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Neural Efficiency of Top-Down Program Comprehension

Norman Peitek[1] Janet Siegmund[2] Chris Parnin[3] Sven Apel[2] Johannes C. Hofmeister[2]
Christian Kästner[4] Andrew Begel[5] Anja Bethmann[1] André Brechmann[1]

Abstract: We observed program comprehension with functional magnetic resonance imaging (fMRI) and found a difference in neural efficiency between top-down and bottom-up comprehension, but failed to find a significant effect from beacons. Furthermore, we were able to replicate the results of a previous fMRI study, thereby strengthening the role of fMRI as measurement technique to observe program comprehension and other related cognitive processes.

Keywords: functional magnetic resonance imaging; program comprehension; neural efficiency

Program comprehension is an important cognitive process, because programmers spend most of their time understanding code [LVD06]. An efficient way to understand source code is top-down comprehension, where *beacons* and *plans* guide programmers to the relevant information [Br83]. When code lacks beacons and plans, or when programmers lack the experience to recognize them, a slow and tedious statement-by-statement process is necessary, which is called bottom-up comprehension [Pe87].

Understanding how programmers comprehend code is inherently difficult, because we cannot directly observe internal cognitive processes. In cognitive neuroscience, functional magnetic resonance imaging (fMRI) is being used to better understand such elusive cognitive processes. In our line of work, we use fMRI to infer neural processes involved in program comprehension based on observed brain activation of programmers in order to evaluate the often decades old models of program comprehension.

In our previous fMRI study on bottom-up comprehension, we found activation in brain areas related to working memory, divided attention, problem solving, and language processing [Si14]. In this follow-up study, we adapted the previously used material to isolate specific neural processes related to top-down comprehension [Si17].[6]

First, we could replicate the results of our first study on bottom-up comprehension. In the original study, we found activation in Brodmann areas (BAs) 6, 21, 40, 44, and 47

[1] Leibniz Institute for Neurobiology, Magdeburg, Germany, firstname.lastname@lin-magdeburg.de
[2] University of Passau, Passau, Germany, {janet.siegmund,apel,johannes.hofmeister}@uni-passau.de
[3] NC State University, Raleigh, North Carolina, USA, cjparnin@ncsu.edu
[4] Carnegie Mellon University, Pittsburgh, Pennsylvania, USA, kaestner@cs.cmu.edu
[5] Microsoft Research, Redmond, Washington, USA, andrew.begel@microsoft.com
[6] More information and material is available on the project's Web site `https://github.com/brains-on-code/paper-esec-fse-2017/`.

within the brain's left hemisphere, i.e. the speech hemisphere. We found part of these areas again (i.e., BAs 21, 40, 44), indicating the suitability of fMRI for measuring program comprehension. However, not all areas were significantly activated, which could be due to individual anatomical differences between the participant groups or the reduced statistical power of the current experiment.

Second, we found that top-down comprehension did not result in stronger activation than bottom-up comprehension, which at first sight is in contrast to program-comprehension models. However, we found a difference in the activation strength, such that the activation is significantly lower for top-down comprehension than for bottom-up comprehension. Thus, top-down comprehension has a higher neural efficiency than bottom-up comprehension.

Third, we could not find an effect of beacons on top-down comprehension, such that it did not matter whether beacons were in the source code or not. Based on the participants' comments and the data, we believe this effect is too small to be captured with the applied study framework.

In a nutshell, our results indicate that fMRI is a useful approach to better understand the cognitive processes of program comprehension. However, with this replication, we also found potential weaknesses of the experimental design, which we are currently addressing. Specifically, we are combining eye tracking with fMRI to help us map what participants are seeing to what the brain is doing.

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