Human Brain Project

Unifying our understanding of the human brain

Dirk Pleiter (Jülich Supercomputing Centre)

Co Funded by
the European Union

Overview

- Introduction
- Selected use cases
- Future supercomputers for brain research
- Federated data infrastructures
- Summary and outlook

Human Brain Project

Introduction

FET Flagships and Scientific Goals

FET flagships

- Future & Emerging Technologies projects (co-)funded by European Commission
- Science-driven, seeded from FET, extending beyond ICT
- Ambitious, unifying goal, large-scale

Human Brain Project (HBP) flagship

- Currently 114 participants in Specific Grant Agreement 1 (SGA1)
- SGA1 runs from 2016-18 with an overall budget of ~110 M€

Goals of the HBP

- Enable research aiming for understanding of the human brain
- Transfer neuroscience knowledge for development of future technologies

Challenge: Complexity of the Human Brain

Extremely large number of neurons

- About 100 billion neurons

Extremely high-radix interconnect

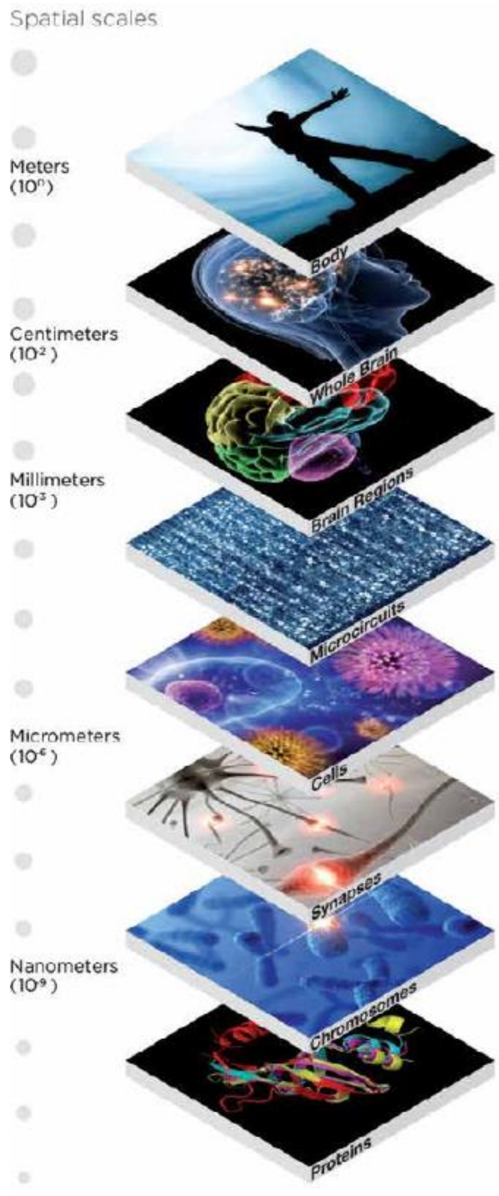
- 100 trillion synapses

Many organisational levels

- Molecular
- Cellular
- Brain regions
- Whole brain

Extremely power efficient

- The human brain consumes only 30 W
- Today we need supercomputers to model fractions of the human brain



Project Objectives

- Create and operate a **European Scientific Research Infrastructure** for brain research, cognitive neuroscience, and other brain-inspired sciences
- Gather, organise and disseminate **data describing the brain** and its diseases
- **Simulate the brain**
- Build multi-scale scaffold **theory and models for the brain**
- **Develop brain-inspired computing**, data analytics and robotics
- Ensure that the HBP's work is undertaken responsibly and that it **benefits society**

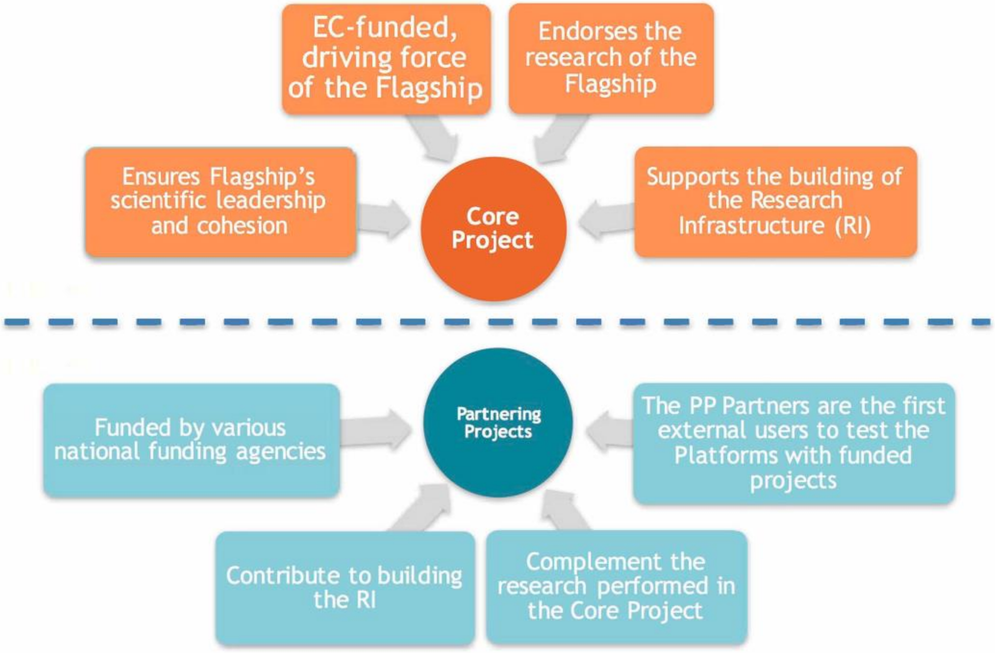
Project Organisation and Approach

Open organisation

- Core project vs. partnering projects
- Competitive calls program

Neuroscience and platform sub-projects

- Neuroscience sub-projects:
  - Mouse and human brain organisation
  - Systems and cognitive neuroscience
  - Theoretical neuroscience
- Platforms: see next slide



Co-design approach to shape future research infrastructure

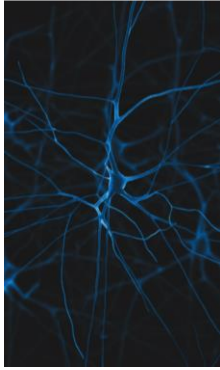
- Neuroscience vs. platform sub-projects
- Dedicated co-design projects

Human Brain Project Platforms

Platform

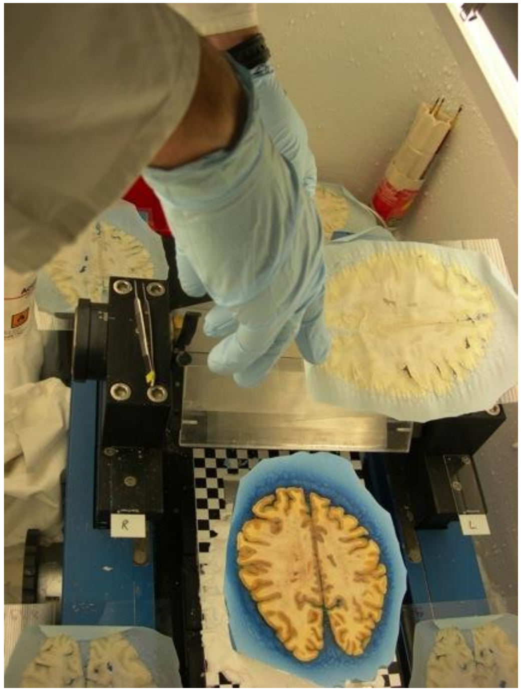
- Neuro-informatics platform
  - Integration of brain data and extreme scale data analytics
- Brain simulation platform
  - Integration of different simulators
  - Molecular level simulations to whole-brain modelling
- High-Performance Analytics & Computing Platform
  - Design, implement and operate a federated HPC and data analytics platform
  - Establish co-design processes involving HPC solution providers
- Medical Informatics Platform
  - Federated clinical infrastructure
- Neuromorphic Computing Platform
  - Design, implement and operate neuromorphic hardware systems
- Neurorobotics Platform
  - Based on integration of models, simulators and neurorobotics systems

Infrastructure



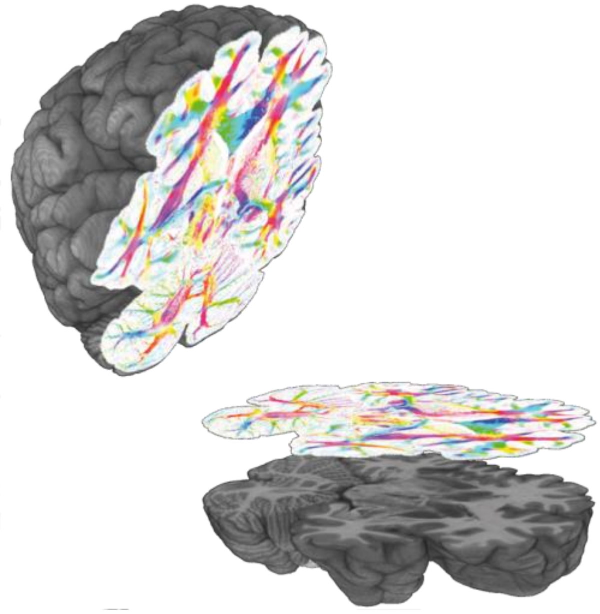

Selected Use Cases

Use Case: High-resolution Brain Atlas



Research goal

- Accurate, highly detailed computer model of the human brain based on histological input

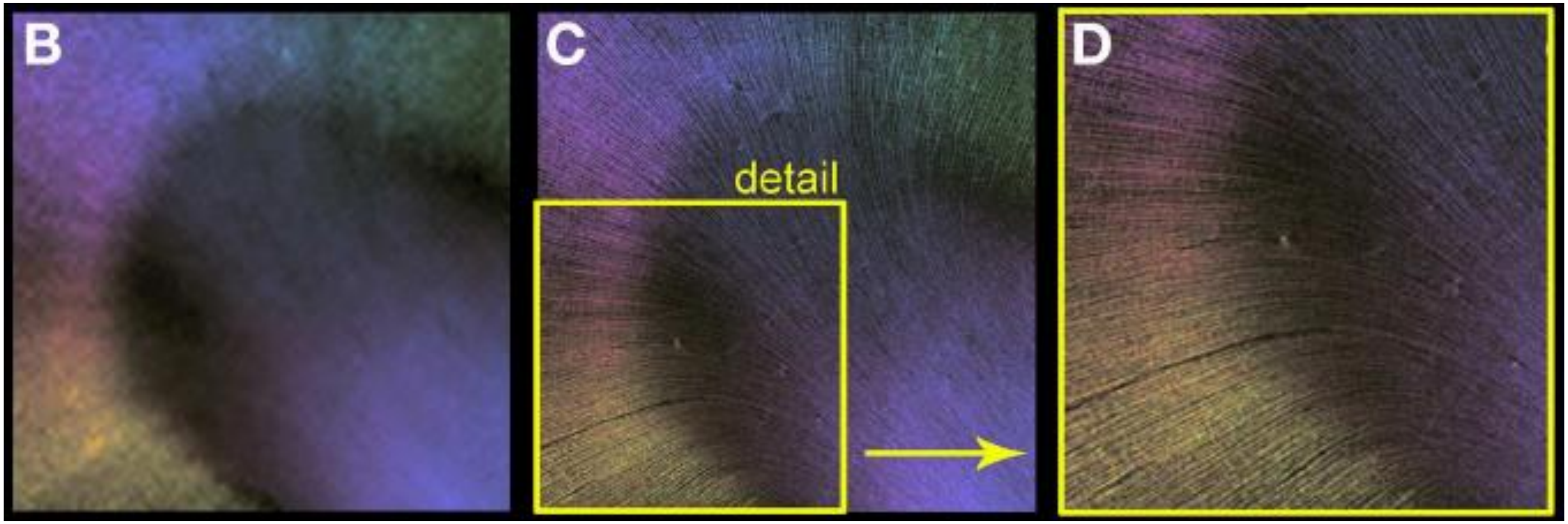


[K. Amunts et al., Science 2013]

Approach

- Create high-resolution 2-dimensional brain section images
- Re-construct 3-dimensional models from these images

Need for High Resolution



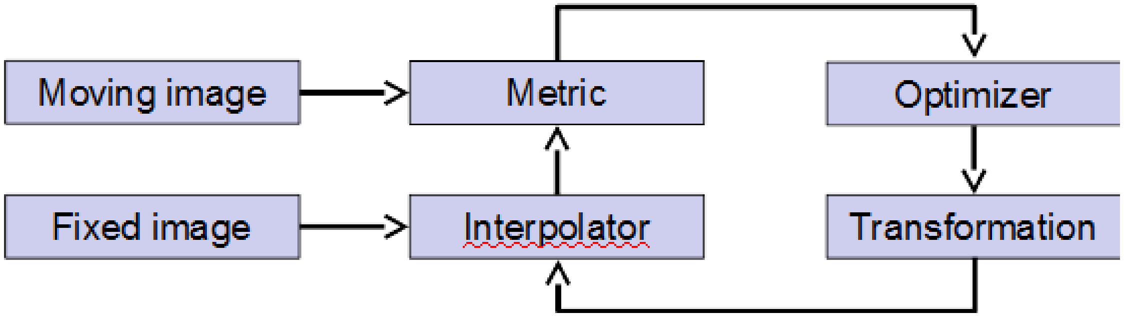
- Large-Area Polarimeter image
- Optical resolution limit = 159 µm
- ~3 GByte / image

- Polarizing Microscope image
- Optical resolution limit = 3.9 µm
- ~700 GByte / image

Brain Atlas: The Computational Challenge

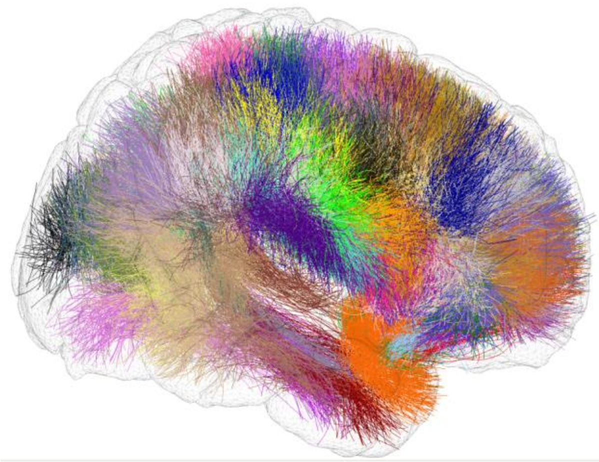
Image registration

- Based on mutual information metric
- Determination of joint histograms
- Runs fast on NVIDIA Kepler GPUs
  - Key feature: support of L2 atomics



Navigation in petabytes of data

- About O(10…100) GByte/image
- O(10^4) images



[S. Lefranc et al., 2016]

Use Case: Whole-Brain Modelling

nest:: initiative

Neural Simulation Technology (NEST)

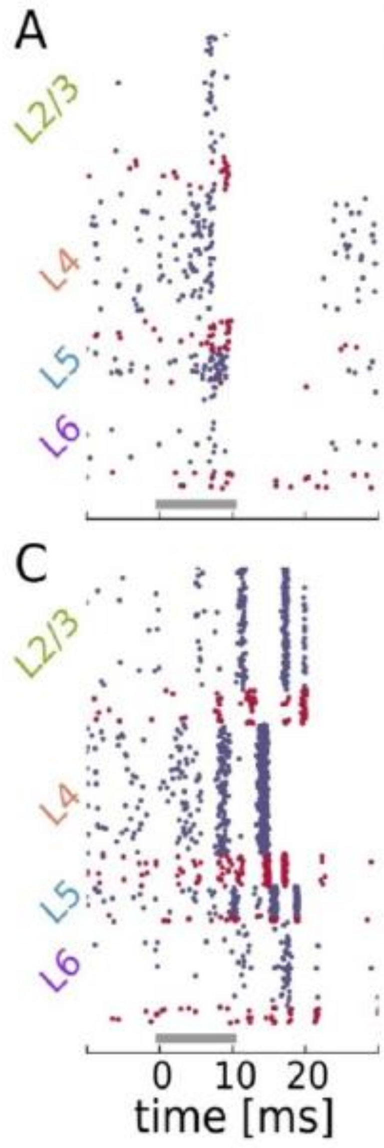
- One out of several brain simulators in the HBP

Application target

- Create models of the brains of mammals and humans
- Push limits of large-scale simulations of biologically realistic networks
  - Huge network: $O(10^{11})$ neurons
  - High connectivity: Neuron connected to $O(10^4)$ neurons

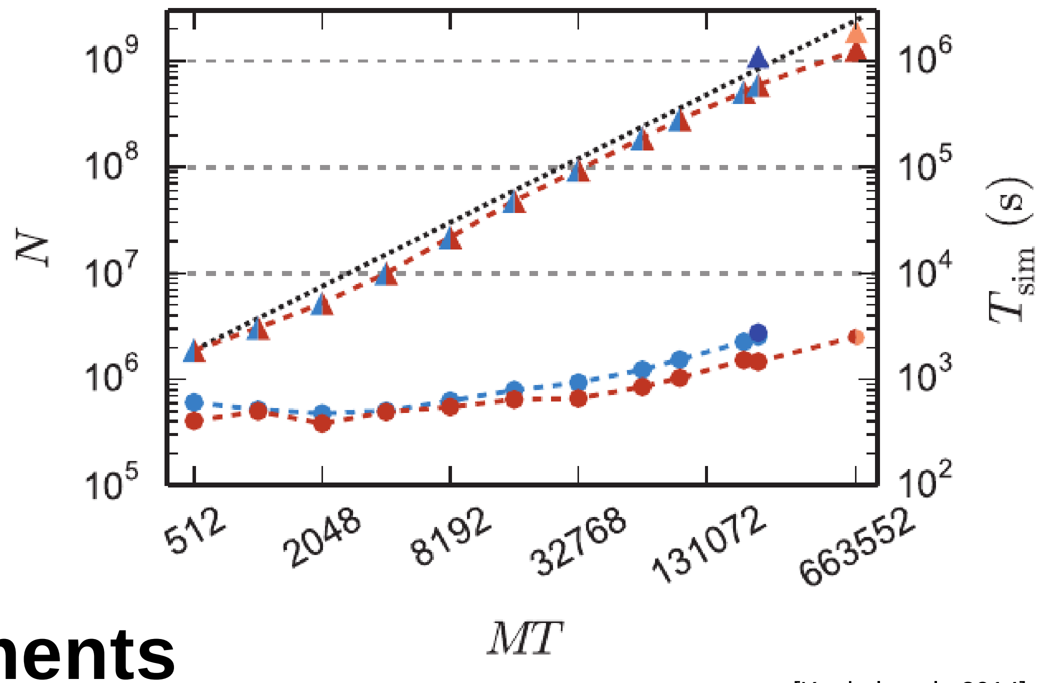
Approach

- Simulation of spiking neuronal network
- Focus on large networks, use of simple point neurons



[Potjans, Diesmann, 2012]

NEST: The Memory Capacity Challenge



[Kunkel et al., 2014]

Simulation work-flow

- Construct network
- Spiking neuronal network simulations
- Analyse observables created by simulations

Supercomputer requirements

- Maximise memory footprint
  - Application today is memory capacity limited
- Optimise processing performance → memory bandwidth
  - Keep ratio simulation versus simulated time small
- **Allow for interactive steering of the applications**

Simulation Virtual Surgery

Scientific question

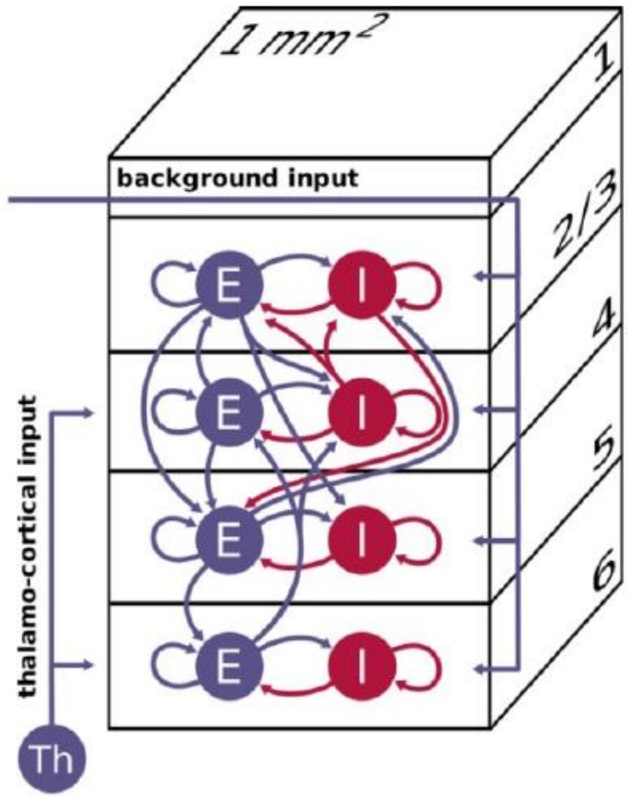
- What happens if particular neuron connections are cut?

Approach

- Interactive manipulation of network during simulation

Future vision

- Interactive access to supercomputers



[M. Diesmann, 2013]

Human Brain Project

Future Supercomputers for Brain Research

Envisioned Use Cases

Future large-scale simulations with need for

- Pre-exascale computers with extreme scale memory footprint
- Ability to steer the simulations
- Concurrent interactive analysis of data
- Scalable data visualisation capabilities

High-performance data analytics

- Image and other data in O(1-10) PByte range
- Need for scalable compute resources to process data

Architectural and Technological Requirements

Integration of dense memory technologies

- Need space to
  - Enable checkpoint/restart or resume mechanisms
  - Hold transient data
- New NVM technologies will help (V-NAND, PCM, ...)
  - Provide high capacity, but only limited bandwidth
  - Challenge: global interface to this memory
- Globally accessible and addressable storage class memory

Technologies enabling exploitation of memory and storage hierarchies

- Support of automatised data staging and migration

Architectural and Technological Requirements

Integration of visualisation capabilities

- Scalability
- Small response times
- Support of various user interfaces

Resource management: co-scheduling and dynamic scheduling

- Co-scheduling of different types of resources
  - Compute vs. data resources
- Ability to cope with resource requirements changing during job execution

HBP Pre-Commercial Procurement

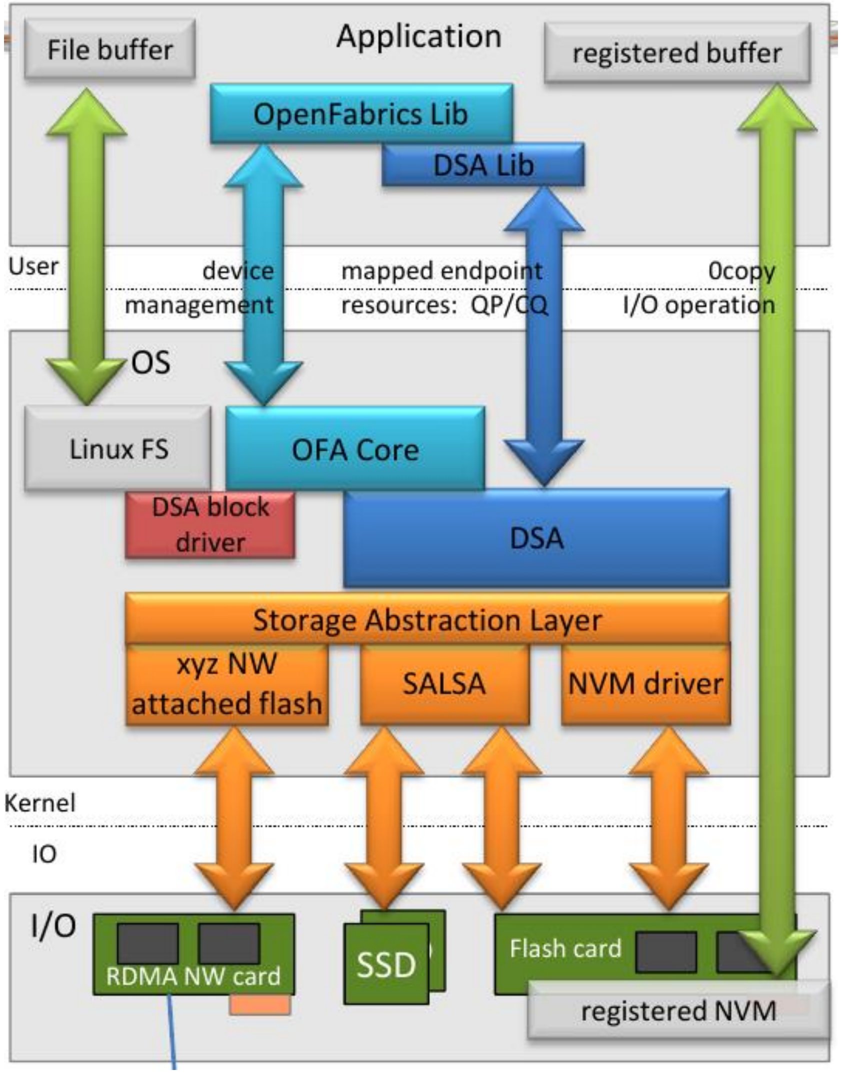
Instrument for procurement of R&D services

- Competitive processed organised in multiple phases

Current status

- Final phase started in July 2015
- Remaining competitors
  - CRAY
  - IBM + NVIDIA
- Pilot systems to demonstrate readiness of the proposed solutions have been recently installed at JSC

Selected R&D Result: DSA



[B. Metzler, 2015]

DSA = Direct Storage-class memory Access

Key idea

- Use OpenFabrics stack for (local) NVM access
- RDMA write/read to/from NVM device

Extension within PCP

- Global address space
- Full saturation of InfiniBand EDR link speed demonstrated

PCP Pilot System Complex

OPA

IB EDR

Cray Pilot System

High-performance storage system

IBM Pilot System

Cray PCP Pilot System

Based on CS Storm with KNL

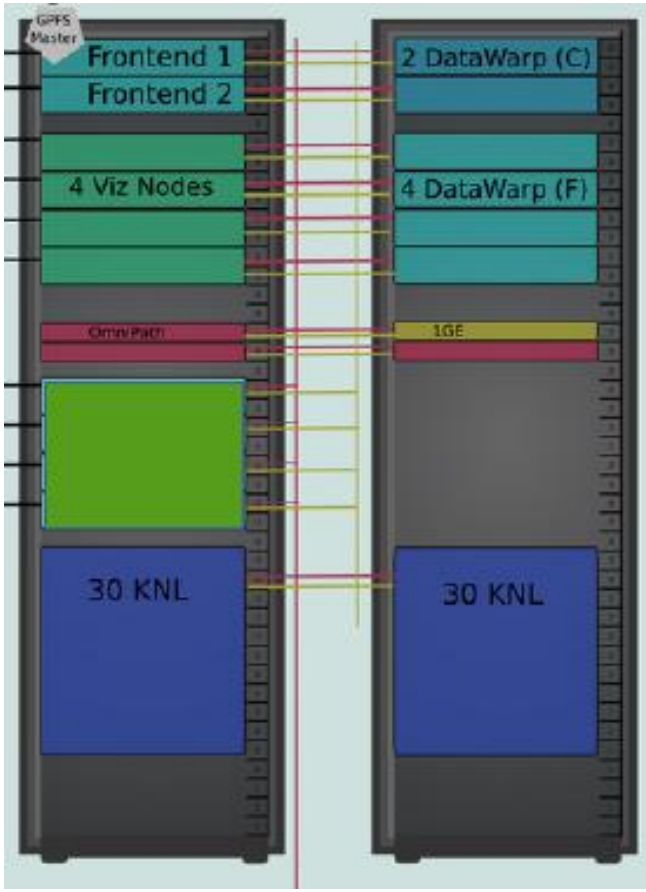
- KNL processors with 64 cores

Deep memory and storage hierarchy

- High-bandwidth MCDRAM
- Capacity optimised DDR4
- SATA-attached SSD
- DataWarp nodes with PCIe-attached SSDs
- …

PCP related features

- Integration of dense memory
- Tightly integrated visualisation nodes
- Dynamic resource management integrated with SLURM



IBM-NVIDIA Pilot System

Based on Minsky platform

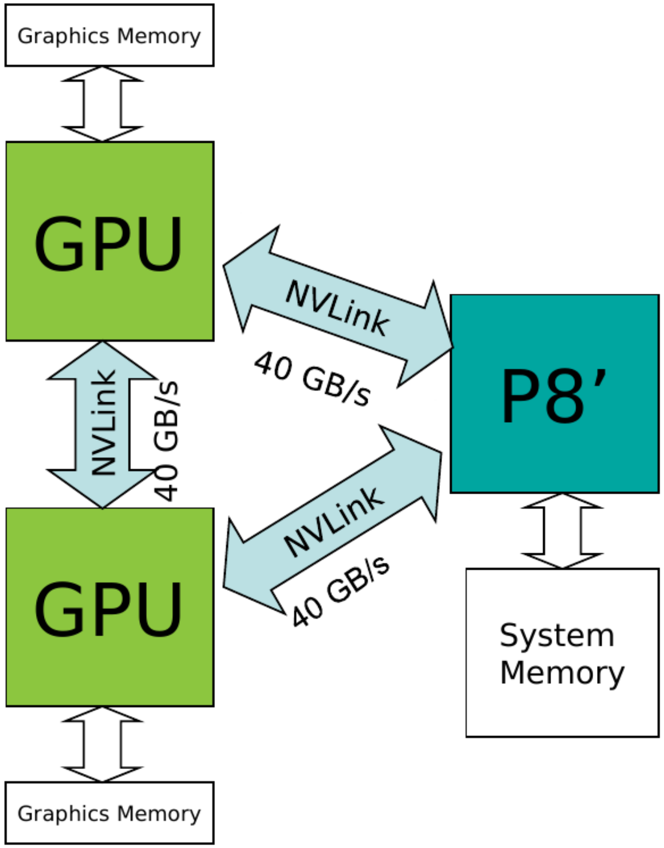
- 2x POWER8’ + 4x Pascal GPUs

Deeper memory hierarchy

- High bandwidth memory technologies
  - 64 GiByte, ~3 TByte/s
- Large capacity system memory
  - ≥256 GiByte, ~200 GByte/s
- Very-large capacity NVM
  - 2 TiByte, ~3 GByte/s

Improved data movement capabilities

- New NVLink and DSA technologies



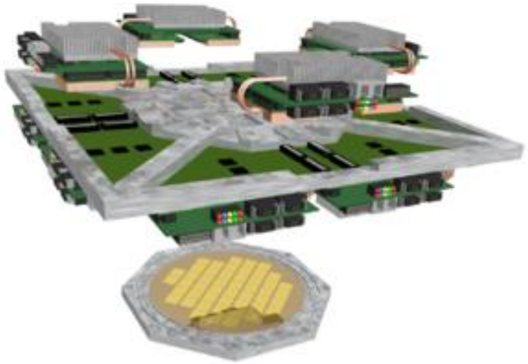
Digression: Neuromorphic Architectures

SpiNNacker [Steve Furber, David Lester et al.]

- System based on custom processors
  - ARM-based SoC design
- Application optimised asynchronous NoC and inter-chip network

Waferscale system NM-PM1 [Karlheinz Meier et al.]

- HICANN ASIC
  - High Input Count Analog Neural Network
  - Implements a particular neuron model
- *O*(100) ASICs on single wafer
- Simulation speed faster than real-time



Human Brain Project

Federated Data Infrastructures

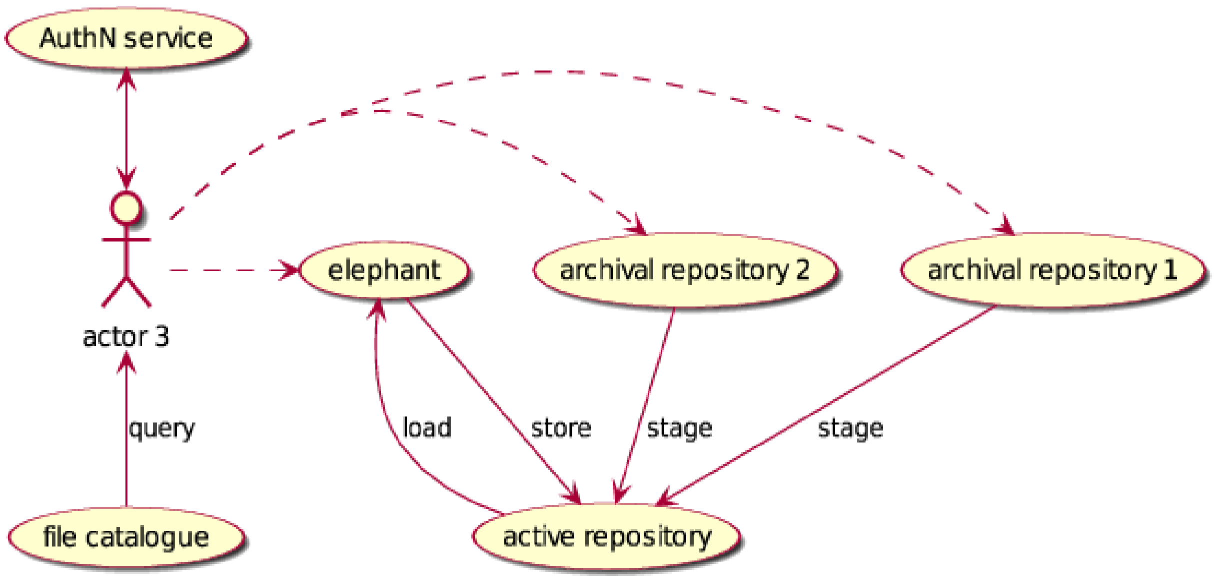
Envisioned Use Case: Modelling the Dynamic Brain

Comparative analysis of data from multiple data sources

- Spike-train data generated by NEST on standard HPC systems
- Data from neuromorphic systems like FACETS
- Electro-physiological data from multi-electrode array measurements

Workflow

- Upload primary data
- Replicate data to location near data analytics facility
- Apply data analytics methods to the data



Selected Requirements

Integrated AAI with single sign-on

- HBP decided for OIDC based AAI

Support of data replication to improve

- Data resilience (not considered critical here)
- Data availability (only foreseen for a subset of the data)
- Data access performance

Data localisation service

Support of different types of data sources, e.g.

- Standard supercomputers
- Neuromorphic special purpose computers
- High-performance image scanners

Different Classes of Data Repositories

Archival Data Repositories

- Data store optimized for capacity, reliability and availability
- Data is not replicated

Active Data Repositories

- Data repository localized close to computational or visualization resources such that high performance access to data is enabled
- Used for storing temporary slave replica of large data objects

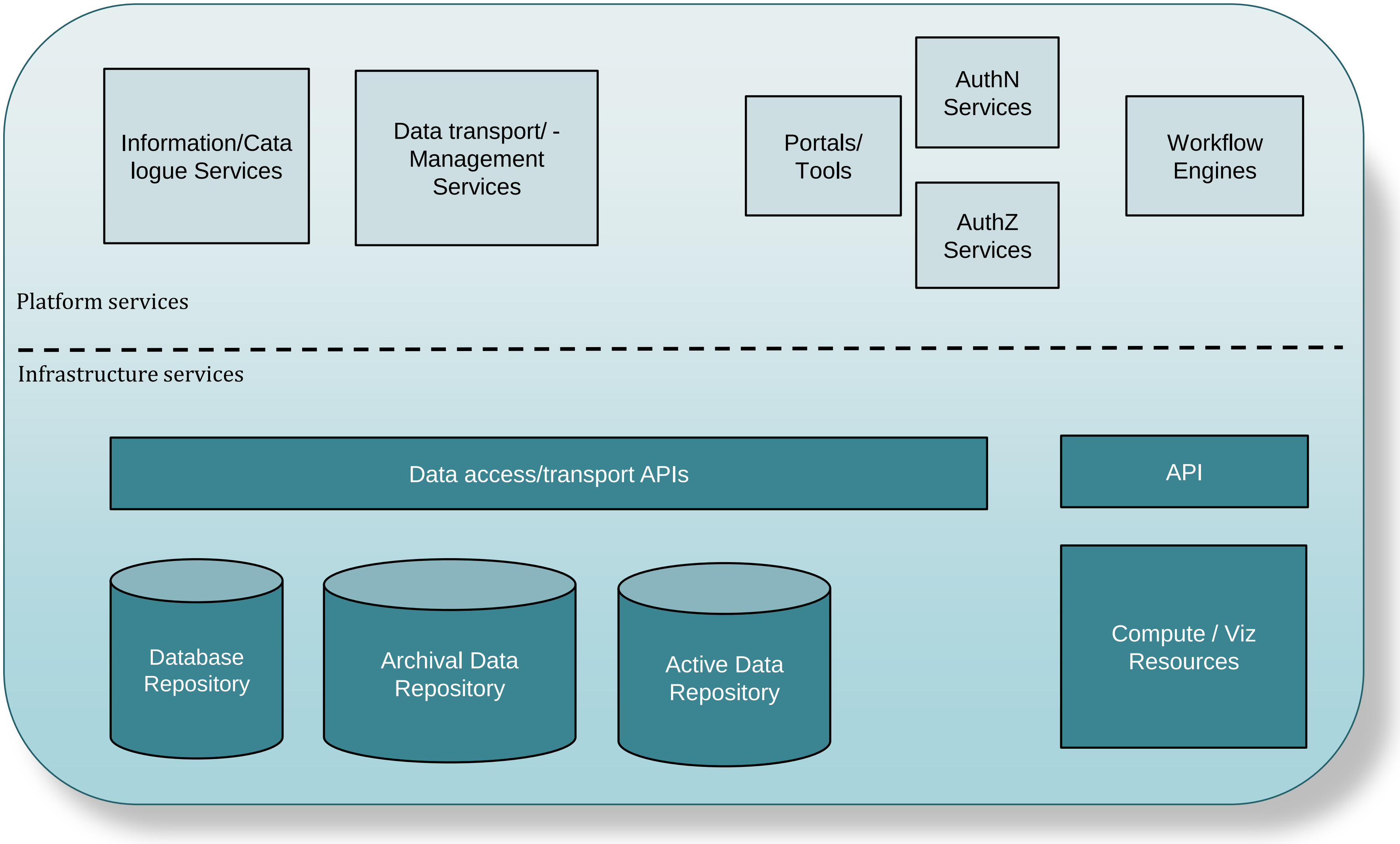
Database Repositories

- Data store optimized for search and retrieval of small data objects

Upload Buffers

- Reliable data store for staging data before upload to archive

Federated Data Infrastructure Architecture



Approach to Realisation

Analysis of use cases

- Identify requirements

Selection of technologies

- Match requirements and identify missing solutions
- Implement POCs

Integration of infrastructure ⇦ **We are here**

- Test interoperability through infrastructure level POCs

Integration of application workflows

- Interface with use case applications

Application-level validation

- Semi-production demonstrators

Summary and Outlook

Summary and Outlook

Overview on Human Brain Project

- 10 years mission started in 2013
- On track towards building a world-class brain research platform

Outlook on future supercomputers

- Requirements from neuroscience applications go beyond "classical HPC"
- Aim for impact on future supercomputer roadmaps

Creation of a federated data infrastructure

- Data is of key relevance for the HBP
- Efficient federation of data and compute resources is key for the success of the HBP

Thank You.