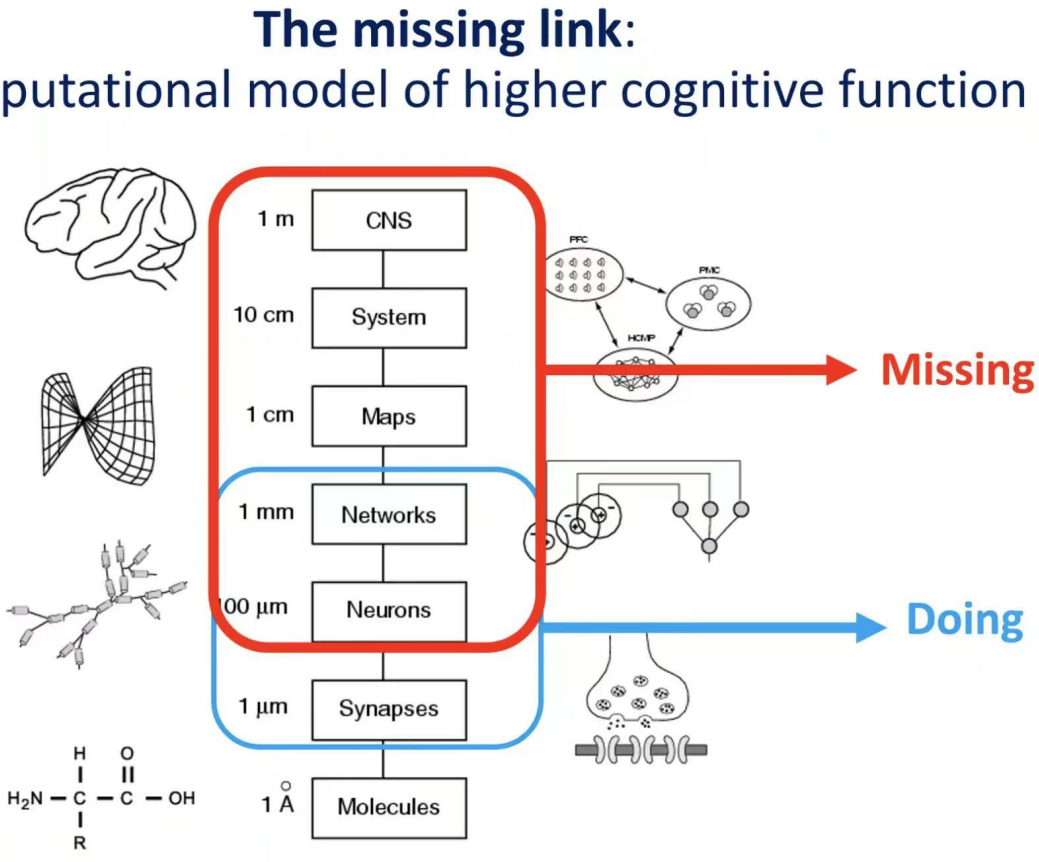
计算神经科学的背景和使命

- 两大目标
  - （What is Computational Neuroscience:Be a bridge from brain science to brain_inspired intelligence）
  - 用计算建模的方法来阐明大脑功能的计算原理
  - 发展类脑智能的模型和算法
- Prehistory of Computational Neuroscience
  - 1907:LIF model
  - 1950s:HH model(fudamental model)
  - 1960s: Roll's cable equation(涉及轴突和树突，精细神经元)
  - 1970s:Amari,Wilson, Cowan et al.（Wilson-Cowan model mean-field-model,neuron population）
  - 1982:Hopfield model(Amari-Hopfield model,吸引子模型，动力学系统方法进入计算神经科学)
  - 1988:Sejnowski et al. "Computational Neuroscience"(science)
  - 对应于物理学的第谷-伽利略时代，大脑工作原理还缺乏清晰的理论！
- Three Levels of Brain Science(→ Brain Science → Computaional)
  - Computational theory(大脑做什么)→ Psychology & Cognitive Science→ Human-like Cogntive function
  - Representation & Algorithm（大脑该怎么做）→ Computational Neuroscience → Brain-inspired model&algorithm
  - Implementation → Neuroscience → Neuronmorphic computing
- Mission of Computational Neurosicence
  - What I can not create,I do not understand --Richard Philips Fetnman
  - What I can not create a computational model,I do not understand

神经计算建模的目标和挑战

- Success of Deep Learning
- limitation of Deep learning
  - 对抗样本
  - 图像理解
  - 全局认知
  - 运动识别
  - 小样本学习
  - 举一反三

- Brain is for Processing Dynamical information（We never see a "static" thing）
  - 动态视觉光流信号
  - 动态脉冲序列传播
  - 动态交互的信息加工
  - 动态跨脑区信息整合
- Brain is a dynamical system targeted for Processing Dynamical information
  - Baby sea squirt swim,have brain
  - Adult sea squirt no movement，without brain
- 类脑智能的钱学森之问
  - 钱学森之问
    - 为什么我们的学校总是培养不出杰出的科技创新人才?
  - 类脑职能的钱学森之问
    - 为什么我们拿不出ChatGPT、Alpha Go这种杀手级应用
- The missing link(a computational model of higher cognitive function)
  - 数据驱动，用生物学做约束
  - 任务驱动，用大模型用工科思路，用端到端的训练网络

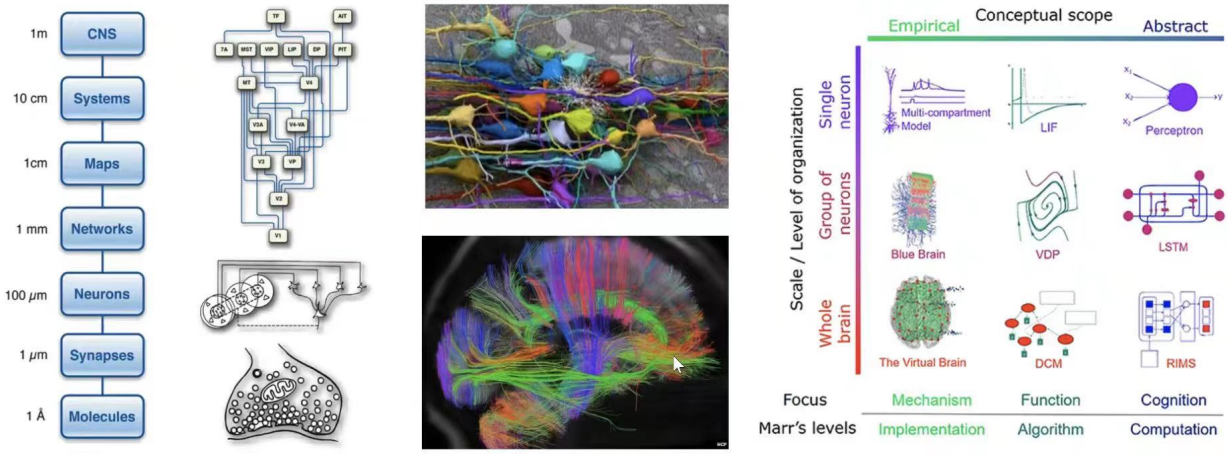


神经计算建模的工具

- 工欲行其事，必先利其器
  - We need"PyTorch/TensorFlow" in Computational Neurosciece
- Challeges in neural modelling

Challenges in neural modelling

Mutiple-scale **Large-scale** **Multiple purposes**



(Frontiers, Mahta, et, al. 2022)

- The modeling targets and methods are extremely complex, and we need a general-purpose framework.

- Limitations of Existiong Brain Simulators

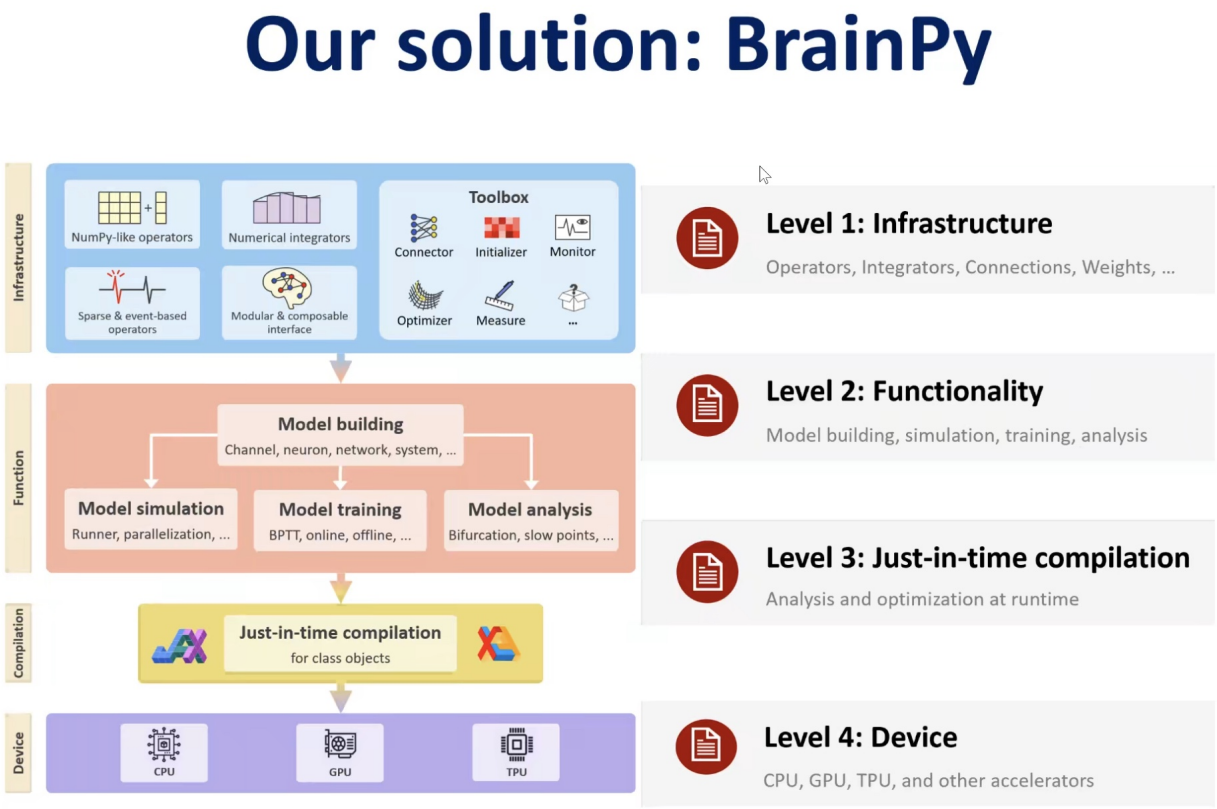
Limitations of Existing Brain Simulators

范式	软件	发源地	编程语言	开发历史	学习难度	灵活性	运行速度	透明程度	模型分析	模型训练
低级编程语言	NEURON	Yale University	Hoc, NMODL, Python	>24年	高	差	较好	差	无	无
	NEST	Blue Brain Project	SLI, Python	>14年	高	差	较好	差	无	无
	CARLsim	UC, Irvine	C++, CUDA, Python	>11年	高	差	高	好	无	无
描述性语言	Brian2	Sorbonne Université	Python, Cython, C++	>13年	低	好	较好	差	无	无
	BMTK	Allen Brain Institute	Python	>3年	低	差	较好	差	无	无
	GENN	University of Sussex	C++ / CUDA, Python	>6年	高	差	高	差	无	无

- What are needed for a brain simulator
  - Efficiency
    - High-speed simulation on parallel conputing devices,etc.
  - integration
    - Integrated modeling of simulation,training,and analysis

- Flexiblity
  - New models at all scales can be accommodated
- Extensibility
  - Extensible to new modeling methods(machine learning)
- It's time to change the programming framework in Computational Neuroscience!

- Our solution:BrainPy



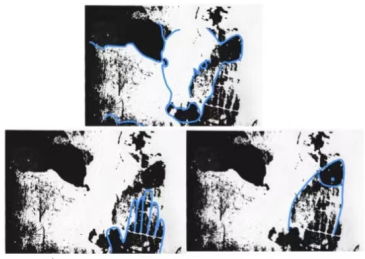
计算建模举例

- Global vs. Local Information Processing
- DNNs mimic the feedforward,hierarchical architecture of the ventral visual pathway
- DNNs extract local rather than global feature of objects
- What does brainscience tell us
  - You see what you want to see
- Image understanding: an ill-posed problem

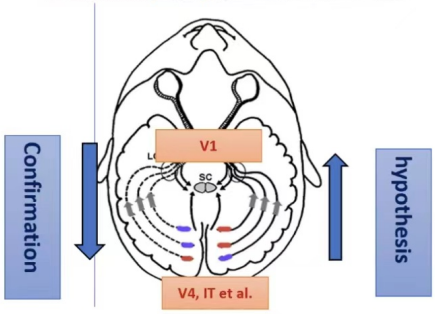
Image understanding: an ill-posed problem

Image Understanding
=image segmentation + object recognition

Chicken vs. Egg dilemma
- **Without segmentation, how to recognize**
- **Without recognition, how to segment**



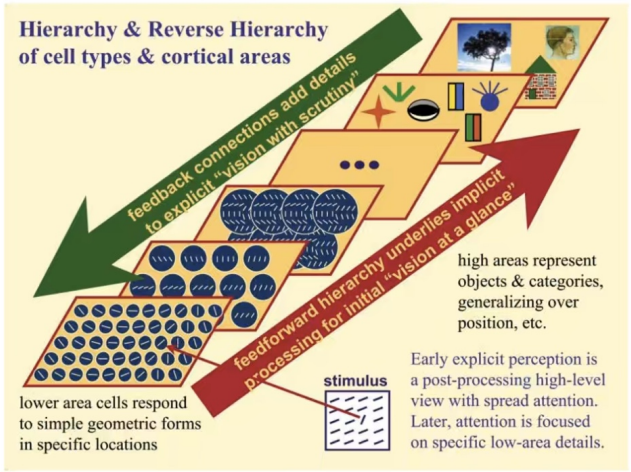
➢ **The solution of brain:**
Analysis-by-synthesis



- Abundant feedback connections in visual pathway: Sillito et al, **Trends in Neuroscience** 2006
- Contour integration in V4 is earlier than that in V1: Chen et al., **Neuron** 2014

- Reverse Hierarchy theory

Reverse Hierarchy Theory

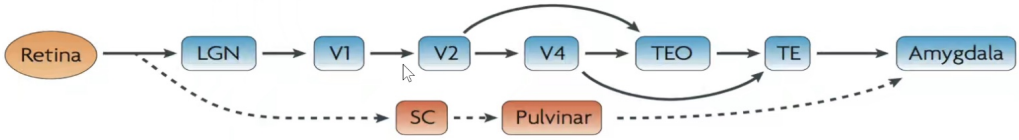


Hochstein et al. Neuron 2002

- The Subcortical pathway

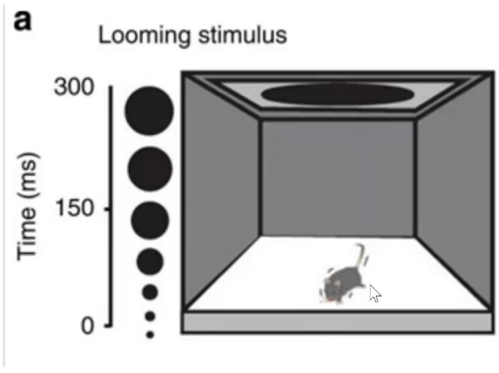
The Subcortical pathway

Blind Sight

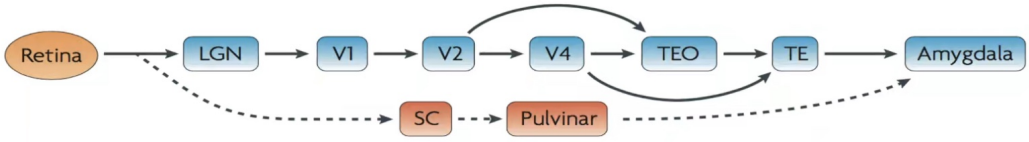


The Subcortical pathway

Innate Response

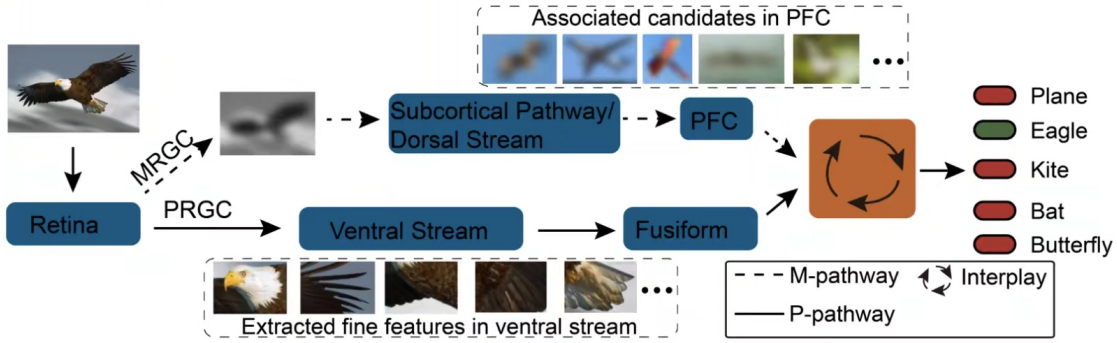


Shang et al, ***Science***, 2015; Wang et al, ***Nat. Comm.*** 2015;
Huang et al, ***Nat. Comm.***, 2016



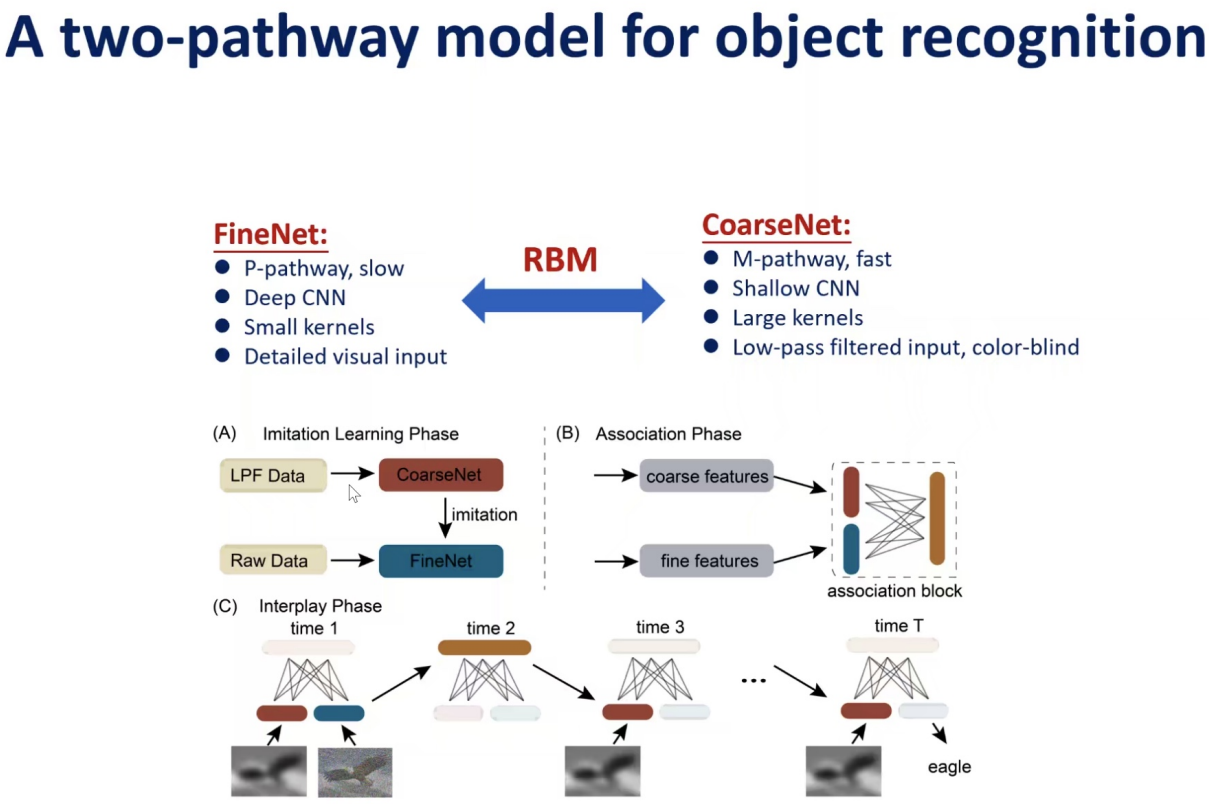
- Two pathways for visual information processing

Two pathways for visual information processing



- Key Computational Issues for Global-to-local Neural Information Processing
  - What are global and local feature
  - How to rapidly extract blobal feature
  - How to generate global hypotheses
  - How to implement from global to local processing
  - The interplay between global and local features
  - others
- How to extract global feature
  - Global first = Topolgy first
  - DNNs has difficulty to recognize topology
  - A retina-SC network for topology detection(White,Brain J.,et al.1980;Rizzolatti,G.,et al.2017)
  - Gap junction coupling：integration+Segregation
  - ConnectivityDetection
  - Hole Detection
- How to discriminate Motion
  - a Model for Motion Pattern Recognition
  - 库网络→上丘（dicision making）
  - a motion-recognition model
  - Gait Recognition(小样本、生物系统、少量参数)
- How to generate "global" hypotheses in the representatino space
  - Attractor neural network(大脑是地形图，local minimum是记忆点)

- Levy Flight in Animal Behaviors(mixer，快速jump+local search)
- Neural Mechanism of Levy Flight(海马睡眠时仍运行的功能)
- Free memory recall in Human
- How to process informatino from glabal to local
  - Push-pull Feedback(A. G.Neuron.78,389-402(2013))
  - A hierarchical hopfield Model(local→Global,什么样的feedback可以优化child layer)
  - The form&function of push-feedback
  - The form&effect of pull Feedback
  - Dynamical Push-pull Feedback
  - Real image with hierarchical constructure
- Interplay
  - two pathways for visual information processing



  -
  - improved performance of FineNet
  - Modeling visual making(Tang et al.,PANS,2018,影响识别，和实验data匹配)
- 解答问题
  - 突触短时程可塑性：抑制和易化本质是滤波（计算功能研究promising）
  - 快速通路和慢速通路同时进行