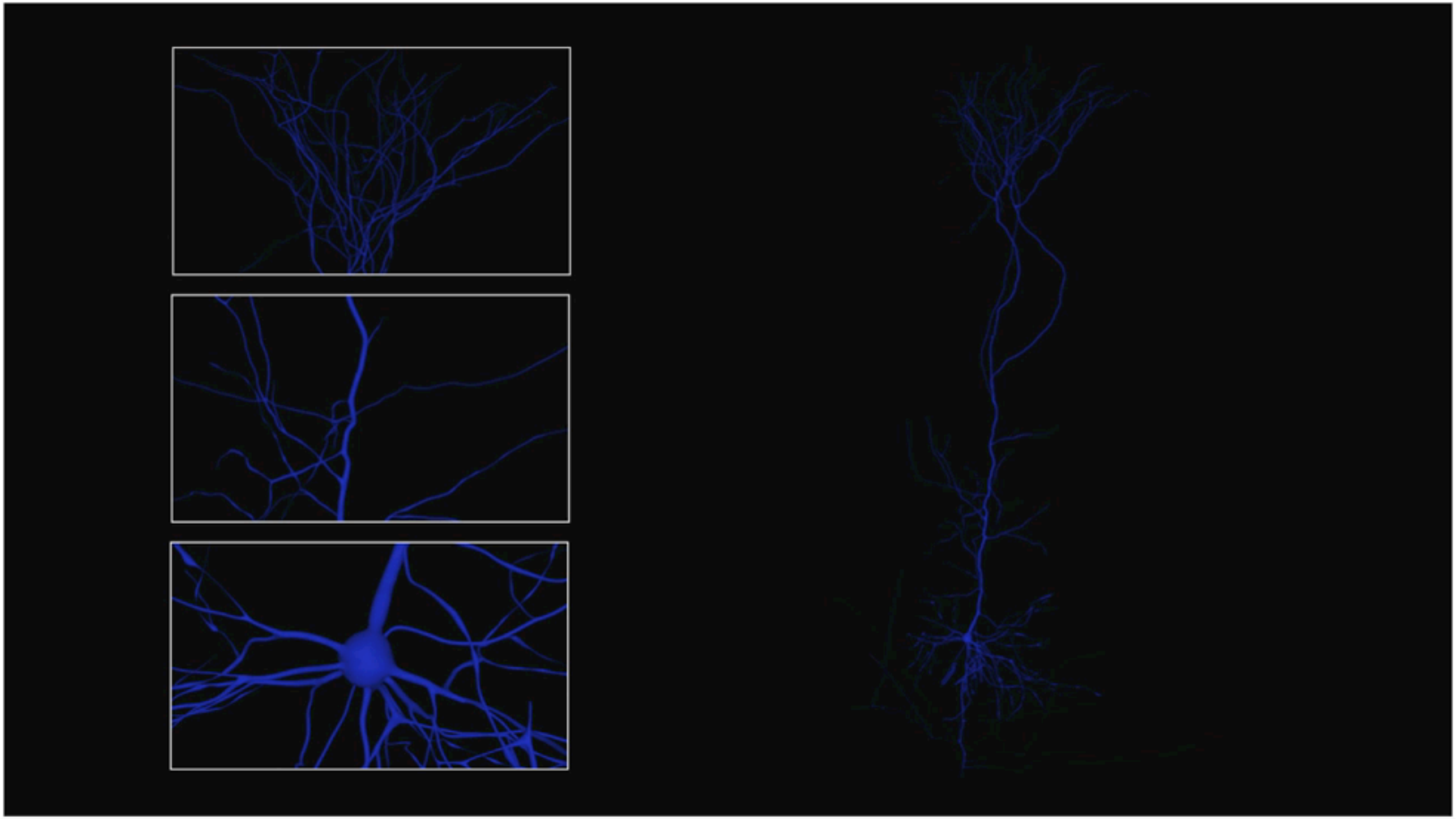
Composition

- Single cell RT-PCR
- ISH expression distribution
- literature

Distribution

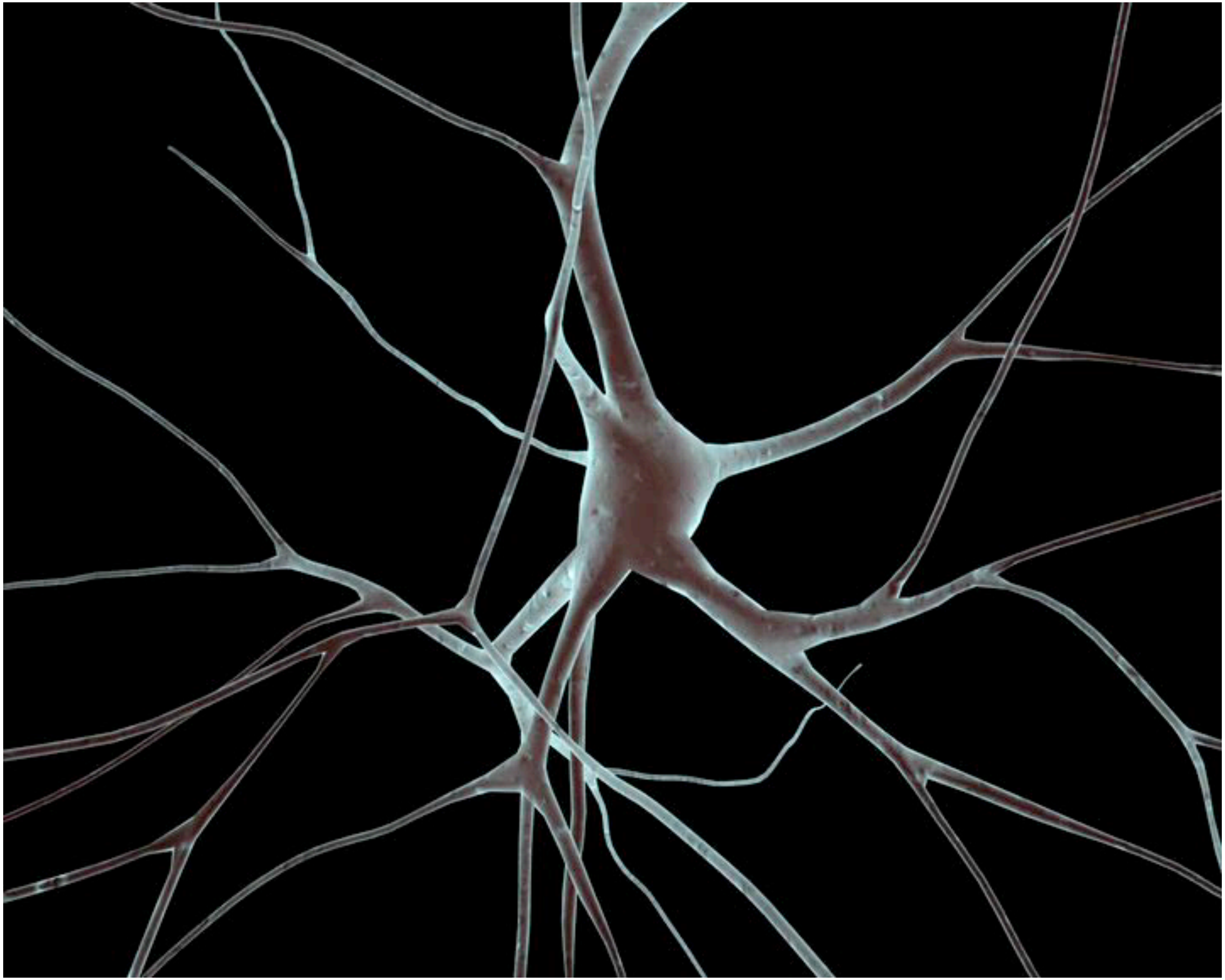
- Staining, Literature, Assumed
- Given Somatic Distance Function
- Fitted within given tolerance

Data-driven biophysical single cell models

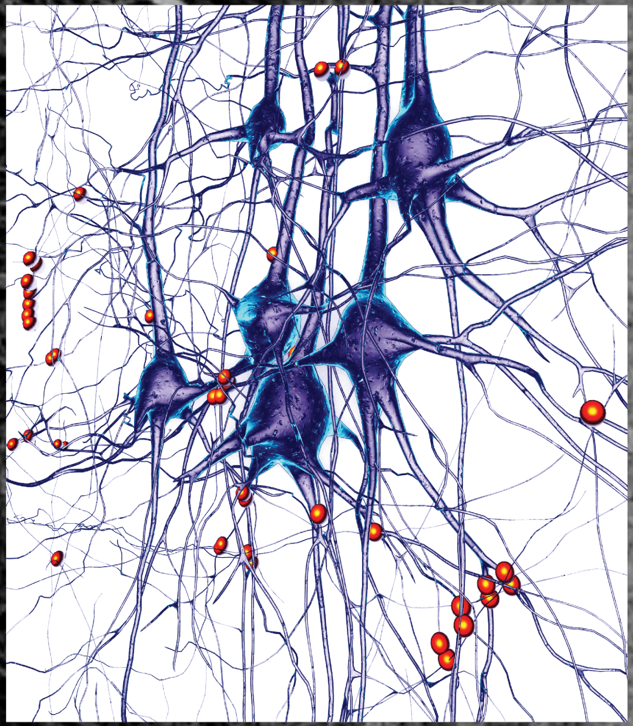


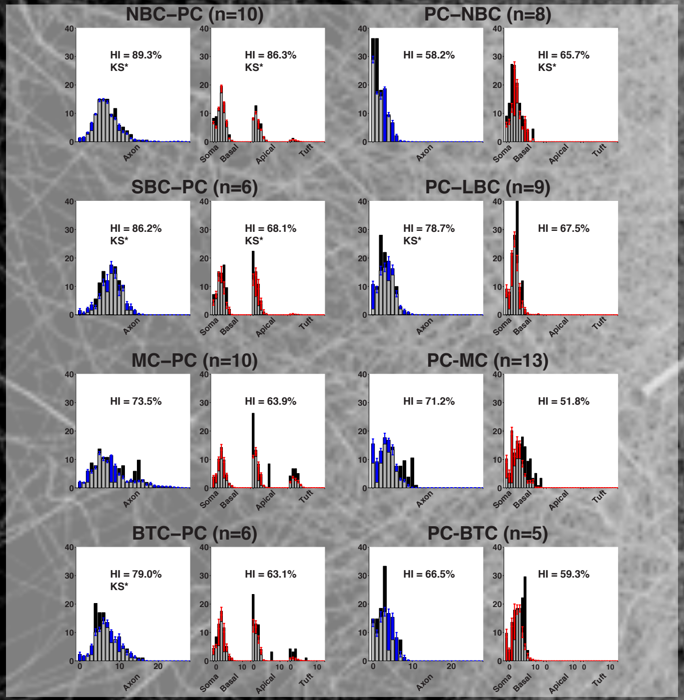
Hay et al., PLOS Comp. Biology, 2012

Building a cortical microcircuit



Predictive Neuroscience: One example

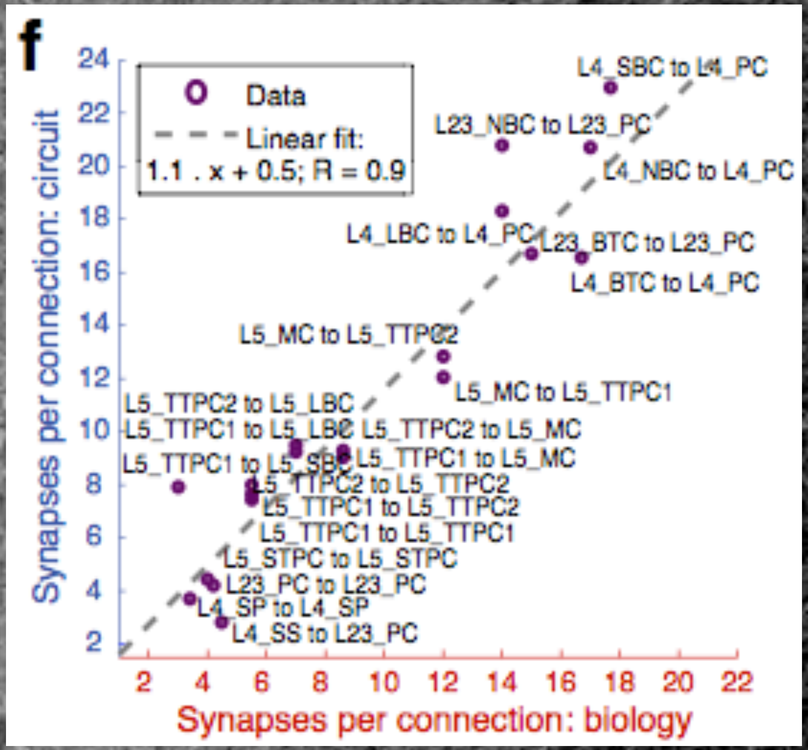


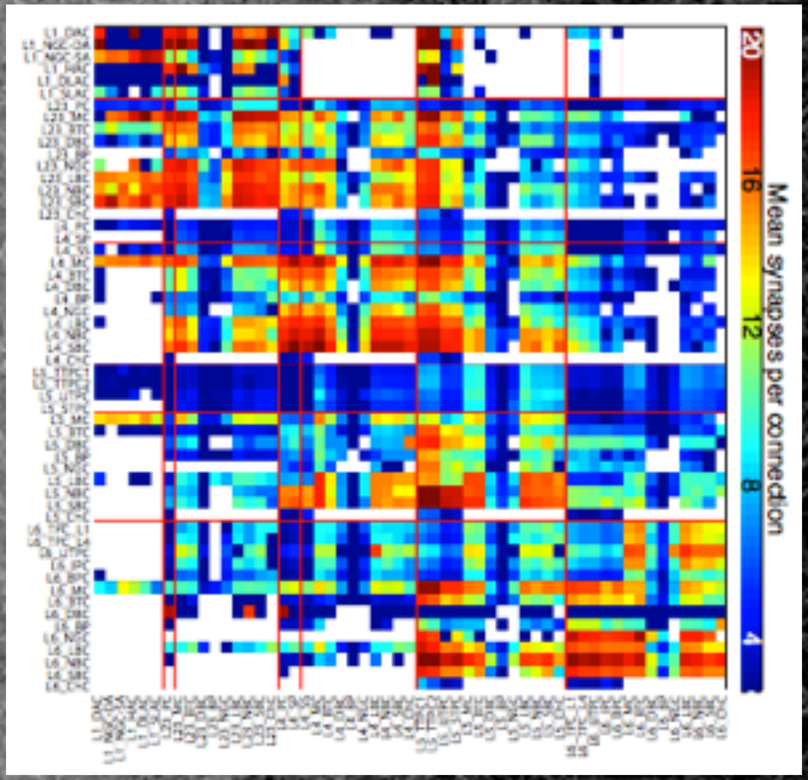


2,970 possible synaptic pathways in a cortical microcircuit alone.

22 have been characterized.

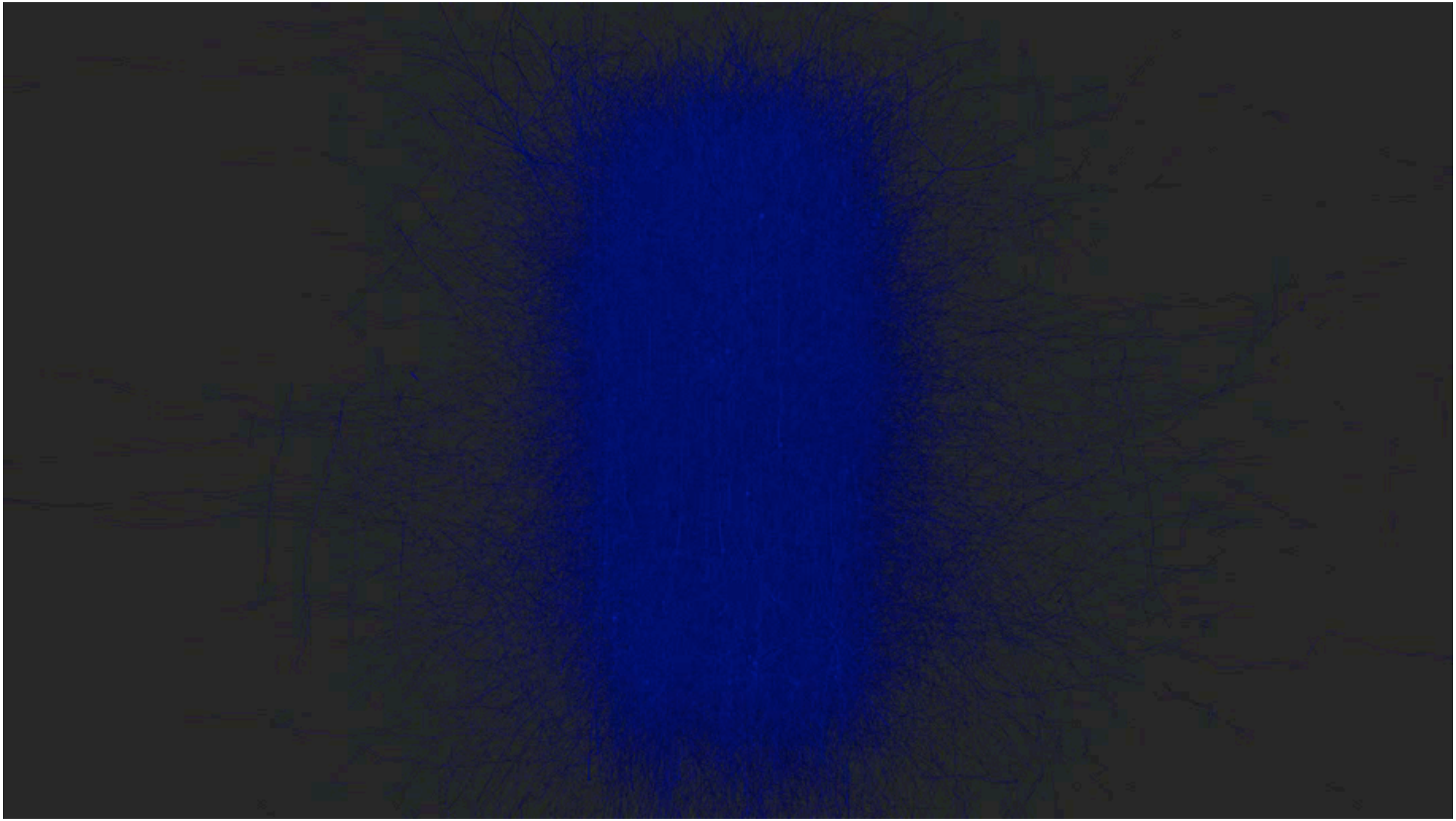
Can we identify principles to predict the rest?



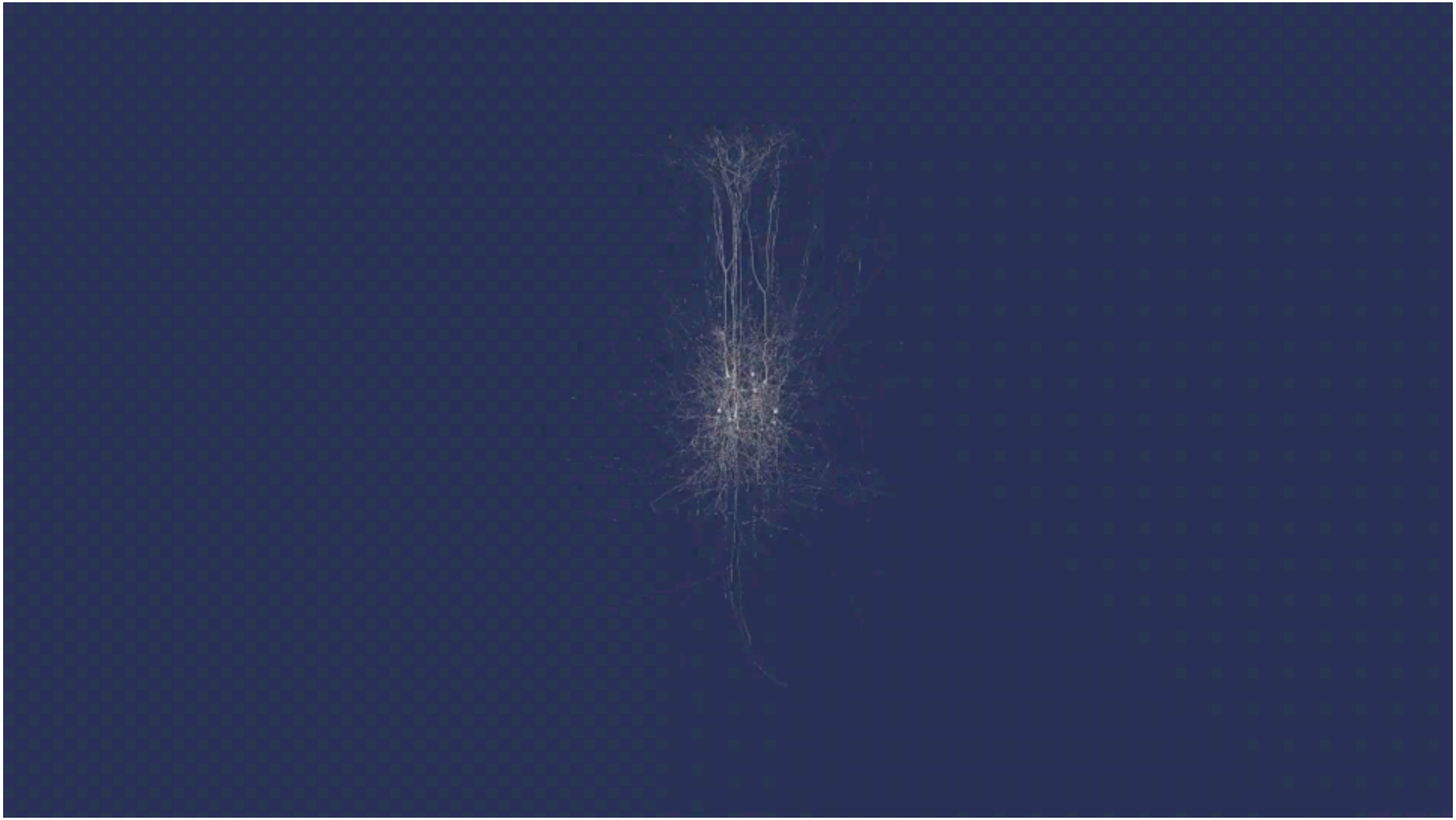


Hill et al. PNAS 2012

Cortical microcircuitry

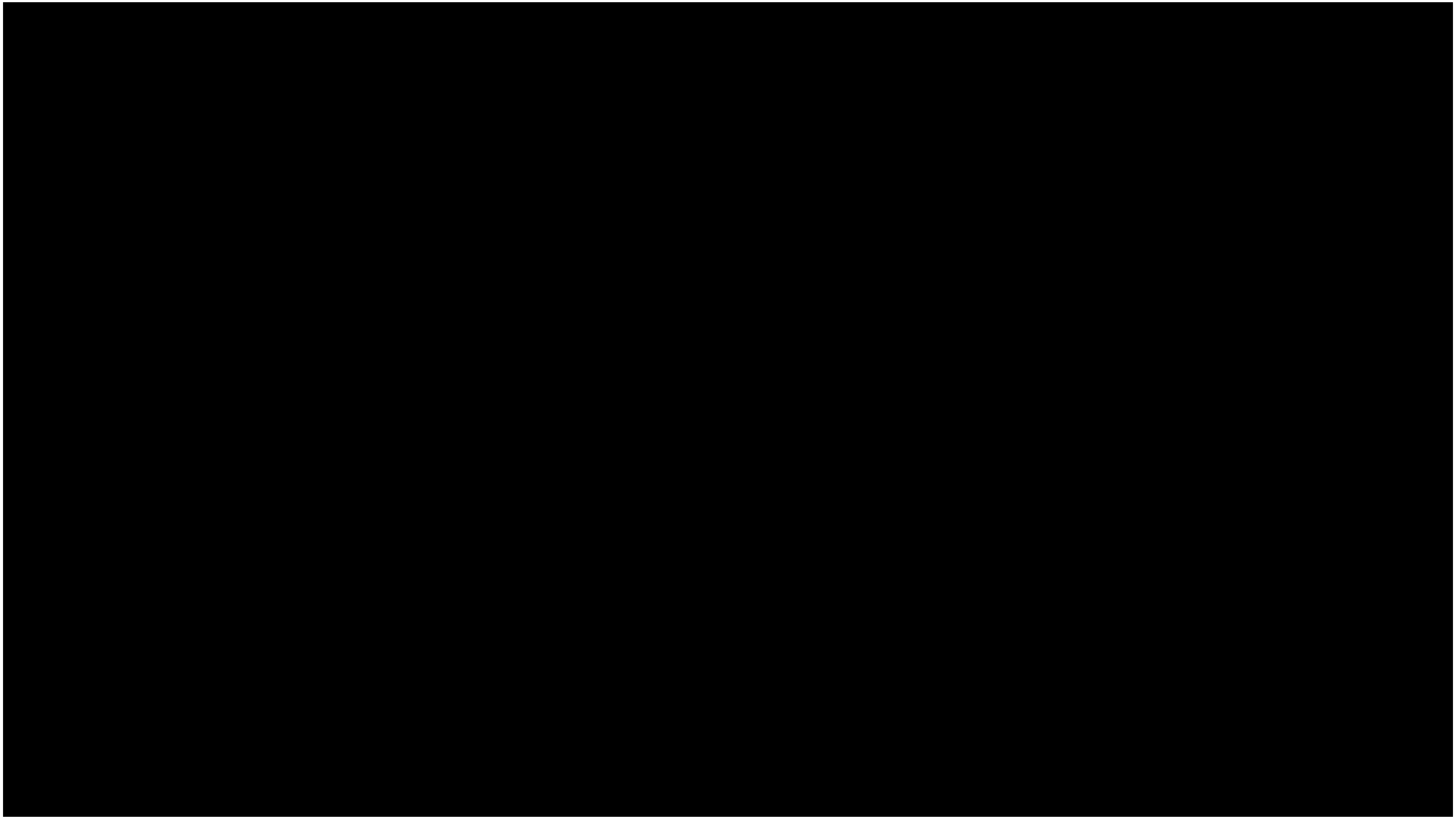


Cortical microcircuitry and local field potential



Reimann et al., Neuron, 2013 in collaboration with the Allen Institute, Seattle, WA

Simulated in vitro cortical slice preparations



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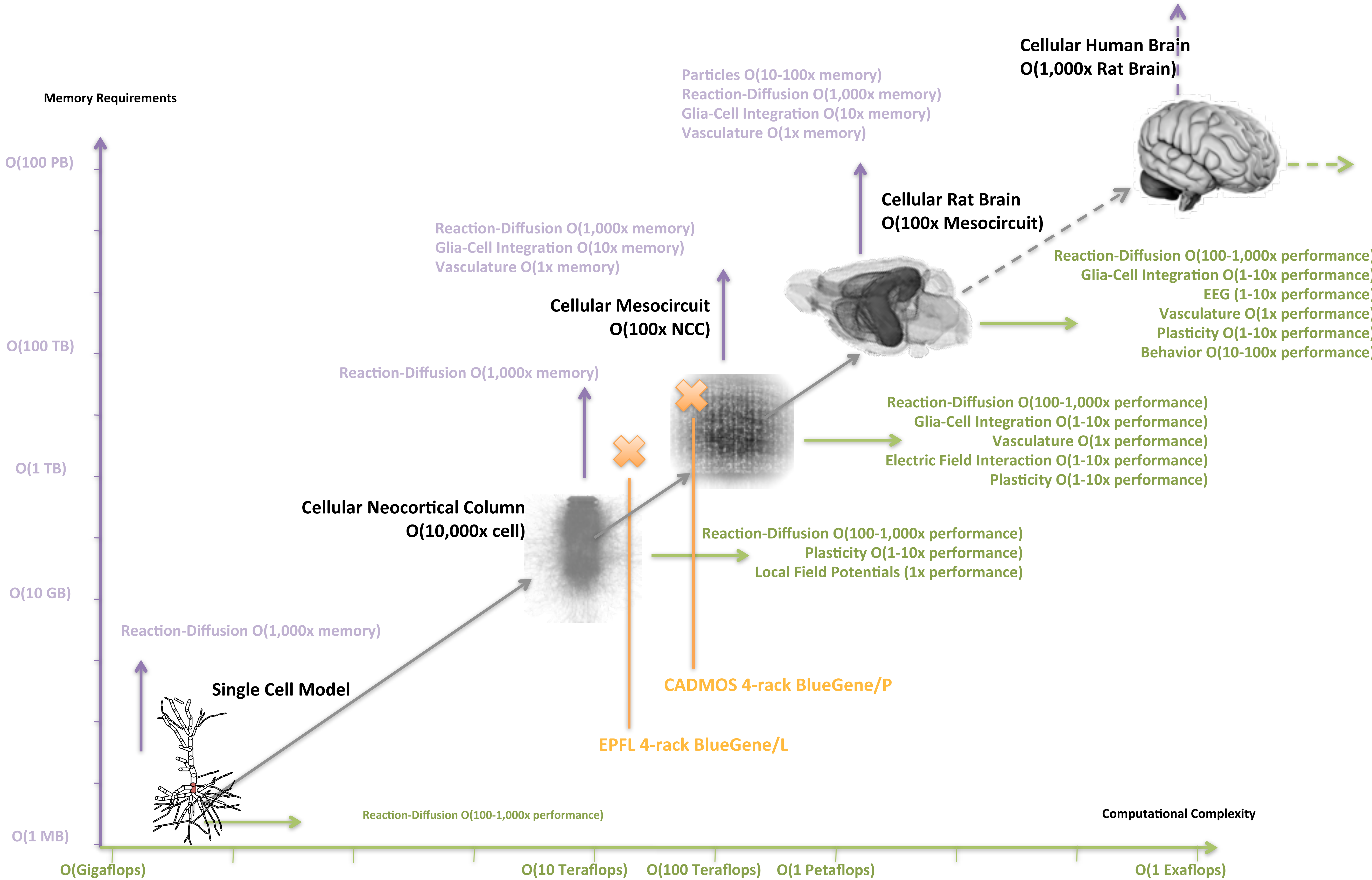
High Performance Computing Platform

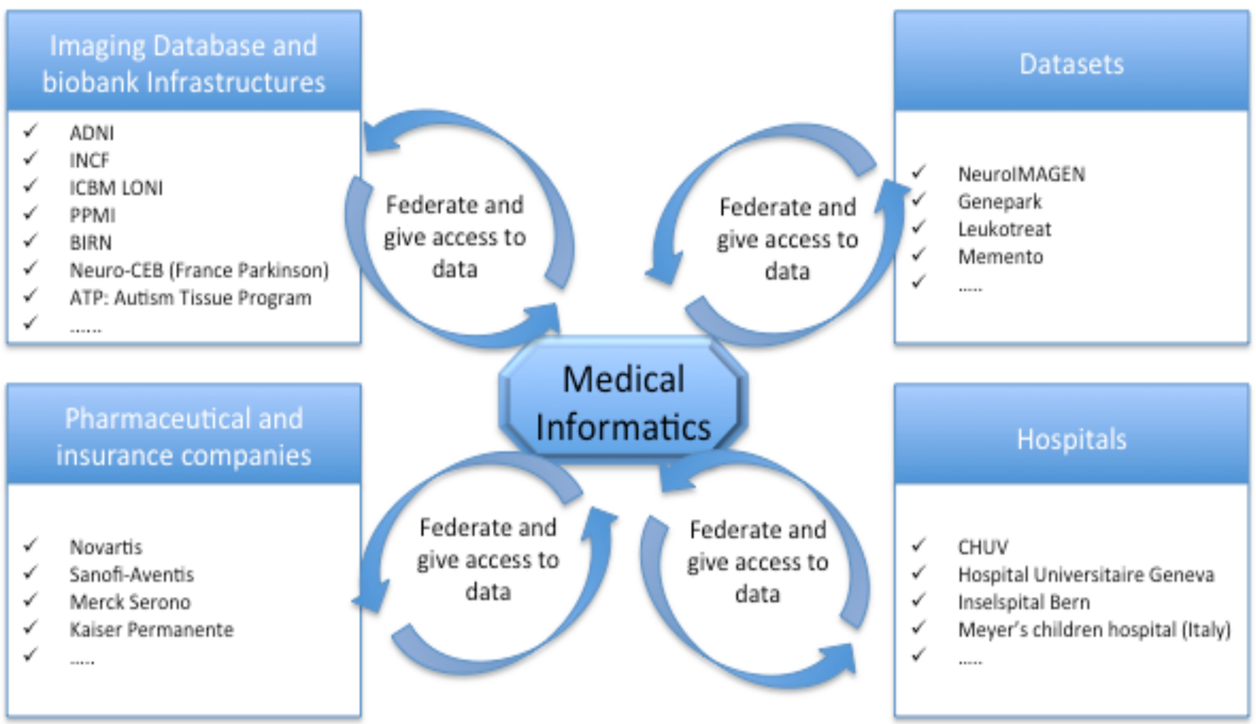
Provide the project and the community with:

- The computing power necessary to build and simulate models of the brain.
- Develop new supercomputing technology, up to the exascale
- Drive new capabilities for interactive computing and visualization.

High Performance Computing Challenges



Medical Informatics

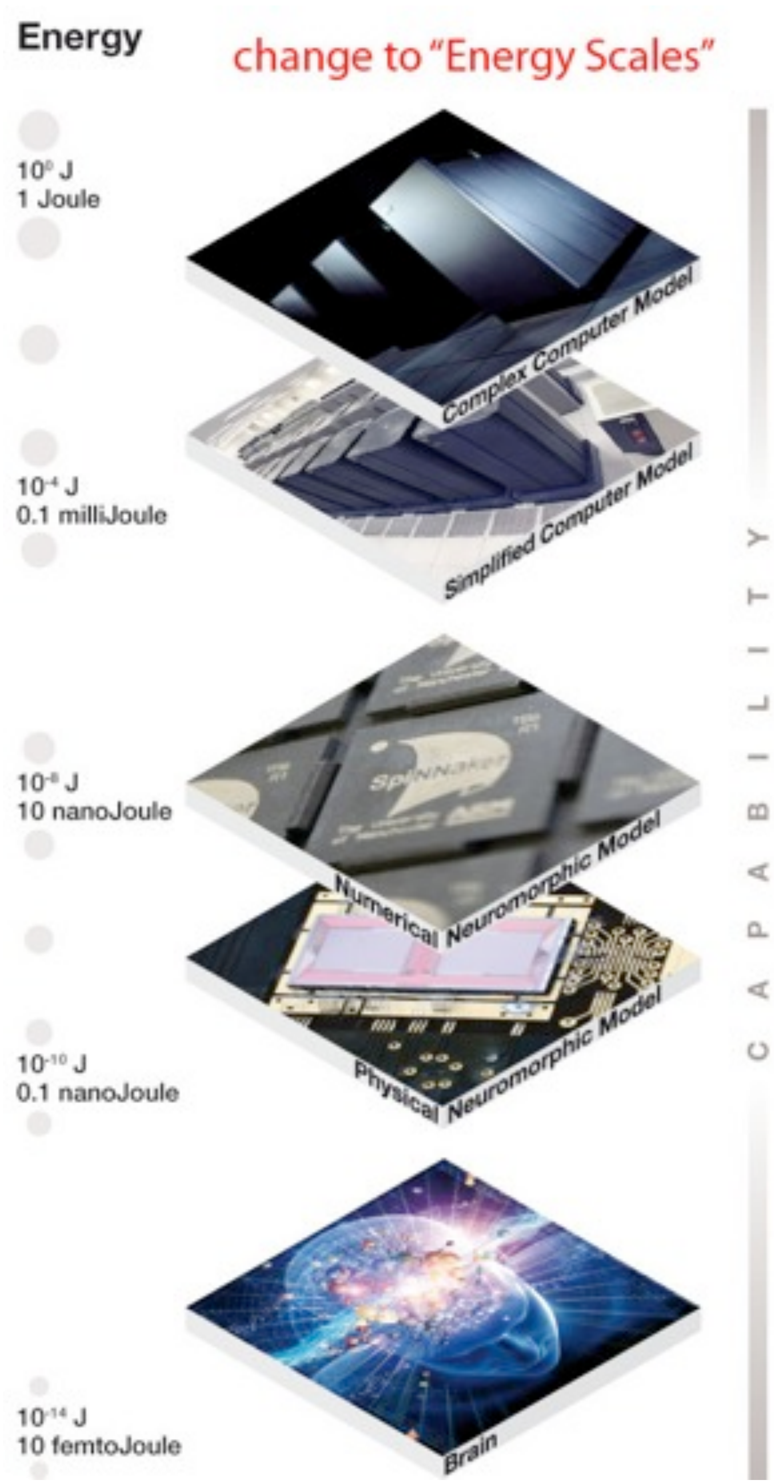


- Federate clinical data from hospital archives and proprietary databases, while providing strong protection for patient data.

- Enable researchers to identify "biological signatures" of diseases.

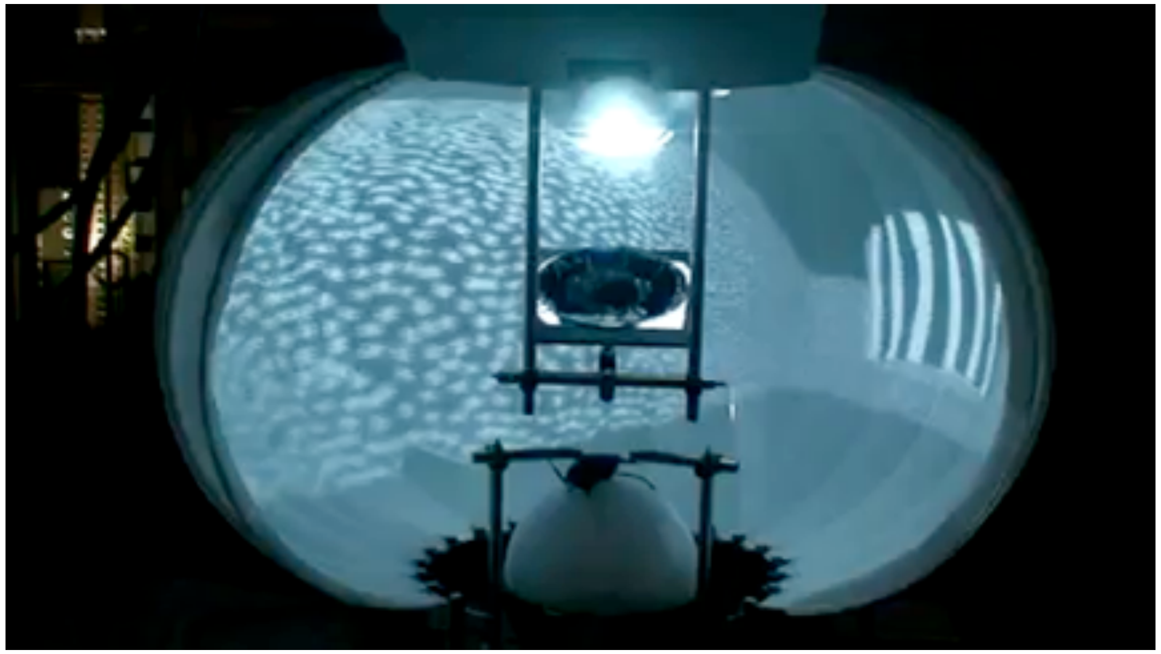
- Develop new approaches to understanding the causes of disease and identifying effective treatments

Neuromorphic Computing Platform

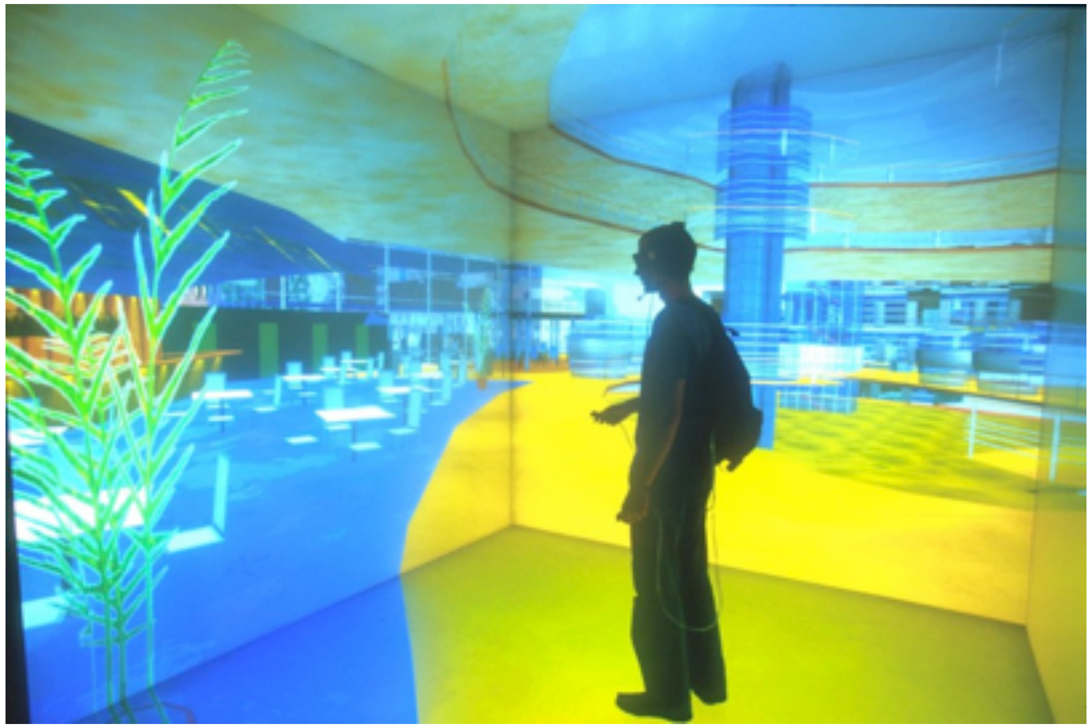


Simulate models on low power chips. Build off of BrainScaleS and Spinnaker projects to provide ability to run large-scale simulations at or beyond real time with low power consumption.

Neurorobotics Platform

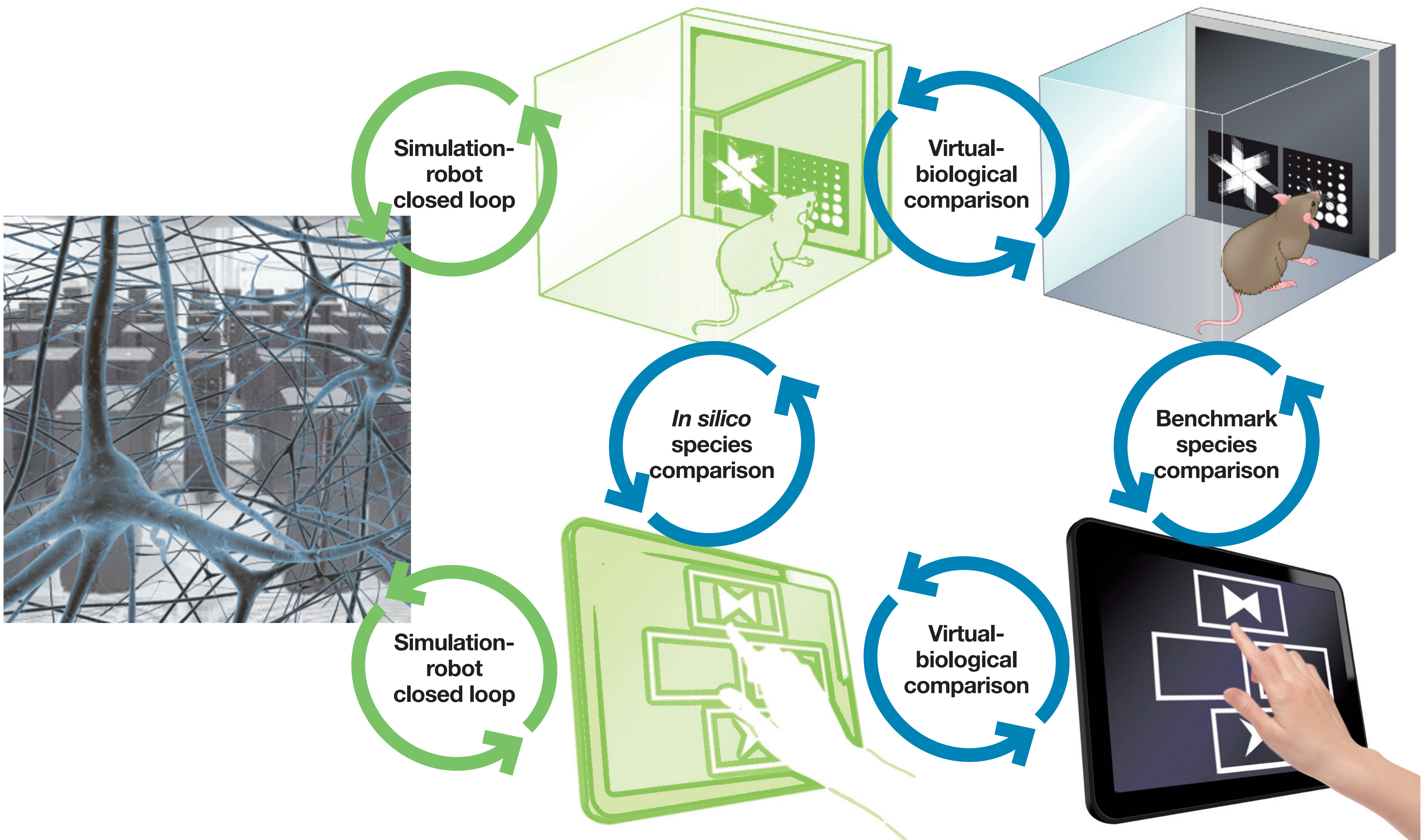


Virtual bodies, sensory input and environments to couple with the simulations. This platform is key to providing sensory input to the simulations and depicting the motor outputs.



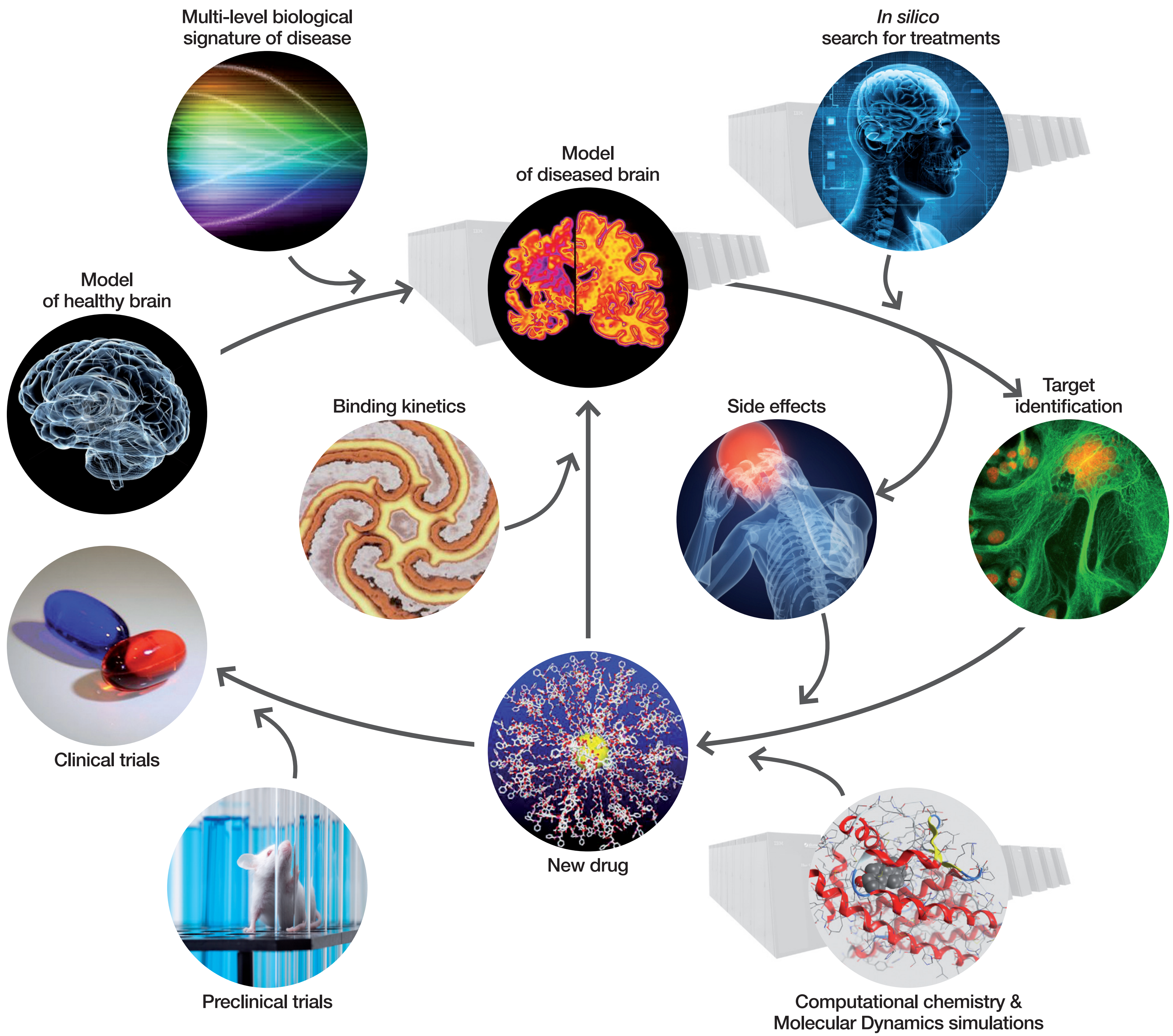
Applications: Understanding principles of cognition

Use Case 1: Tracing causal mechanisms of cognition



Applications: Developing new drugs for brain disorders

Use Case 2: Developing new drugs for brain disorders



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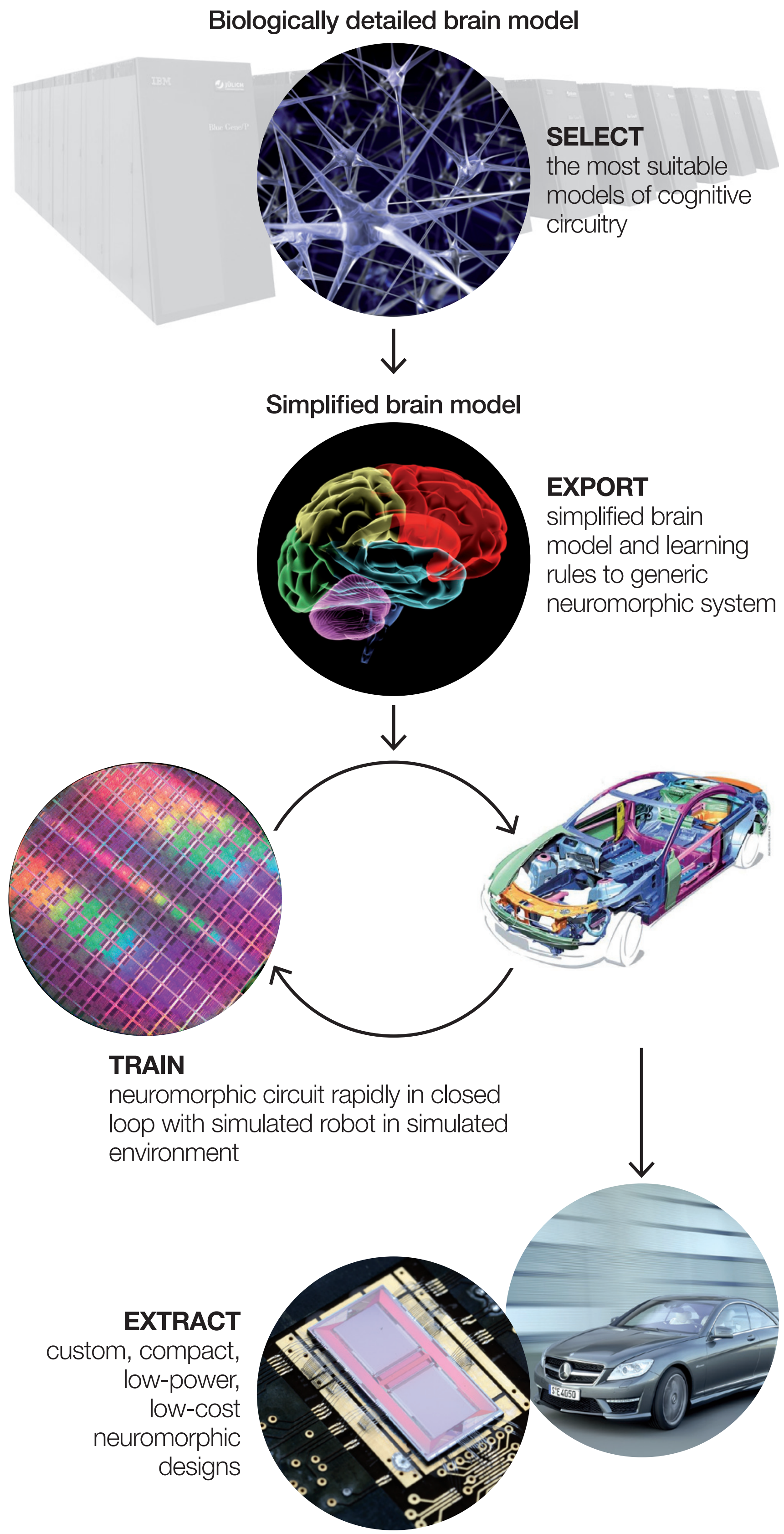
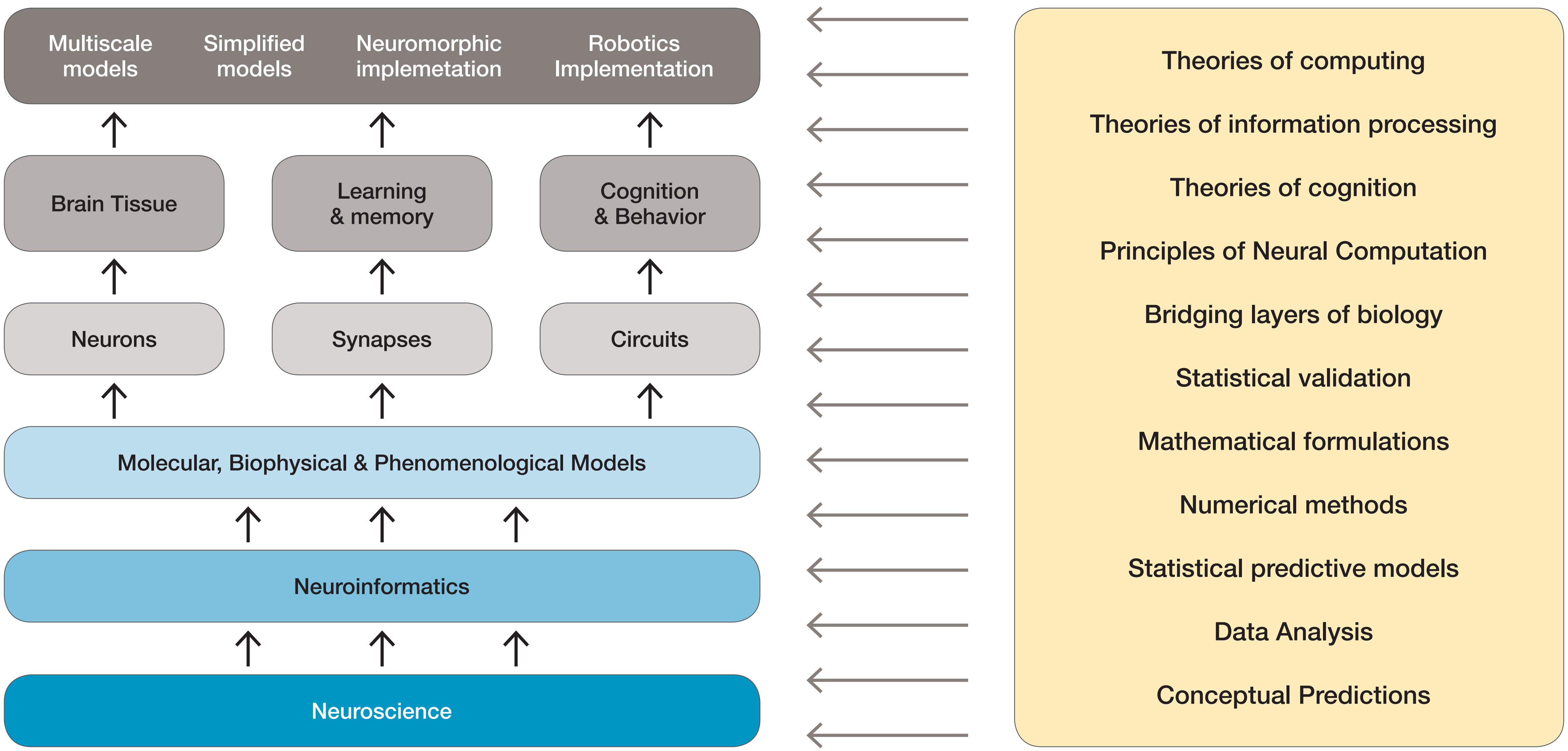
Applications: Developing neuromorphic controllers



Theory

Theory enables effective application of knowledge about the brain to medicine or computing.

The Integrative Role of Theory in the HBP



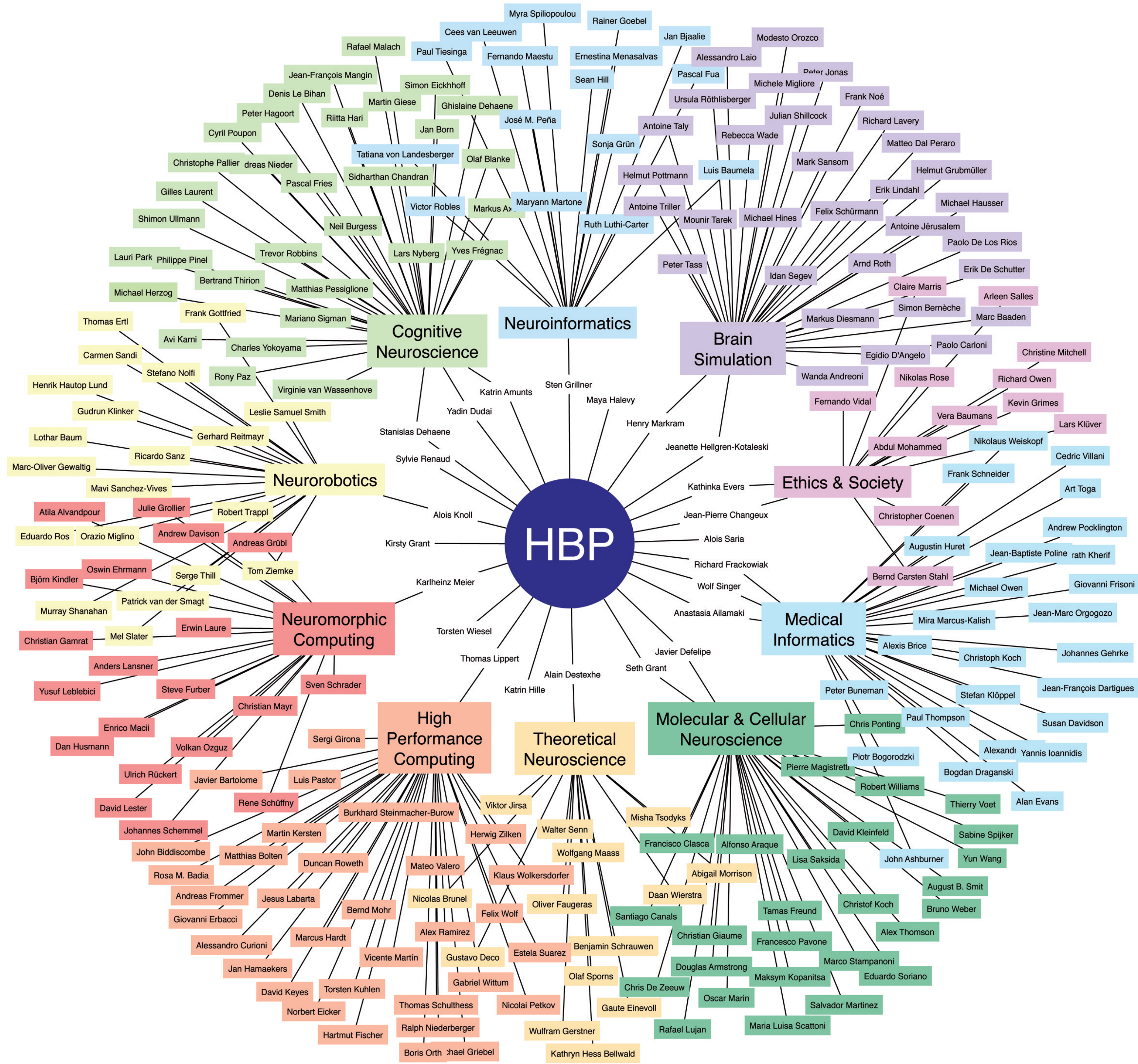
Society and Ethics

"A far-reaching Society and Ethics program, funding academic research into the potential social and economic impact of HBP research, and its ethical and conceptual implications…

…managing programs to raise ethical and social awareness among HBP researchers, and, above all, encouraging an intense dialog with stakeholders and with civil society."

HBP
The Human Brain Project

Participating Scientists



~20% of funding (~200M€) allocated to open calls

HBP open calls
Point of entry for individual researchers

HBP Advanced Research Grants for internationally recognised senior researchers

HBP Young Investigator Grants for advanced postdoctoral researchers

HBP Post-Doctoral Fellowships for entry into independent research

HBP Studentships for mobility, exchange and interdisciplinary training

ERANET+
Point of entry for European research groups

Three-year research grants jointly financed by the EU and the Member States awarded to research groups with proven competence to contribute to

- data generation
- platform building
- research using the platforms

in the areas of expertise covered by HBP divisions

HBP
The Human Brain Project

The Initial HBP Consortium

For more information and a full list of leaders, partners and collaborators

please visit:

www.humanbrainproject.eu

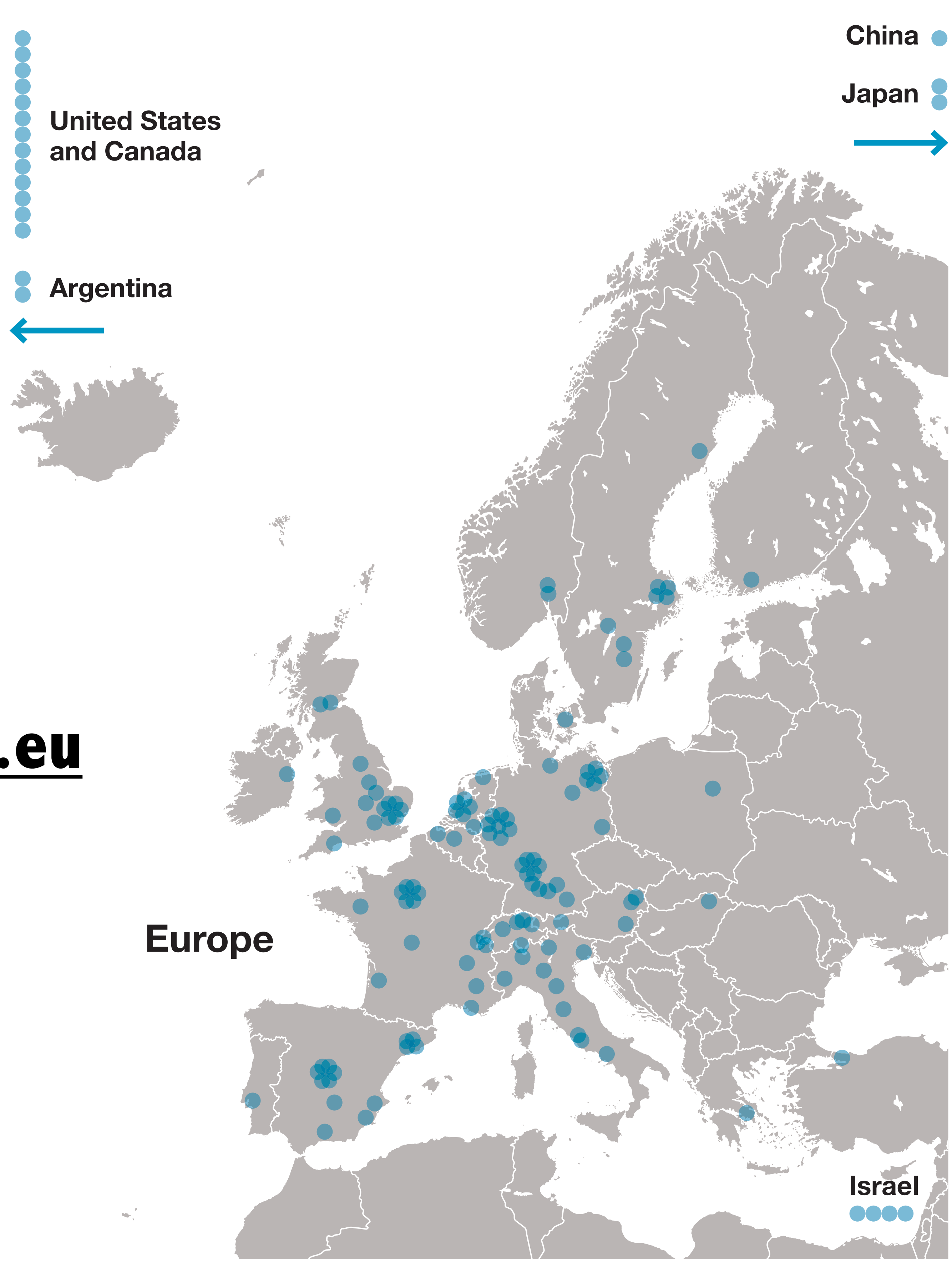


Figure 40: Research institutions identified to participate in the HBP, if approved as a FET Flagship Project