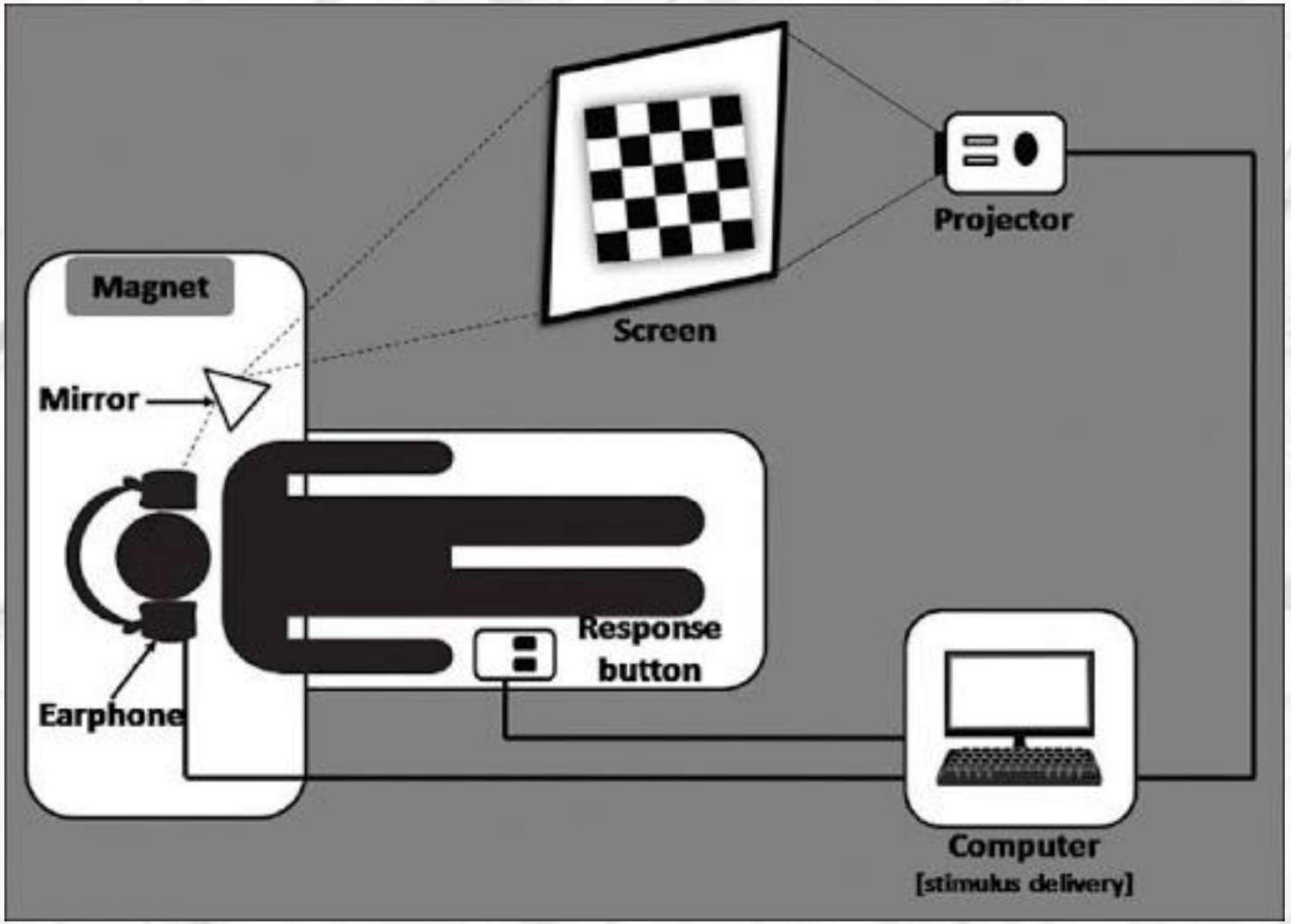
Automated planning for fMRI paradigms design using PDDL

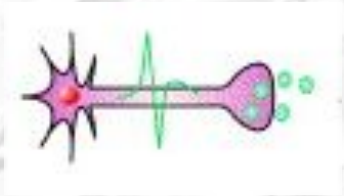
Katherine Bianchini Esper
katherine.esper@edu.pucrs.br

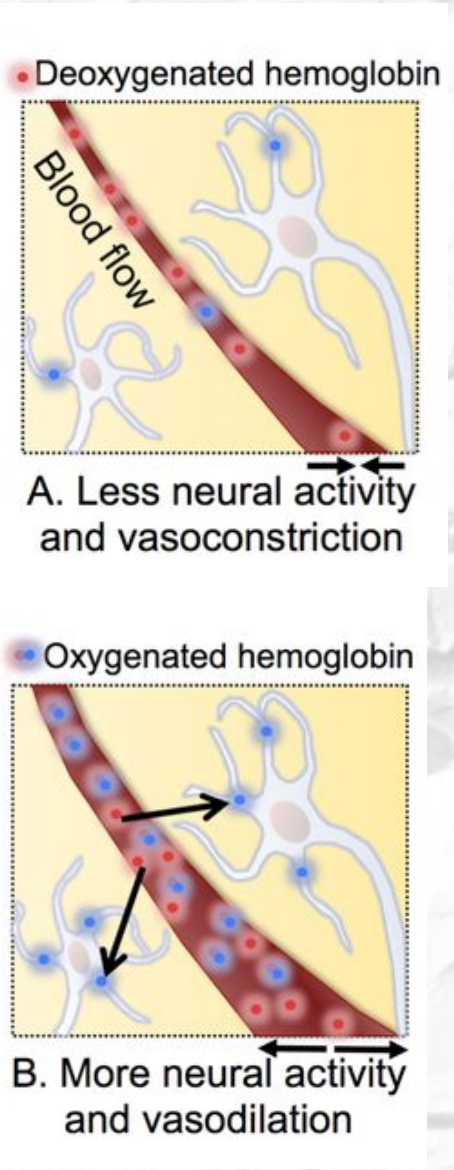
Graduate Program in Computer Science - School of Technology
Pontifical Catholic University of Rio Grande do Sul - PUCRS
Porto Alegre, Brazil

Functional Magnetic Resonance Imaging - fMRI

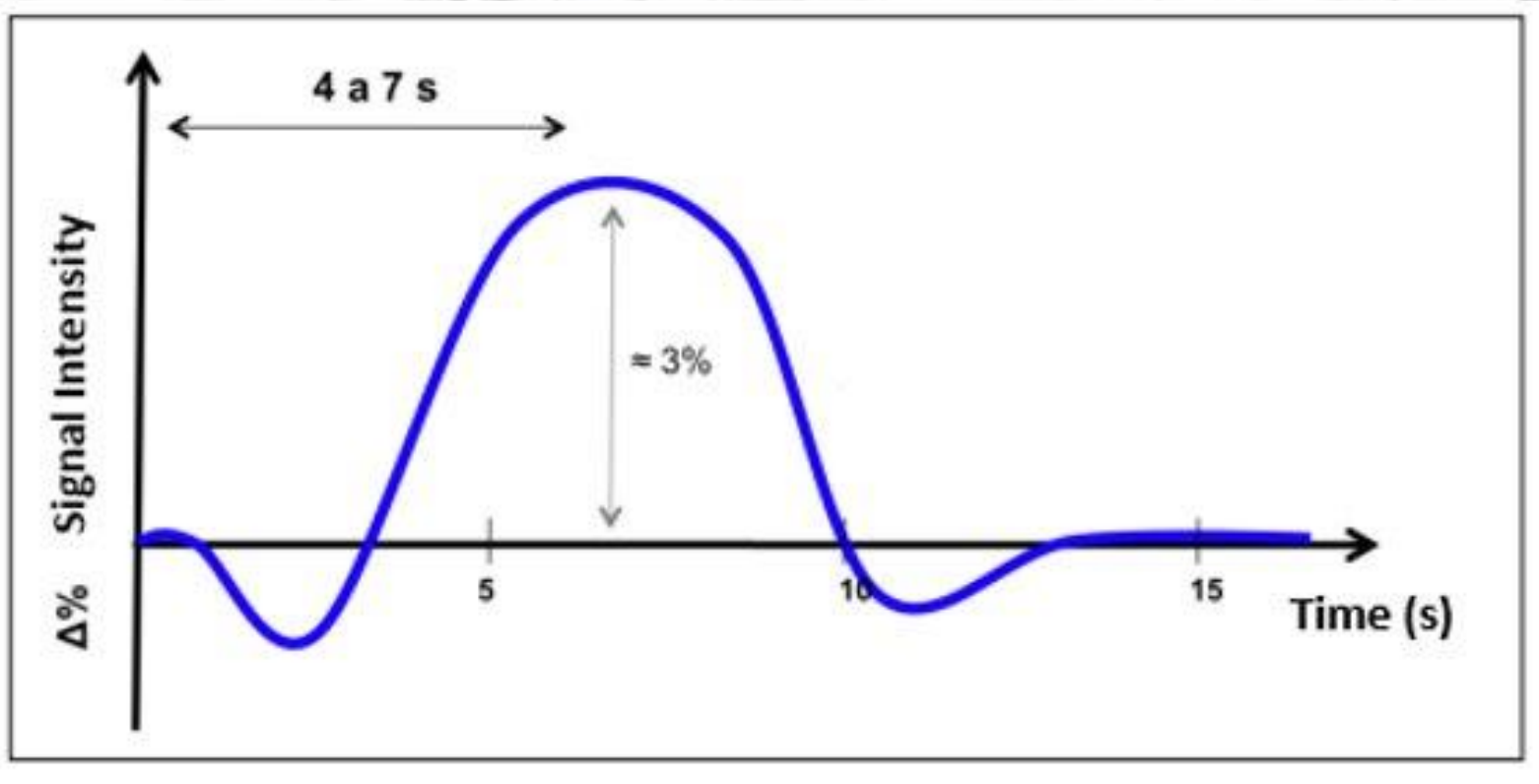


BOLD Signal

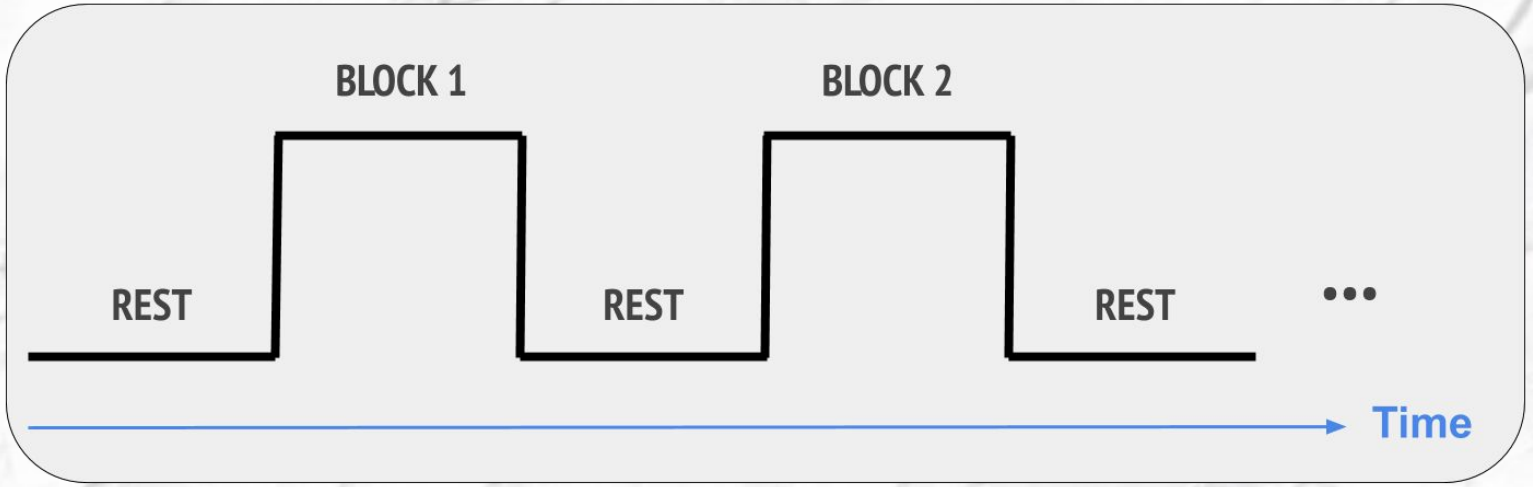



Deoxygenated hemoglobin
Blood flow
A. Less neural activity and vasoconstriction
Oxygenated hemoglobin
B. More neural activity and vasodilation

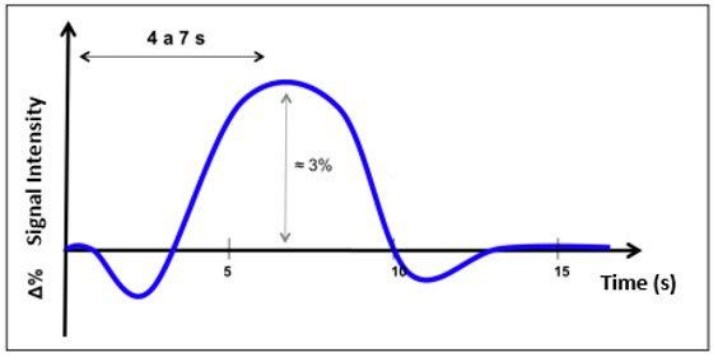
BOLD Signal

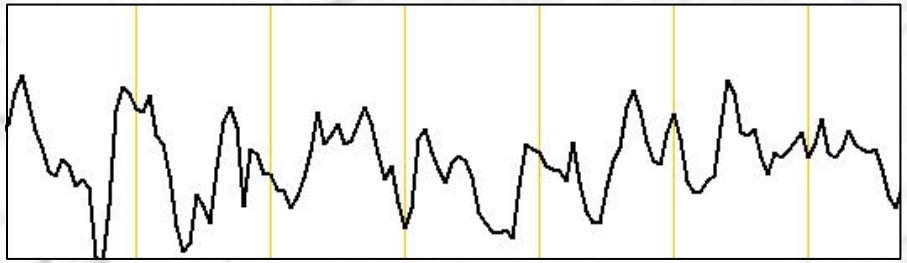


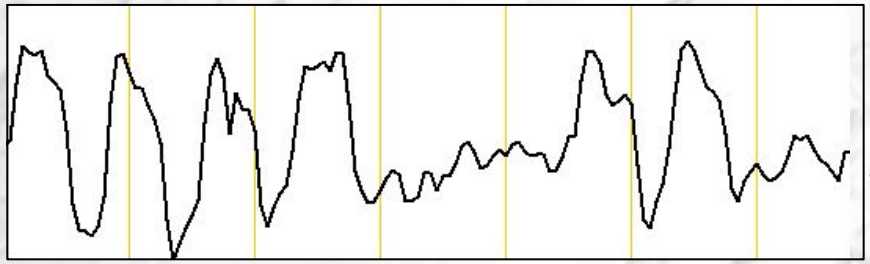
fMRI Block Design Paradigm

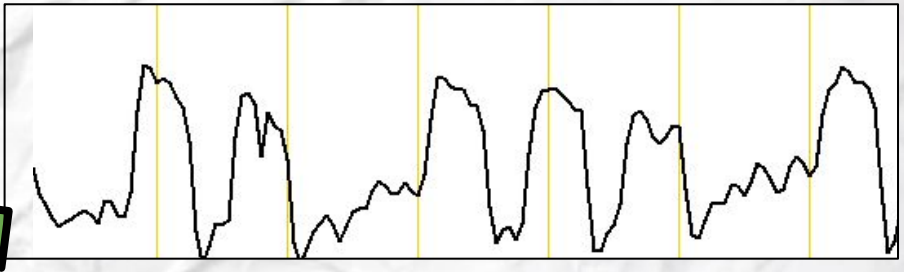


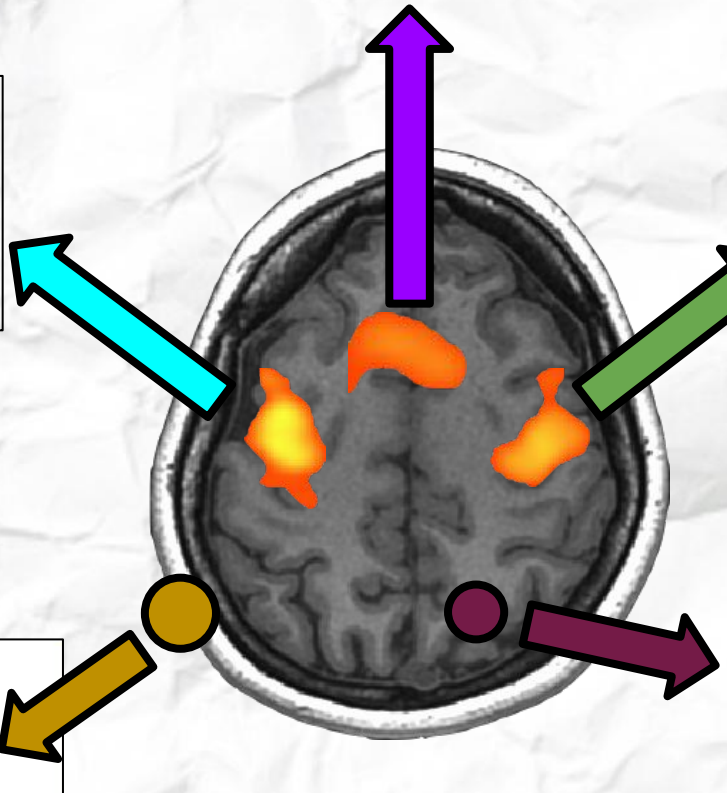
R + L + RL + R

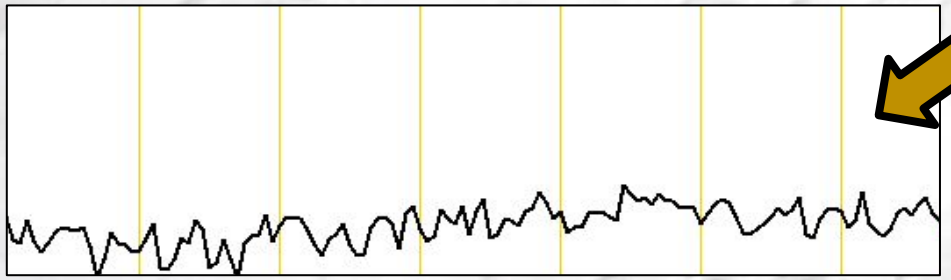

4 a 7 s
≈ 3%
Signal Intensity
Δ%
5
15
Time (s)

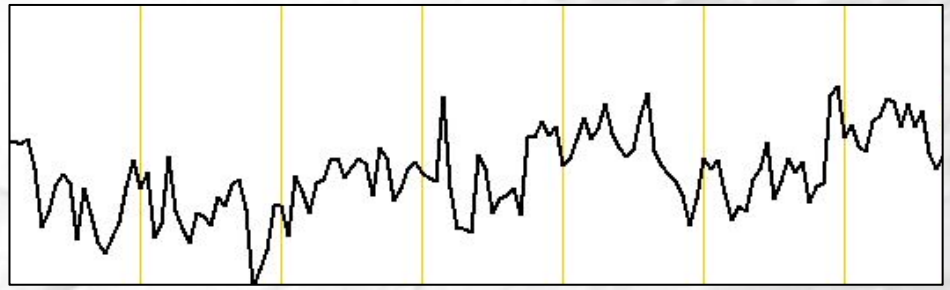










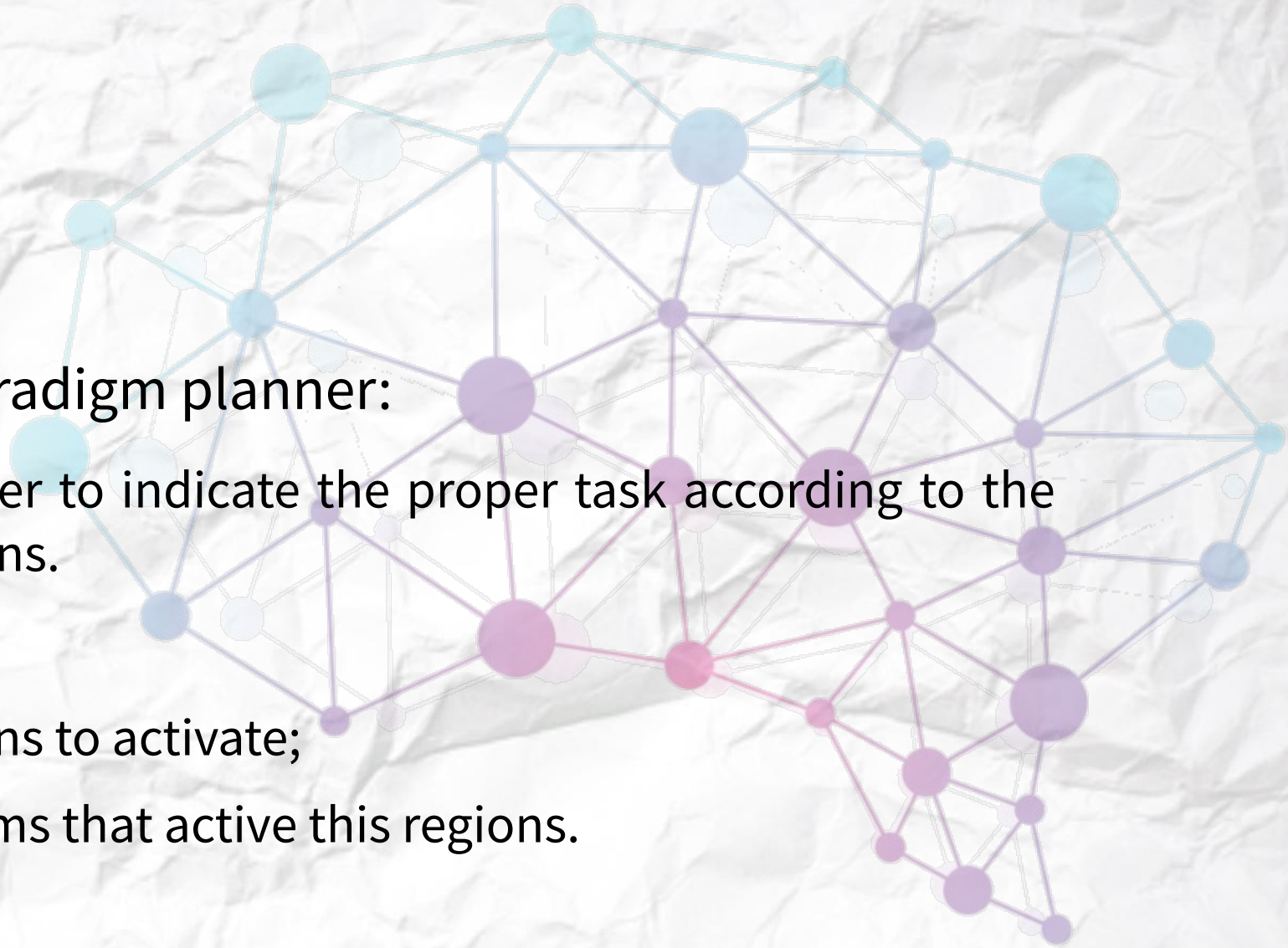


fMRI Design Paradigm

An fMRI experiment relies on precise and effective paradigm design.

- Ensure good experimental design:
  - Design proper task according to the research questions.

Objective



- Design an fMRI paradigm planner:
  - Develop a planner to indicate the proper task according to the research questions.
- PDDL
  - Goal: brain regions to activate;
  - Actions: Paradigms that active this regions.

Paradigm Database

Dataset

a. Task database provided by BraIns;

b. Paradigms that activate areas related to: Motor skills, language, visual, auditive, memory, attention network and default mode network.

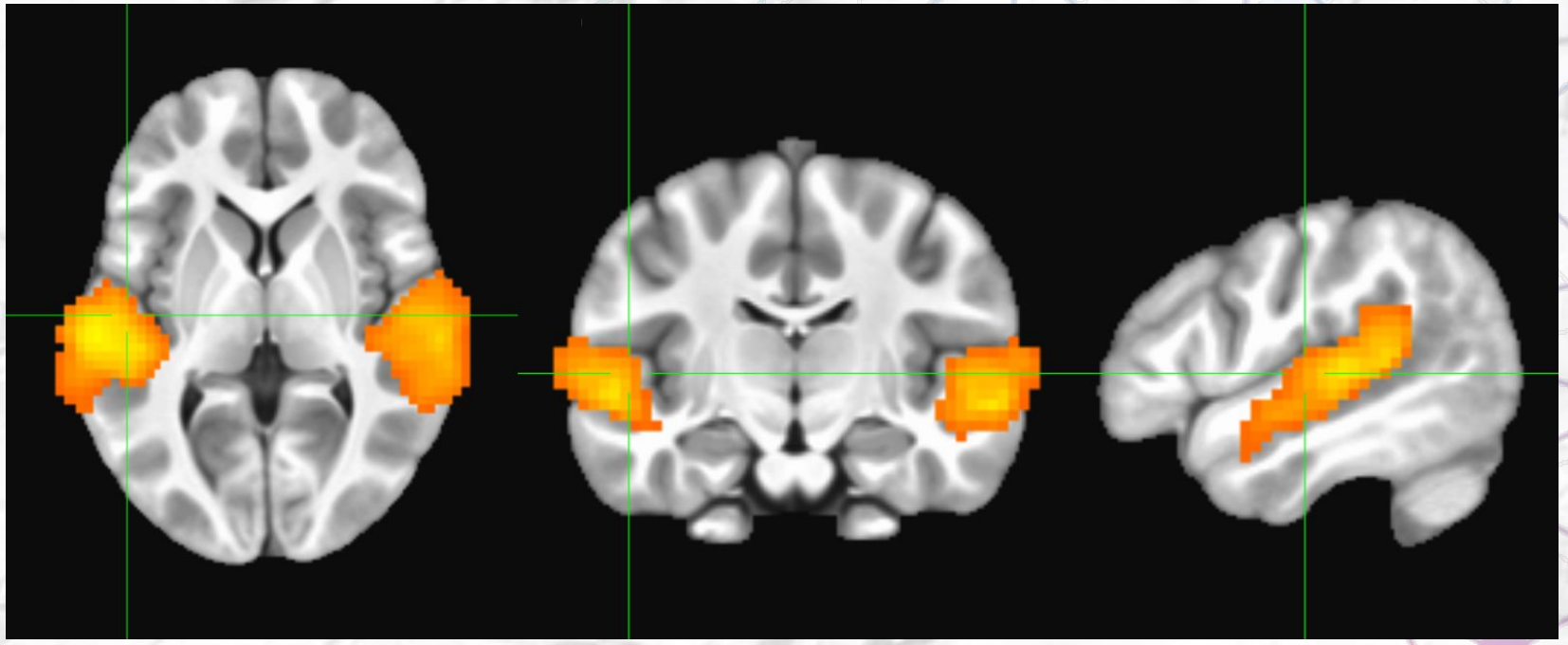
Paradigm	Stimuli Blocks	Data (n)
Calculus	Equation	46
	Number	
Sennum	Fig	51
	Resp	
Words	Regular	100
	Iregular	
	Pseudo	
Fastloc	Print	43
	Falsefont	
	Speech	
	Vocod	
CHANGE	Change	46
FalMem	False	49
	True	

Paradigm Database

3dttest++ - Analysis of Functional NeuroImages (AFNI)

```
3dttest++ -setA Green
          sub001 a+tlrc'[3]' \
          sub002 b+tlrc'[3]' \
          sub003 c+tlrc'[3]' \
                    ...
```

Paradigm Database



Auditory cortex: Left and Right Superior Temporal Gyrus

Task: FASTLOC - block: VOCOD

Paradigm Database

Task: FASTLOC - **Block:** VOCOD

Region	Abbreviation	Function	Cerebral Lobe
Middle Temporal Gyrus	MTG	Auditory System	Temporal
Superior Temporal Gyrus	STG	Auditory System	Temporal
Thalamus	THA	Sensory System	Subcortical
Lingual Gyrus	LG	Analysis of logical conditions; encoding visual memories	Occipital

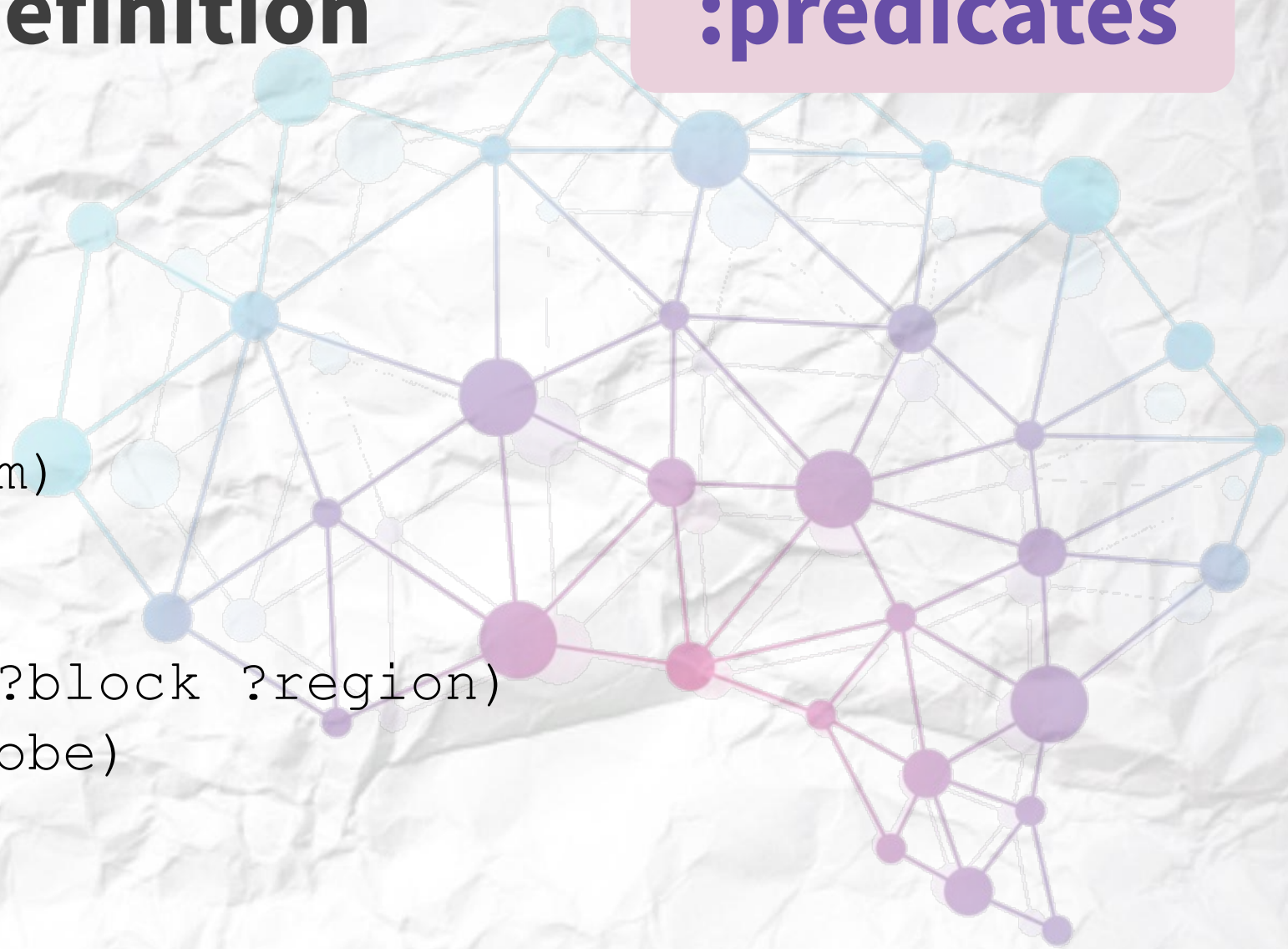
Paradigm Database

Final Database

a. 6 paradigms;
b. 14 blocks;
c. 22 brain regions;
d. 5 cerebral lobes.

PDDL - Domain definition

:predicates



```
(:predicates
    (region ?region)
    (paradigm ?paradigm)
    (block ?block)
    (lobe ?lobe)
    (active ?paradigm ?block ?region)
    (belong ?region ?lobe)
    (actived ?region)
)
```

PDDL - Domain definition

:action

```
(:action chosen_paradigm)
(:action chosen_paradigm2)
(:action cerebral_lobe)
```

PDDL - Domain definition

:action

```
(:action chosen_paradigm
   :parameters (?paradigm ?block ?region)
   :precondition (and
      (paradigm ?paradigm)
      (block ?block)
      (active ?paradigm ?block ?region)
   )
   :effect (and
      (actived ?region)
   )
))
```

PDDL - Domain definition

:action

```
(:action chosen_paradigm2
   :parameters (?paradigm ?block ?region1 ?region2)
   :precondition (and
      (paradigm ?paradigm)
      (block ?block)
      (active ?paradigm ?block ?region1)
      (active ?paradigm ?block ?region2)
   )
   :effect (and
      (actived ?region1)
      (actived ?region1)
   )
))
```

PDDL - Domain definition

:action

```
(:action cerebral_lobe
   :parameters (?paradigm ?block ?region ?lobe)
   :precondition (and
      (paradigm ?paradigm)
      (lobe ?lobe)
      (block ?block)
      (belong ?region ?lobe)
      (active ?paradigm ?block ?region)
   )
   :effect (and
      (actived ?region)
      (actived ?lobe)
    )
))
```

PDDL - Problem definition

:init

22 Brain Regions

```
(region AG)   ; Angular Gyrus
(region LG)   ; Lingual Gyrus
(region THA)  ; Thalamus
```

…

6 Paradigms

```
(paradigm calculus)
(paradigm change)
```

…

14 Stimuli Blocks

```
(block equation)
(block number)
(block chang)
```

…

5 Brain Lobes

```
(lobe parietal_lobe)
(lobe temporal_lobe)
```

…

PDDL - Problem definition

:init

Activation mapping: 82

```
(active calculus equation AG)
(active calculus equation LG)
(active fastloc vocod MTG)
(active fastloc vocod STG)
(active words regular CUN)
(active words regular LG)
```

…

Cerebral lobes: 22

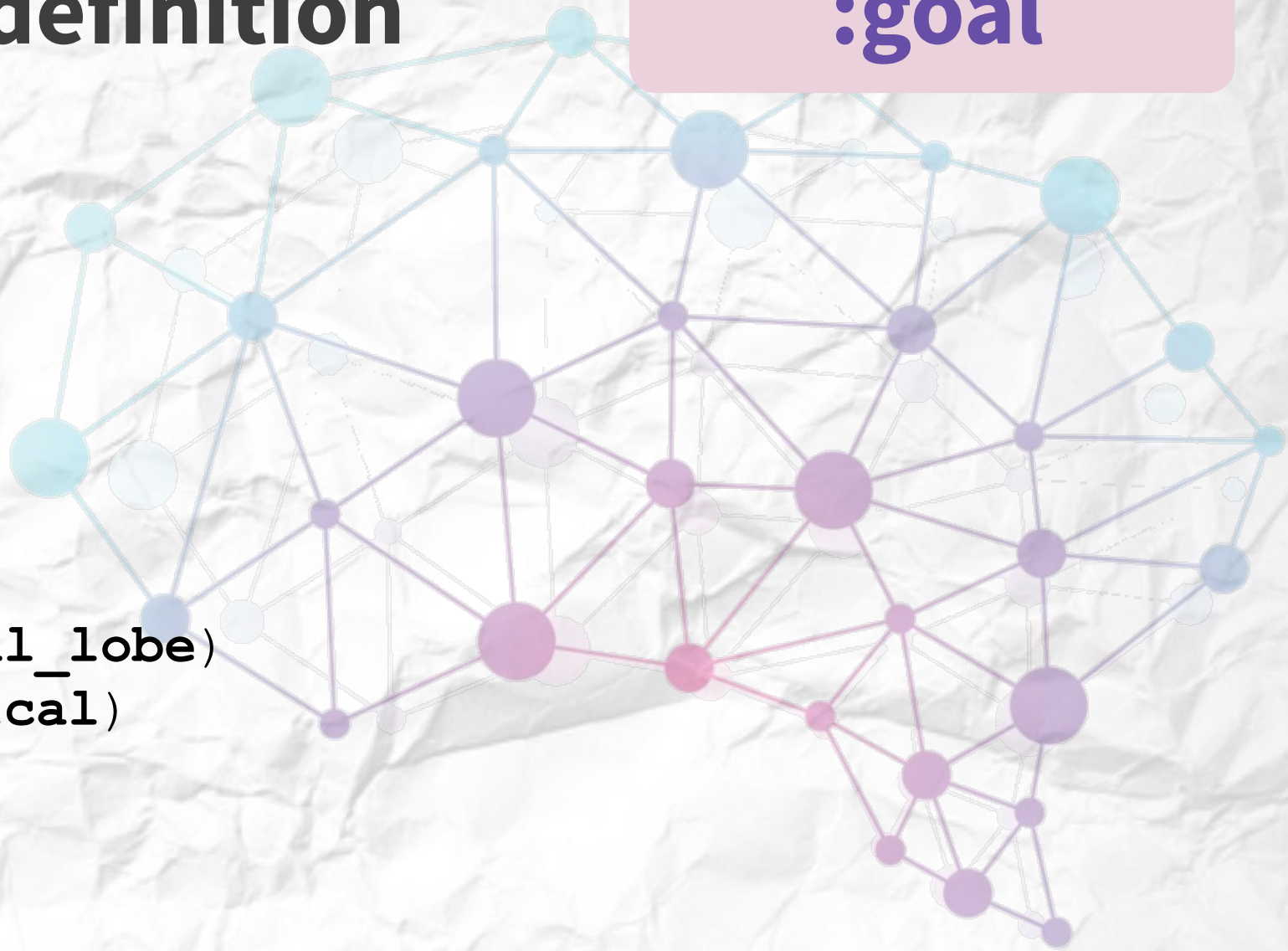
```
(belong AG parietal_lobe)
(belong LG occipital_lobe)
(belong MTG temporal_lobe)
(belong STG temporal_lobe)
(belong CUN occipital_lobe)
```

…

PDDL - Problem definition

:goal

```
(:goal (and
    (actived THA)
    (actived MOG)
    (actived CUN)
    (actived occipital_lobe)
    (actived subcortical)
))
```



PDDL tools

Web Planner

0.4020s

```
(:goal (and
    (actived THA)
    (actived MOG)
    (actived CUN)
    (actived occipital_lobe)
    (actived subcortical)
))
```

```
(chosen_paradigm fastloc falsefont mog)
(cerebral_lobe fastloc vocod tha subcortical)
(cerebral_lobe palavras regular cun occipital_lobe)
```

PDDL tools

PDDL Editor

0.02s

```
(:goal (and
    (actived THA)
    (actived MOG)
    (actived CUN)
    (actived occipital_lobe)
    (actived subcortical)
))
```

```
(cerebral_lobe fastloc falsefont mog occipital_lobe)
(cerebral_lobe fastloc vocod tha subcortical)
(cerebral_lobe palavras pseudo cun occipital_lobe)
```

Alteration

:action

```
(:action cerebral_lobe
   :parameters (?paradigm ?block ?region ?lobe)
   :precondition (and
      (paradigm ?paradigm)
      (lobe ?lobe)
      (block ?block)
      (belong ?region ?lobe)
      (active ?paradigm ?block ?region)
   )
   :effect (and
      (actived ?region)
      (actived ?lobe)
    )
))
```

PDDL tools

Web Planner

10.2711s

```
(:goal (and
    (actived THA)
    (actived MOG)
    (actived CUN)
    (actived occipital_lobe)
    (actived subcortical)
))
```

```
(chosen_paradigm fastloc falsefont mog)
(chosen_paradigm2 palavras regular tha cun)
(cerebral_lobe calculo equation lg occipital_lobe)
(cerebral_lobe calculo equation hip subcortical)}
```

PDDL tools

PDDL Editor

0.032s

```
(:goal (and
    (actived THA)
    (actived MOG)
    (actived CUN)
    (actived occipital_lobe)
    (actived subcortical)
))
```

```
(chosen_paradigm2 palavras pseudo cun mog)
(cerebral_lobe calculo equation lg occipital_lobe)
(cerebral_lobe calculo equation hip subcortical)
(chosen_paradigm2 fastloc vocod tha mtg)
```

Conclusions

- This is the initial step for the automated planning of fMRI paradigms. The brain activation region mapping, according the presentation of a task, is essential for further work.
- In this study, we develop and use the planner, using PDDL language, to identify the paradigm block that activates certain brain regions or lobes.

Future Work

- Still studying the best actions to this domain;
- Include other parameters associated to the paradigms;
- The metric planning to minimize the planner costs;
- Plugins in the PDDL Editor tool: *Planimation*.

References

[1] G. H. Glover, “Overview of functional magnetic resonance imaging.,” *Neurosurg. Clin. North Am.*, vol. 22, no. 2, p. 133–9, vii, Apr. 2011.

[2] N. Logothetis and B. Wandell, “Interpreting the BOLD signal.,” *Annu. Rev. Physiol.*, vol. 66, no. 1, pp. 735–769, 2003.

[3] E. Amaro and G. J. Barker, “Study design in fMRI: basic principles,” *Brain Cogn.*, vol. 60, no. 3, pp. 220–32, 2005.

[4] J. S. James, P. Rajesh, A. V. Chandran, and C. Kesavadas, “fMRI paradigm designing and post-processing tools.,” *Indian J. Radiol. & Imaging*, vol. 24, no. 1, pp. 13–21, Jan. 2014.

[5] H. Geffner and B. Bonet, “A Concise Introduction to Models and Methods for Automated Planning,” *Synth. Lect. Artif. Intell. Mach. Learn.*, vol. 7, no. 2, Jun. 2013.

[6]M. Ramirez and H. Geffner, “Plan recognition as planning”, *Twenty-First International Joint Conference on Artificial Intelligence.*2009.