Measuring Program Comprehension with Functional Magnetic Resonance Imaging (fMRI)

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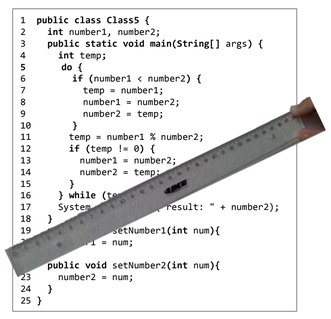
http://fosd.net/experiments/

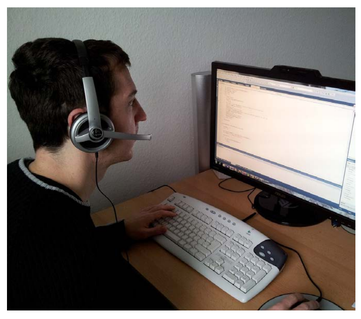
Measuring Program Comprehension

Program comprehension is a complex, **internal, cognitive process**. Programmers understand source code either bottom-up by analyzing each statement, or top-down by recognizing familiar statements. The kind of process depends on the knowlege we have of a program's domain. However, we cannot observe program comprehension directly, but have to use an **indirect measurement** approach:



Software Measures

Controlled Experiments



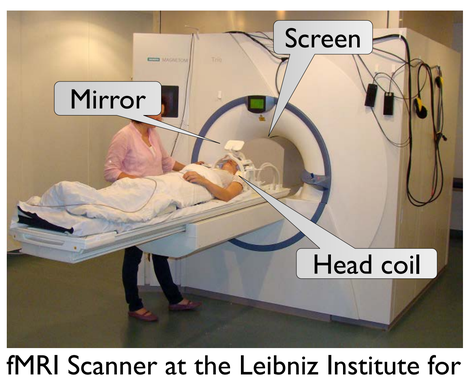
Think-Aloud Protocols

However, no indirect measure captures the comprehension process completely. Instead, we want to **directly observe** the comprehension process. With our work, we **measure** program comprehension **directly** with **functional magnetic resonance imaging.**

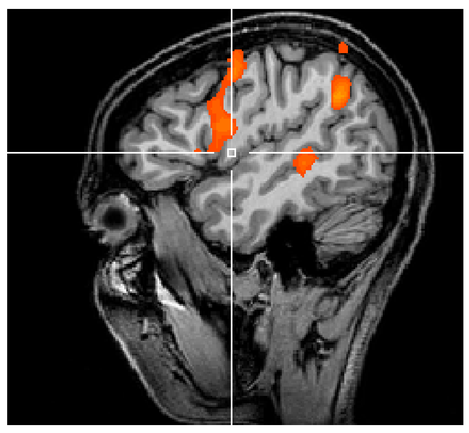
Can we look inside a programmer's brain?

Functional Magnetic Resonance Imaging

fMRI has been successfully applied to **better understand cognitive processes**, such as perception, attention, memory, or language understanding. Many of the relevant brain areas involved in these processes are to some degree recruited for program understanding, as well. We set out to **unravel** the differential **contributions of the different brain** areas in program comprehension with the aim of **learning more** about how different programmers with different skills and knowledge **solve programming tasks**.



fMRI Scanner at the Leibniz Institute for Neurobiology, Magdeburg, Germany



Can we get a better understanding of program comprehension?

How does fMRI Work?

When a brain area gets activated, its oxygen need increases. Thus, the amount of oxygenated blood increases, and the amount of deoxygenated blood decreases. Both have different magnetic properties, which we can measure inside an fMRI scanner.

Challenges of fMRI Studies

The design of fMRI studies has to meet **several requirements**:

First, we need **two** kinds of **tasks**, one **activating program comprehension** and one control task that **does not trigger program comprehension**. By **comparing resulting activation** of both kinds of tasks, we get only the brain activation caused by understanding.

Second, all tasks must meet the following requirements. The difficulty must lead to **response times between 30 and 120 seconds**.; the **code size** needs to fit on the **small screen** inside the fMRI scanner; overall, the time limit of one session should **not exceed 60 minutes**, to ensure attention of participants.

Our fMRI Study

Experimental Design

```
1  public static void main(String[] args) {
2    String word = "Hello";
3    String result = new String();
4
5    for (int j = word.length() - 1; j >= 0; j--)
6      result = result + word.charAt(j);
7
8    System.out.println(result);
9  }
```

Understanding task (60 seconds)

What is the output of the method? (olleH; String is reversed)

Press button when output determined

\+

Rest condition *(30 seconds)*

Do nothing

```
1  public static void main(String[] args {
2     int var1 = 23;
3     int var2 = 42;
4     inttemp;
5     temp = var1;
6     var1 = var2;
7     var2 = temp;
8     System.out.println(var1)
9  }
```

Control task (30 seconds)

Locate 3 syntax errors (Line 1, 4, and 8)

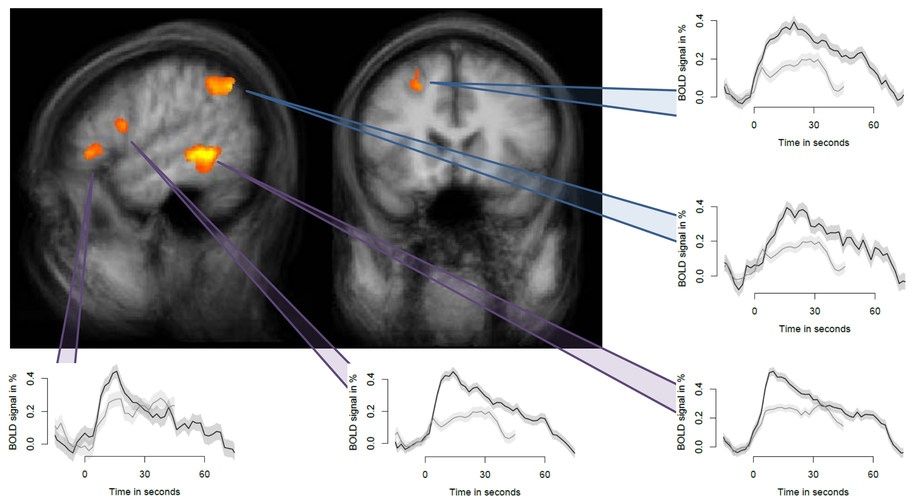
Press button when all errors located

\+

Rest condition *(30 seconds)*

Do nothing

Results



1. Activation in typical **language-processing** areas
2. Activation in areas related to **working memory**, including problem solving and the phonological loop
3. All activated areas are in the **left hemisphere**, which is known to be related to **analytical processes**

In a nutshell, our results describe program comprehension as analytical problem-solving process that requires language comprehension and keeping values of variables in working memory

Future Work

Based on our results, we plan to address the following research questions in the near future:

- How does program comprehension differ from reading comprehension?
- What is the role of memory during understanding source code?
- How do software metrics and program comprehension relate?

What the Future Might Bring

In the long run, when we have an in-depth understanding of what happens inside a programmer's head, we might be able to answer long-asked questions:

How should we teach programming?

What makes an excellent programmer?

How should we design tools and languages?