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Theme 12: Understanding, monitoring, improving human cognition with AI

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Université Fédérale
Toulouse Midi-Pyrénées

Agenda

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MEMBERS

Definition/scientific perimeter of the theme

Threads

On-going work

Highlight & main results

Scientific animation of the theme

MEMBERS

Chairs (PI): F. Dehais, R. Van Rullen, T. Serre & R. Alami

People involved: (co chairs): R. Roy, F. Lotte, N. Drougard, C. Chanel, A. Clodic, L. Reddy, T. van de Cruys, G. Faye, F. Filbet

ANITI Resources (post doc, PhD, Industrial partners, DEEL):
Phd: X. Xu, Zerroug, Vaishnav, Chalvidal, Fel
Post doc: B. Somon, Boutin, Bentanfous

Other Resources (other Phd project):
Dehais: 2 Research Engineers and 1 post doc
Serre: 4 PhD, 3 post-doc, 3 staffs
VanRullen: 2 PhD, 2 post-docs (ANR)

Definition/scientific perimeter of the theme

This theme embodies the cross-pollination between Neuroscience and Artificial Intelligence (AI). The motivation is to (1) employ state-of-the-art AI methods (eg. GAN) to effectively address outstanding neuroscience questions, and (2) use knowledge of the brain to design improved AI algorithms and artificial neural network architectures.

- the first thread focuses on the use of GAN and deep learning tools to find patterns in vast amounts of fMRI and EEG data, and to relate them to stimuli, cognition and behavior. We intend to compare the representations learned by the deep nets to the human ones. To facilitate these projects, we will develop new tools to annotate and store the data in a standardized fashion.
- the second thread aims at applying the knowledge of the brain to improve AI tools, in particular artificial neural networks (ANN) and reinforcement learning (RL). Finally, we will encourage (or "regularize") the representations in ANNs to be more human-like, e.g. to resemble brain- or behavior-derived representations, which should improve their robustness.

Threads

Thread 1: AI for decoding brain activation

- Implementation of on-line signal processing, features extraction and machine learning algorithms that are robust to noise (i.e. out of the lab) & handle transfer learning issue
- Using generative models (GANs) to improve visual image reconstruction from fMRI brain signals

Thread 2: Reverse-engineer the brain to improve AI algorithms

- Using inverse reinforcement learning techniques to understand and learn brain processes supporting attentional dynamics (i.e. explore vs exploit) with fMRI and EEG
- Comparison of human brain representations (via EEG or fMRI) and deep neural network representations to understand brain functioning and identify which neural network models are compatible with human representations, and possibly design new ways to improve this compatibility
- Computational neuroscience and Brain-inspired neural network architectures

On-going work

On-going collaboration between chairs

- The Serre and VanRullen chairs have ongoing collaborations on topics related to brain-inspired neural network architectures: representation learning, visual reasoning, predictive coding, recurrent neural circuits in deep learning.
- The Alami and Dehais chairs strongly intend to run experiments with humanoid robots and human in the loop

On-going collaboration with ANITI Industrial partners

Discussion have been made with Airbus, Thales Avionics and Dassault aviation

On-going collaboration with external projects (national, EU, industry. . .)

ANR-NSF collaborative grant (2020-2023) awarded to Serre-VanRullen to explore the potential use of brain oscillations in neural coding strategies to improve visual reasoning abilities in neural networks. RAPID (DGA) grant (2019-2021) awarded to Dehais to explore "invisible" BCI

Thread 1: AI for decoding brain activation

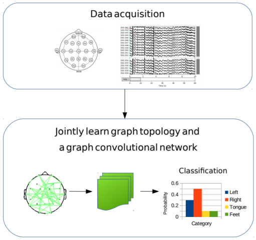

Figure: A diagram illustrating our on-going project using spatial temporal graph convolutional networks (STGCN).

The thesis of Xiaoqi Xu aims at decoding EEG signals by leveraging the power of machine learning techniques to learn BCIs that are robust to session and subject-related variability.

Feb. 2020

- tools from geometry [1], topology, connectivity & graph theory for new BCI pipelines
- new passive BCI opendatabase

Jan. 2023

[1] *Spatial analysis of EEG signals via the Laplace-Beltrami operator*, to be submitted

Thread 2: Modeling shift from efficient to inefficient divided attention using EEG/fMRI/MEG

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Nov. 2020

- **Experimentation to assess attentional focus and switching:**
  - Visuo-Auditory Switching Steady State Response experiment
  - With 64 electrodes EEG recording
  - Measure the effect of attention on visual and auditory steady state activity (GED, MVPA), and identify the sources of these attentional processes (source localization)
  - Identify cross-frequency coupling involved in efficient and inefficient attentional switch (connectivity graphs)

Jan. 2021

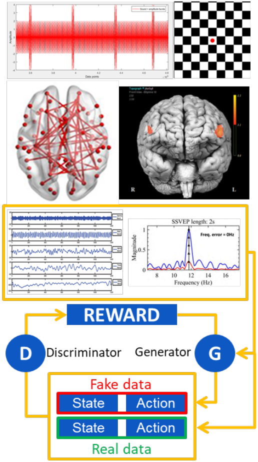
- **Feature extraction and selection:**
  - Extraction of attention-related EEG metrics
  - Selection based on participant level (Experts vs. Novice)

Mar. 2021

- **Inverse Reinforcement learning**
  - To define the expert's policy based on Experts EEG features
  - Identification of most performant algorithms according to the physiological data characteristics (non-stationarity, incomplete observation, multitasking…)

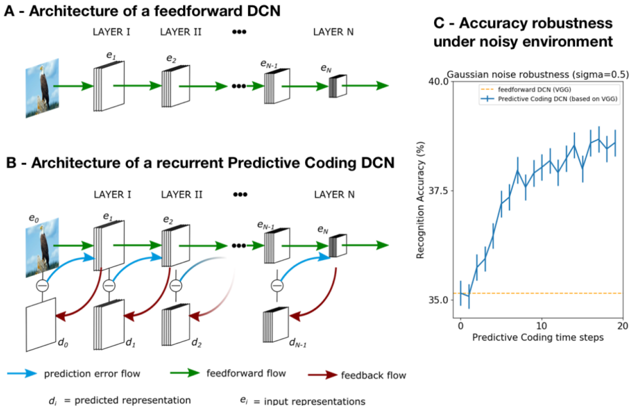
Sept. 2021

- **Predictions based on expert reward function**
  - Real-time monitoring/classification of operator state
  - Prediction of future state and\or novice training



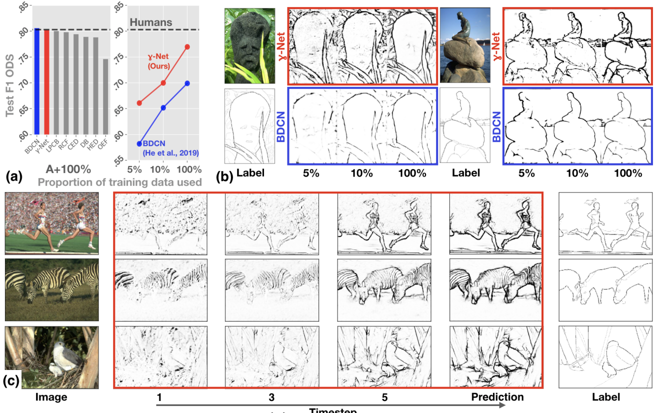
Kim et al., 2019; Shaw and Routray, 2016; Zelinsky et al., 2020; Durantin et al., 2017

Thread 2: Brain-inspired neural network architectures (Serre, VanRullen)



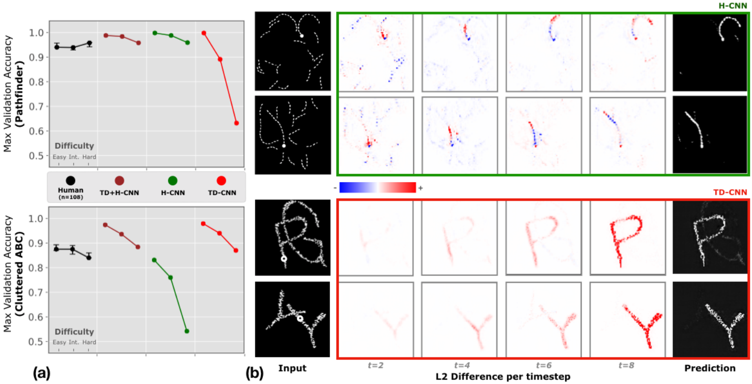
Comparison of feedforward Deep Convolutional Networks (DCN) with bio-inspired predictive coding networks. The same backbone feed-forward DCN (e.g., VGG16) can be adapted to use reccurrent Predictive Coding connections, without any additional supervision (reconstruction objective).

Thread 2: Brain-inspired neural network architectures (Serre, VanRullen)



Object contour detection in BSDS500 images. (a) Our brain-inspired deep RNN performs on par with humans and the state-of-the-art for contour detection (BDCN) when trained on the entire training dataset with augmentations. In this regime, it also outperforms the published F1 ODS of all other approaches to BSDS500. Our approach also outperforms the BDCN when trained on 5%, 10%, or 100% of the dataset. Performance is reported as F1 ODS. **(b)** BDCN and predictions after training on the different proportions of BSDS500 images. **(c)** The evolution of predictions across timesteps of processing. Predictions from a trained on 100% of BSDS are depicted: its initially coarse detections are refined over processing timesteps to select figural object contours.
D. Linsley*, J.K Kim* T. Serre. Recurrent neural circuits for contours detection. In ICLR 2020

Thread 2: Brain-inspired neural network architectures (Serre, VanRullen)



Visual reasoning challenges developed in the Serre lab (Pathfinder and cABC challenges) disentangle the relative contributions of horizontal (H-) vs. top-down (TD-) connections for perceptual grouping. (a) Accuracies of human and neural network models on 3 levels of the Pathfinder and cABC challenges. While human participants and the TD+H-CNN model are able to solve all difficulties of each challenge, Pathfinder strains the TD-CNN and cABC strains the H-CNN.(b) We visualized the computations learned by our networks and found that H-CNN and TD-CNN learn distinct strategies to solve Pathfinder and cABC challenges, respectively. **J.K. Kim*, D. Linsley*, K. Thakkar T. Serre. Disentangling neural mechanisms for perceptual grouping. In ICLR 2020**

Thread 2: Brain-inspired neural network architectures (Serre, VanRullen)

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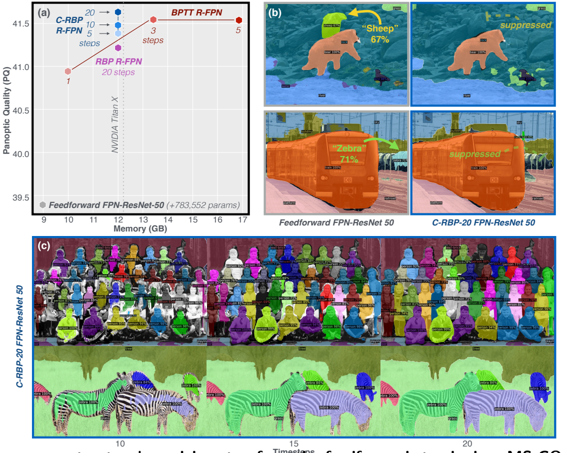
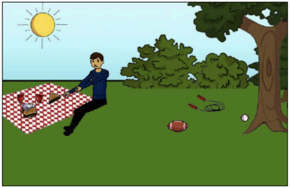


Brain-inspired deep recurrent network models outperform the feedforward standard on MS-COCO Panoptic Segmentation despite using nearly 800K fewer parameters. (a) Performance of our recurrent FPN-ResNet 50 trained with C-RBP improves when trained with more steps of processing, despite remaining constant in its memory footprint. (b) Recurrent processing refines instance segmentations and controls false detections of the standard feedforward architecture. (c) Timecourses for our RNN. **D. Linsley*, A.K. Ashok*, L.N. Govindarajan*, R. Liu*, T. Serre. Stable and expressive recurrent vision models. NeurIPS 2020.**

Thread 2: Brain-inspired neural network architectures (Serre, VanRullen)

What color are her eyes?
What is the mustache made of?

How many slices of pizza are there?
Is this a vegetarian pizza?



Is this person expecting company?
What is just under the tree?

Does it appear to be rainy?
Does this person have 20/20 vision?

Brain-inspired neural networks for visual reasoning. Visual Question Answering (VQA) requires a learning algorithm to answer questions involving common sense, counting, object recognition. Image source: Visual Question Answering Challenge 2019. **M. Ricci, R. Cadene T. Serre. Same-different conceptualization: A machine vision perspective. Current Opinion in Behavioral Sciences, 2020**

Highlight & main results

Scientific event organization (conference, workshop, GDR) & participation

- International Neuroergonomics Conference, Munich with a dedicated topic on AI/Ethics sponsored by ANITI (postponed to sept 2021)
- Launch of the journal "Frontiers in Neuroergonomics"(sept 2020)- co-chief editor F. Dehais with a specialty dedicated to AI for neuroscience (F. Lotte: chief specialty editor)
- Dehais, Serre and VanRullen chairs coordinated the Nuit des Chercheurs 2020 exhibition on "AI and the brain" (November 2020).
- R. Roy participates in organizing the annual meeting of the French BCI association: CORTICO. Remote version this year, in Grenoble next year.

Awards:

- IEEE brain initiative awards (Dehais et al, 2019, IEEE SMC conference)

Submissions to ANR, EU and other related projects

- Individual fellowship Marie Curie (coPIs Dehais Callan)
- ANR grant (2019-2022) awarded to Reddy (co-PIs VanRullen, Asher, van de Cruys) to compare visual or linguistic representations in the human brain vs. AI architectures.
- Collaborative grant request submitted to Merck (August 2020) by Serre-VanRullen to explore brain-inspired recurrent neural circuits in deep learning.

Scientific animation of the theme

Description of the theme agenda (weekly seminar,. . .)
Van Rullen and Serre chairs: "daily" collaboration
Monthly meetings (presentation/talk)
Emerging collaboration between chairs & industrial partner
Discussions with Airbus, Thalès, Continental
Strong interests for medical industry (eg. Siemens, Pierre Fabre, Sanofi)
Theme roadmap (year 2, 3 and 4 - cf p38 roadmap)
monthly seminars (start: year 2)
need for use cases from industrial partners
Serre & VanRullen = identify key components of brain/cognitive architecture + neuroscience applications (year 2); state-of-the-art recurrent vision models (years 3-4) and applications (year 4)
Dehais et Alami = definition of an experimental protocol involving humans and robots (year 2); off-line experiments (year 3); on-line (experiment 4)