Automated planning for fMRI paradigms design using PDDL

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Abstract

Within the last decades, neuroimaging have been used several techniques to assess brain activation patterns. The task design is the most important challenge for neuroimaging studies, to achieve the best modeling for assessing brain patterns with and across participants. Every subject has their own way to model their functional connectivity, and this functional process differs across subjects. An functional magnetic resonance imaging (fMRI) experiment relies on precise and effective paradigm design. The objective of this work is to create an fMRI paradigm planner. Planning a paradigm is especially important for functional studies, to ensure an experimental design that allows the analysis of the brain regions that are interesting in the study. This work proposes the use of an automated planning techniques using PDDL language to solve the paradigm choice problem and the analysis of the results generated by two planner tools to this domain.

Functional Magnetic Resonance Imaging (fMRI) is a non-invasive method and is a widely used technique to analyze brain functions (Glover 2011). This imaging technique attempts to measure neuronal activity by measuring the concentration changes of oxy- and deoxy-hemoglobin in the stimulated area. It is an indirect measure and it is called Blood Oxygen Level Dependent (BOLD) or hemodynamic response (Logothetis and Wandell 2004).

First, a research question is necessary to develop an fMRI study. Then, the researchers start the design of the fMRI protocol. During a fMRI experiment, specific paradigms (or tasks) are used to evoke hemodynamic response or brain activation in certain brain areas. Paradigms are the activities performed or stimulus received by the subject during an exam (Amaro Jr and Barker 2006). The brain areas evoked in an exam are possibly related to the research question, due functional differences between subjects. Visual, motor, language and memory are some examples of common paradigms. In order to activate the brain area of interest, it is necessary to work with a paradigm which will increase the BOLD signal of those regions. The paradigm of an fMRI experiment will change according to the specific research question.

In an fMRI study we work with the hypothesis that the activity in certain brain area will be evoked by a task. There are an extensive study designs and software available for fMRI projects (James et al. 2014). The main problem is to choose one of the available designs (or create one) and combining this task with the research question. Generally, researchers reviewed the literature for studies related to their main objective. Then, according to the review, a task will be created or chosen. An fMRI experiment relies on precise and effective paradigm design, aiming the cost reduction (more time inside the machine is more money spend by the researcher). If the paradigm does not show the interest brain areas, all of that investment in time and money may be wasted.

Planning is an area in Artificial Intelligence interested in the automated generation of behavior for achieving goals (Geffner and Bonet 2013). The classical planning is the problem of finding a sequence of actions, or plan, then when applied in the initial state of the problem results in a goal state (Ramırez and Geffner 2009). An AI planning system, called planner, takes the problem formalisation as input and uses some problem solving technique to work out its solution (Haslum et al. 2019). The Planning Domain Definition Language (PDDL) is a problem description language in automated planning. PDDL is one of the most widely supported languages by planning systems. This work proposes the use of automated planning techniques using PDDL to solve the paradigm choice problem.

The first section of this work describes an fMRI paradigm based on a block design. Then, we describe the paradigm dataset we used and the process to create this database. In the ending on the methods section, we provide a PDDL formalisation, with the domain and problem definition. The experiments section presents the planning results generated by two different tools. The, we ending this paper with the conclusions and future works.

fMRI Block Design Paradigm

During an fMRI task, there is an increase in the neuronal activity in the brain area that is related to the task. For example, during a motor task, there is a neuronal activation in the motor area. One of the most used paradigm designs is the block-related, as shown in Figure 1. Each block is presented for a certain amount of time and the stimuli of this block can be, for example, auditory or visual. Between each task block, a rest period is presented in order to return the neuronal activation for its basal state. A paradigm can contains a variety of tasks blocks and can show the same block more than once.

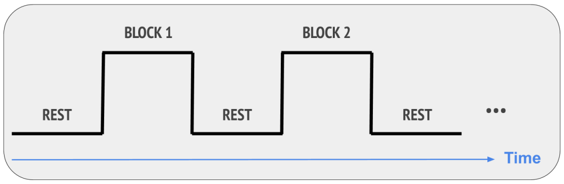

Figure 1: Example of a block design paradigm

One of the paradigms used in this work is called calculus and is composed by to types of blocks. The first one is called equation. When the block equation is presented, an equation appears in the screen, like "1+1", for example. After the equation block, that appears for 7 seconds, is presented a rest period. The second block is called number. When the block number is presented, a number appears on the screen. The participant will decide if the number presented is the answer for the equation block. This answer is collected through a button box. An activation is expected in the brain regions associated with logical reasoning in the equation block. In the number block is expected an activation in brain areas related to memory.

Paradigm Database

The first step in this work was to create a paradigm database based on the brain areas that these paradigms activates. We used the tasks provided by the Brain Institute of Rio Grande do Sul (BraIns) to create the paradigm database. This dataset is composed of tasks that activate areas related to motor skills, language, visual, auditory, memory, attention and default mode network.

From the dataset provided by BraIns, we used 6 different paradigms. First, we analyze the brain activation areas in each one of the paradigms, resulting in a total of 14 stimuli blocks. We performed a t-test for each block stimulus and then, we analyze the results in the Analysis of Functional NeuroImages (AFNI) software (Cox 1996; Cox and Hyde 1997; Gold et al. 1998). For each block stimulus, we chose all the activations in brain areas related with each block. For example, the superior temporal gyrus is the brain area responsible for sound processing. This area was expected to be activated in the *FASTLOC* paradigm, more specifically in the *VOCOD* block. The superior temporal gyrus, extracted from the t-test of the *VOCOD* block, can be seen in Figure 2.

After all image analysis, we got 22 brain areas activated, all related to their blocks. Each one of the areas were associated with the brain lobes in which they belong: frontal, parietal, occipital, temporal or subcortical. The definition of the brain activation was manually made in this work. In the future, this step will be made by an automated method, a brain activation classifier. We will compare the results of the manual and the automated methods.

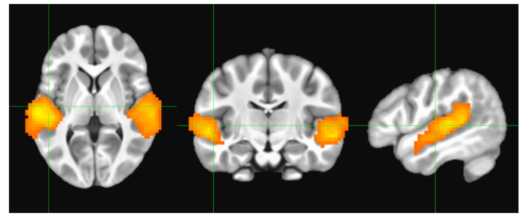

Figure 2: A t-test result example of the Superior Temporal Gyrus activation in the *VOCOD* block

The table describes all tasks used to create the paradigm database. The first column contains the name of the task, follow by the number of stimuli block used in this work and the number of participants that complete the task.

Paradigm	Stimuli Blocks	Data (n)
Calculus	2	46
Sennum	2	51
Words	3	100
Fastloc	4	43
CHANGE	1	46
FalMem	2	49

Table 1: Dataset description

PDDL Formalization

The definition of planning is made in two steps in the PDDL language. These steps are called domain definition and problem definition. The domain defines the actions and the state variable, that can be true or false. The problem defines the initial state and the goal condition. The development of these two steps is specified in the following sections.

Domain Definition

A domain in PDDL is described by **:requirements**, **:predicates** and **:action**. The section **:requirements** indicates which features of PDDL the domain uses. The **:predicates** of the domain definition contains the list of the model's state variables. These are binary variables, representing facts that are either true or false. The model implemented in this work was described with 6 predicates:

- **(region ?a)**: where *a* is the brain region;
- **(paradigm ?b)**: where *b* is the paradigm;
- **(block ?c)**: where *c* is the stimuli block;
- **(lobe ?d)**: where *d* is the brain lobe;
- **(active ?b ?c ?a)**: defines which block *c* from paradigm *b* actives the region *a*;
- **(belong ?a ?d)**: define which lobe *d* belongs to region *a*.

The actions that the planner can follow are described in **:actions**, and these actions defines the transitions between states. In this first phase of the work, three actions were described: *chosen_paradigm*, *chosen_paradigm2* and *cerebral_lobe*.

The action *chosen_paradigm* has three input parameters: *paradigm*, *block* and *region*. This action associate the *region*, defined in **:goal** section, with the *paradigm* that activated the brain region. When one *block* from a *paradigm* activated the goal, the effect of action is activate the region with the predicate **(actived ?region)**.

In some cases, two brain regions in :goal are activated by the same *paradigm*. For this cases, we create the action *chosen_paradigm2*. The action works in the same way as described bellow, but now it considers the two regions. This is necessary for a optimization in the number of the selected paradigms. In this case, the planner choose just one *paradigm*, instead of two. The effects of the actions are **(actived ?region1)** and **(actived ?region2)**. To exemplify,

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

A function was created when the goal is to activate a specific brain lobe. The *cerebral_lobe* action receive as parameters the *paradigm*, *block*, *region* and *lobe*. Its work is similar then described, but now we have the inclusion of the predicate *lobe*. The effects of this action are **(actived ?region)** and **(actived ?lobe)**, that activated the region and the lobe, respectively.

Problem Definition

The problem definition is described in three sections: **:objects**, **:init** and **:goal**.

The **:objects** section lists all of the objects in the problem instance. In this work, the objects are the names of brain regions, paradigms, blocks and the cerebral lobes.

The initial state of this problem instance are defined in the section **:init**, by detailing all facts that are true in this state. The initial states declared in the problem file describe the brain regions, the paradigms and its stimulus blocks and the brain lobes. Also, we made associations between each initial state, from the defined predicates. We account 22 brain regions, 6 paradigms, 14 blocks and 5 brain lobes. The predicates **(active ?b ?c ?a)** and **(belong ?a ?d)** had 83 and 22 associations, respectively.

The section **:goal** list the conjunction of facts that must be true for the goal to be achieved. We used the function **(actived ?x)** for the main goals of the planner, where x can be the brain region or lobe that the planner must activate.

Experiments

The PDDL was tested in two different tools: Web Planner (Magnaguagno et al. 2017) and PDDL Editor (Muise 2015). The goal section used is described bellow to exemplify the planning differences in the tools.

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

In the goals, THA is Thalamus, MOG is Middle Occipital Gyrus and CUN in Cuneus. For these objectives, the Web Planner tool found the sequence with a 0.4020 seconds of execution time. The PDDL Editor tool found the planning for the same objectives in 0.02 seconds. For each tool, the plans were the following:

- **Web Planner**
  - *(chosen_paradigm fastloc falsefont mog)*
  - *(cerebral_lobe fastloc vocod tha subcortical)*
  - *(cerebral_lobe palavras regular cun occipital_lobe)*
- **PDDL Editor**
  - *(cerebral_lobe fastloc falsefont mog occipital_lobe)*
  - *(cerebral_lobe fastloc vocod tha subcortical)*
  - *(cerebral_lobe palavras pseudo cun occipital_lobe)*

As demonstrated above, the two tools chose the same paradigms, *fastloc* and *words*, but using different blocks in each paradigm. When used the **(actived THA)** as goal, the Web Planner found the plan using the action *chosen_paradigm*. In all tests, PDDL Editor choose to prioritize the use of the action *cerebral_lobe*. When using a single region, using the **(actived THA)** as example, the plan remained with the action *cerebral_lobe*; which indicates the block and the paradigm that activated the THA region and the brain lobe.

To test, we made an alteration in the action *cerebral_lobe*. Initially, this action have as effects the activation of the brain region and lobe, **(actived ?region)** and **(actived ?lobe)**. We remove the **(actived ?region)**, and now we just have the activation in the brain lobe. With this alteration, the found planning were:

- **Web Planner**
  - *(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 Editor**
  - (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)*

For this case, the execution time of the Web Planner was about 10.2711 seconds and the PDDL Editor presented an execution time of 0.032 seconds. Both tools chosen the same paradigm, but different blocks. To activate the THA region, PDDL Edition used the action *chosen_paradigm2*, considering a brain region that was not in the initial objectives. The two tools used the action *cerebral_lobe* for the goals **(actived occipital_lobe)** e **(actived subcortical)**.

Related Works

Nowadays, there are few works that uses planning techniques in fMRI-related problems. One of the works that combine these two areas (planning and fMRI) tried to reduce the loss in fMRI activation images during the scan. This loss can indicate that the participant is not performing the task correctly (Pereira et al. 2016). This work created an approach to detect when a subject was following the specified task and provide a feedback, in real time, for the researchers, so that the examination could be stopped when the subject was no collaborating with the task.

We did not find any research paper that uses planning for generate an fMRI task automatically.

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.

We are still studying the best actions to this domain. As future work, we are studying the use of other parameters associated to the paradigms, as the duration time of the task created by the planner. The duration time is important so that not very extensive paradigms are generated, causing a higher financial cost for the studies. The metric planning approach have been studied for a future implementation, to minimize the planner costs. We still are studying the use of plugins in the PDDL Editor tool. This tool has the Planimation plugin (Chen et al. 2020), that is a solver to Animate PDDL Plans.

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