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Acknowledgements

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Kurzfassung

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Abstract

200-250 words or 10-15 lines Enter your text here.

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Introduction

Motivation

Software system underlie continuous changes throughout their life cycle. It evolves from the beginning of development until its release and maintenance phase. Large software systems¹ and most of all, software classified as type E [CHLW06], gets more complex over time. If there are more than a few developers/development teams involved or the developers/development teams are spread allover the world, there exists more foreign code than self written. Most of all when it comes to making changes, enhancements and fixes, there is a very high level of understanding of the software at hand necessary[Boe76][SLea97]. Due to [CZvD⁺09] "... up to 60% of the maintenance effort is spent on gaining a sufficient understanding of the program ...". These facts emphasize the need for computer aided methods to improve program understanding.

This thesis addresses the task of improving program comprehension of the concatenative programming language forth on several levels. The terms "program understanding" and "program comprehension" are considered synonym.

Namely the reading of source code, static analysis, dynamic analysis and the assistance of writing readable and easy to understand source code.

Due to the nature of concatenative languages, it is possible to write source code which reads very similar to natural language. There are no hard boundaries to the structure of the source code(custom defined loops and control structures) as in most object oriented languages. Since forth directly operates only on stacks and memory, the information which is immediately needed to follow program execution is limited to those structures. In contrast, in object oriented languages there is also object state, object life cycle and concurrency to keep in mind.

mental model(LaToza et al., 2006) read: ..comment

¹"The term large is, generally, used to describe software whose size in number of lines of code is greater than some arbitrary value. For reasons indicated in [leh79], it is more appropriate to define a large program as one developed by processes involving groups with two or more management levels."[LR03]

Problem statement

There has been done plenty of work on the task of program comprehension in object oriented and procedural languages[CZvD⁺09], but nearly none for concatenative languages. The qualitative exploratory approach of this thesis does not encourage the formulation of specific hypothesis. Therefore the first question, is the applicability of existing methods and their visualization techniques. The second question to be answered, concerns new approaches, which may be exclusive to concatenative languages or gforth/forth.

Aim of the work

This work aims to give a brief overview on the field of program comprehension and its methods, to show existing aids to program understanding in Gforth/Forth and to study the applicability of some existing analysis and visualization approaches for other paradigms. Further more the suggestion of new methods or the modification of existing methods to meet the characteristics of gforth/forth.

Structure of the work

In chapter 2 I will line out the methodological approach of this thesis. In chapter 3 there will be a brief overview on the topic of program comprehension, an overview on the existing tools to improve program understand in general and on those specific to Gforth/Forth and after wards I will present a selection of visualization approaches for procedural and object oriented languages. In chapter 4 I will present some of the previously mentioned approaches for other paradigms applied on a real worlds forth program, analyze their applicability and propose modification to those approaches. Afterwards I will present a prototype implementation of a program trace visualization enhancement to Gforth. chapter 5 concludes the paper with a summary and topics of further investigation.

Methodology

This chapter contains the methodological methods used to approach the topic of this thesis.

I will use a qualitative approach. In chapter 3, I will gain an over view of program comprehension and it's techniques in general and I will summarize the currently available techniques for Gforth/Forth. The main resources for that was [CZvD⁺09] and the keyword search on the ACM digital library¹. Since I will investigate the applicability to Gforth/Forth of only a handful of concrete techniques, I used the following criteria for selection:

- Graphical visualization
- Applicable to imperative languages(procedural and object oriented)
- Behavioral analysis
- Suitable for trace visualization

A probable issue, introduced by the initial keyword search, is the lack of previous knowledge on the topic and the lack of experience with Gforth/Forth.

In chapter 4, I will analyze the graphics which would be produced as a result of the selected techniques. First, I will introduce the software on which I applied those techniques. The software was chosen with the following criteria in mind:

- Size: The software should consist of at least hundred kilobytes of source code.
- Complexity: It should have at least a medium level of complexity.
- ? Practicality: It should solve a real problem.

¹<http://dl.acm.org/>

Since software characteristics can vary greatly depending on the domain, the selection of only one program might not be meaningful enough to confirm, whether a certain technique is useful or not for arbitrary Gforth/Forth programs. Second, I will analyze the graphics in an exploratory fashion. Due to the lack of automated implementations of the selected techniques for Gforth/Forth, I will produce these graphics manually. **wenns fertig ist dann schreib ich rein obs verbessert werden oder nicht, das geht so nicht** If necessary, I will propose modifications of these techniques to improve their usefulness **in this specific case**. Third, I will introduce the prototype of an enhancement for the Gforth step-debugger which was implement in the course of this thesis and discuss its usefulness. **TODO bei den methoden noch irgendwo meine erwÄdhnen** Fourth, i will **suggest new techniques**.

It is obvious, that due to the chosen methodology, there will be no quantitative confirmation for the usefulness of the techniques under investigation. Due to the limited selection of techniques, there may be other methods which maybe invaluable to program comprehension, but are not covered by this thesis.

In chapter 5, I will **?schreib ob und welche unterschied es gibt zwischen program comprehension zwischen verschiedenen paradigm**

Analysis of existing approaches

The focus here lies on so called E type software systems. E stands for evolving [CHLW06], most of the real world software systems are type E. These systems are of particular interest since they underlie continuous changes throughout their whole life cycle. Thus understanding existing code, which might not be well documented, is crucial for the maintenance of those systems.

3.1 Program comprehension

Program comprehension can be gained through several approaches. First of all, reading the code. In [Bas97], Basili et al. approach the concept of reading on a very fundamental level. The natural way to learn writing, is to learn to read first. The reading then forms a model for our writing. His research shows that reading is most effective compared to testing. This suggests, that readability of code does impact the efficiency of failure discovery. According to Basili et al., the most severe problem is the fact that programming languages are learned the other way round. We first learn to write code and then learn to read it. Furthermore, the ability to read code is not properly addressed in education. The syntactical flexibility, Forth provides compared to other languages (and paradigms), allows it to achieve a very natural seeming reading experience. Thus our skills in natural languages could become handy and make program reading and thus understanding even more efficient. This would in the end result in higher code quality in terms of failures and unexpected or unintended behavior.

There emerged several strategies on how to read and understand a program [SFM99][SWM97]:

Top down program comprehension

Using the top down strategy, the reader begins on the highest level of abstraction, the main purpose of the program and then builds a hierarchy by refining it into sub tasks until the lowest level of abstraction is reached.

Bottom up program comprehension

Using the bottom up strategy, the reader builds the mental model by grouping low level parts of code building high levels abstraction until the whole program is understood.

Knowledge based program comprehension

The knowledge based strategy, allows both, the bottom up and the top down approach. The assumption is, that programmers have a certain mental model of the software, this model is evolved by both refinement and abstraction.

Systematic and as-needed program comprehension

This strategy embodies detailed reading as well as only focusing on the code necessary to fulfill the task at hand.

Integrated approaches of program comprehension

This strategy allows freely switching between the top down, the bottom up and the knowledge based approach.

As Storey et al.[SFM99] points out, there are certain factors which influence the choice programmers take. Thus programming environments should provide methods to support all of these strategies. (See later section — make a connection to the strategie later?! or leave out)

Since software evolves throughout its whole life cycle, also the before mentioned mental model, of the reader has to evolve. It has to be kept in sync with the software system. This suggests, that it is essential to keep all types of artifacts(documentation, source level documentation, graphics,...) up to date.

3.2 Analysis to support program understanding

Besides reading of the source code and other textual documentation, there are also other methods to increase program understanding.

3.2.1 Dynamic analysis

Dynamic analysis is performed on the image of a program, executed on a real or virtual processor. The advantage is, that due to the availability of the data to be manipulated, the actual behavior of a program can be investigated. The major drawback however is that there exists only an incomplete view of the software system at hand[Bal99]. Dynamic analysis is a very efficient way to evolve or correct the mental model of developers, but not to create it. In large software systems, some scenarios might not occur during analysis. TODO einfach weglassen? I will distinct here between two categories of dynamic analysis: TODO... ???

- interactive
The characteristics of interactive (stepped debugging, interpretative execution) approaches, is that the program is still executing during the analysis and thus time is a critical factor. This makes some analysis methods like performance analysis impossible. In networked environment, timeouts can make interactive analysis very hard.
- non interactive (real-time and post-mortem)
In real-time analysis (log analysis, trace analysis), data changes very quickly, which can make the task of tracking execution scenarios very resource intensive. In contrast, in post-mortem analysis (log analysis, trace analysis), the processing of very large files becomes a problem.
- **INTEGRATE THIS?: observer effect**
Andrews, J. (1997). Testing using log file analysis: tools, methods, and issues. In Proc. International Conference on Automated Software Engineering (ASE), pages 157–166. IEEE Computer Society Press
- scalability
Zaidman, A. (2006). Scalability Solutions for Program Comprehension through Dynamic Analysis. PhD thesis, University of Antwerp
- debugging -> different kind of paradigms and languages and tools
see @incollectionreiss1993trace, title=Trace-based debugging, author=Reiss, Steven P, booktitle=Automated and Algorithmic Debugging, pages=305–314, year=1993, publisher=Springer

3.2.2 Static analysis

Although this thesis focuses on dynamic analysis, for the sake of completeness, also static analysis should be mentioned here. Static analysis is performed on the source code. Therefore and in contrast to dynamic analysis, it has the capability to provide a complete view of the software at hands. The drawback is that there is no actual data present and thus there are no means of covering the actual data flow and the manipulation of data.

3.3 Existing approaches

3.3.1 Gforth/Forth

In this section I'm going to present the tools, Gforth/Forth provides to support program understanding and maintenance¹.

¹For further tools see <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Programming-Tools.html#Programming-Tools>

Examining data and code

Gforth provides several tools to display data and code, which supports program understanding and software maintenance.

For displaying data, the most important words are `.`, `.s`, `."`, `type` and `dump`.

`.` and `.s` simply display elements of the stack, there are also words to visualize the other stacks. The words `."` and `type` display text and `dump` displays memory areas(address, hex and ascii). `~~` displays the location of itself in the source-file(file and line number) as well as the data stack.

All these words can be utilized to display logging information.

They are usable in interactive as well in non-interactive analysis.

There are also words to investigate the inner workings of other words. `see` displays the definition of words written in Forth. It can be used to quickly look at the behavior of words provided by Gforth without looking into source-files. The use of `see` and its relatives only makes sense in interactive analysis.

status.fs

Status.fs is included in Gforth(since 0.7.0). It opens a separate xterm window, displaying the current number base, the float stack, the data stack and the current search order. The view is updated after each execution in the interpreter. Thus it is only useful for interactive analysis.

Stepping debugger

`dbg`², the stepping debugger, supports among others, single step, step into, step over as well as break points. It displays the address of the word to be executed and the content of the data stack after its execution. `dbg` is only usable for interactive analysis.

Assertions

Assertions³ can be used to verify, that the program, at a certain point, is in a certain state. For example pre-conditions and post-conditions of words could be implemented using assertions. It is also possible to prevent code from breaking during maintenance activities. The word `assert(` starts the assertion, the following words until the `)` are executed and have to leave a flag on the stack. If that flag is true, the asserted condition is met, otherwise, the execution of the program ends and the location of the failed assertion is displayed(source file and line number).

There are several assertion levels and by setting the `assert-level`, assertions can also be deactivated.

²For further information see: <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Debugging.html#Debugging>

³See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Assertions.html#Assertions>

Documentation

Thorough and up-to-date documentation is undoubtedly important, this also applies to concatenative languages. Besides behavior description of words, since forth is by default an untyped language, there is also a special kind of documentation encouraged to ease the understanding of words, namely the stack effect comment⁴. It is written next to the name of the defined word and contains the number and kind of elements on the stack which are manipulated by the word. These comments describe the state of the stack before and after the execution of a word. In these comments, there is also a distinction to be made between interpretation, compile and run-time behavior.

Words and word lists

Like in any other language, words should be named expressively. However sometimes, it may not be avoidable to reuse names. Forth provides an elegant mechanism, called word lists⁵, to address these issues and to organize words. With word lists, words can be defined in a certain context. Like in natural languages words can have a different meaning in separate contexts. Using word lists, developers can prevent name clashes and separate interface words from internal words. In large projects it might be necessary to define a naming strategy.

Factoring

As in any other programming language, it is necessary to split the overall problem down into manageable, less complex sub problems. In concatenative languages this is also referred to as factoring. Factoring helps keeping definitions short (and thus easier to understand), reusable and easier to test (<https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Factoring-Tutorial.html>).

Aliasing

In Gforth, there can be multiple aliases⁶ for one word. Aliases can be used to use the same underlying implementation in different contexts, to make code more readable.

Emacs forth-mode

The emacs forth-mode (gforth.el, which is based on forth.el) provides many helpful features⁷ to ease the writing of Forth. Most notable, related to program understanding:

⁴See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Notation.html#Notation>

⁵For more information on word lists, see <http://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Word-Lists.html#Word-Lists>

⁶See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Aliases.html>

⁷For a more information see <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Emacs-and-Gforth.html#Emacs-and-Gforth>

- Word documentation lookup
- Jump to line from, error messages, debug output, failed assertions and `~~` output
- Highlighting
- Indention handling

Kgforth

There has also been an effort to integrate some of those tools into a graphical development environment. The project is called Kgforth⁸, but its development seems to be discontinued.

3.4 Applicability of methods for other paradigms to concatenative languages

In this section I will present a hand full of visualization methods and discuss their applicability to Gforth/Forth.

Sequence diagram, interaction diagram and scenario diagram

The Unified Modeling Language sequence diagram can be used to model event sequences on any level of abstraction. Since I left out object oriented Forth and there is no standard for concurrency, the word-only level provides little help. On this level, the actors would be represented by words and the messages⁹ would represent word executions. Therefore the sequence diagram would degrade to a list. On the system level although, the sequence diagram can provide useful information on the interaction between system components. The scenario diagram as implemented by [KM96], is essentially the same as the sequence diagram and the interaction diagram which has been proposed by Jacobson, 1992 — Citation unclear...

Since system level visualization is applicable to almost any paradigm and word level visualization does not seem promising for dynamic analysis, I will not investigate the benefits of those diagrams in this thesis.

Hierarchical edge bundles

Hierarchical edge bundles as proposed by [Hol06] display hierarchic and non hierarchic relations between nodes. In context of forth, word execution can be mapped to non hierarchic relations and directory/file tree and the definition could be the hierarchic relations. Like in object oriented systems, the proper organization of directories, files and word definitions has to be considered to make such a visualization helpful. Another

⁸<http://sourceforge.net/projects/kgforth/>: Kgforth is a simple IDE for the gforth interpreter/compiler for KDE 2.** It provides an editor, gforth window, debug and dump window, forth toolbar and menu.

⁹The edges in UML's sequence diagram are called messages.

possible mapping could depend on word list as words hierarchic and word execution as non hierarchic relation.

The hierarchic edge bundle can be used for interactive and non-interactive(real-time) dynamic analysis. In the following chapter I will analyze both possibilities using a real forth software as an example.

Information murals and massive sequence view

The information mural was initially proposed by [JS98]. A modified version, the mass sequence view, was later proposed by [Cor09]. It turns the horizontal scrolling into vertical scrolling and also included the hierarchic aspect be more suitable. As with the hierarchical edge bundles, the usefulness of the hierarchical element depends highly on the organization of the software system at hand.

As well as the hierarchic edge bundle, these two methods can be used for interactive and non-interactive(post-mortem) dynamic analysis. In the following chapter I will analyze the massive sequence view using a real forth software as an example.

High-Level polymetric views

Polymetric views[DLB04] are a very interesting and promising approach to grasp the behavior of very large systems. In polymetric views, system attributes or measures are mapped to attributes of a graph. The attributes proposed by[DLB04], are position, height, width, color and the relations(and the thickness) between rectangles, representing aspects of the software to analyze. In terms of forth, the mapping to words seems most obvious. This would result in some kind of a word cloud with additional information attached. This could be most valuable, when used with the appropriate metrics, to analyze and optimize performance. Another advantage is, that there is no complete, but only condensed **evt footnote erkl rung was das bedeutet** data required.

This method is suitable for interactive as well as non-interactive analysis. In the following chapter I will analyze a polymetric view of real software as an example.

Fisheye views

Fisheye views were first proposed by [Fur86] and formulated by [SM96] and [SB94]. The essence of fisheye views is a principle also found in nature. It's basically described as a function, expressing the degree of interest of an subject, depending on an a priori importance and the distance from the current point of view. Growing distance lowers the degree of interest.

This method is related to polymetric views, as mentioned above. **is it a special case of a polymetric view?!**

Execution pattern view

The execution pattern view, proposed by [PLVW98], visualize large traces in a scalable manner and helps to identify execution patterns. I represent an interesting evolution of

simple sequence diagrams and interaction diagrams.

Since it is somehow related to the massive sequence view, I will not pursue this approach in detail.

Method invocation view and taxonomy view

The tool GraphTrace[KG88] is meant to analyze object oriented programs. It provides a method invocation view and a taxonomy view. Although the method invocation approach of GraphTrace seems not practical for forth programs, the authors mentioned two very interesting ideas.

- Displaying variable access:
The idea of showing words which access variables and the other way round, showing which words access a specific variable is very interesting. Thus it would be easier to track the global state of a program.
- Concurrent views:
The authors of [KG88] present a quiet interesting analogy. They compare the execution of a program with a tennis and football and refer to the multiple perspectives necessary to understand all aspects of a match and the whole outcome.

The variable access graph in a tree like visualization as in GraphTrace seems highly useful since variables represent a global program state, which can increase complexity. Although this approach seems to make only sense for in static analysis, I will analyze the variable access graph of real software as an example in the next chapter.

Frequency spectrum analysis

The frequency spectrum analysis as proposed by [Bal99] provides an interesting approach. It is similar to parametric views as mentioned before, but the visualization is not graphical but textual. The word execution frequency could provide valuable information about the actual performed work and incorporated with execution time, it could help in understanding programs and support performance analysis. In [Bal99], Ball shows the application of frequency spectrum analysis at the example of an obfuscated c program. Although this is not the main focus of this thesis, his approach should also apply to concatenative languages.

In the following chapter I will briefly analyze this approach at an example of a large forth program.

TODO evt weglassen??

CHAPTER 4



Results

In this chapter, I will introduce the chosen forth software. Afterwards, I will manually or semi automatically produce the graphics according to the selected Visualization methods.

4.1 The software under investigation: Brainless

Brainless¹ is chess-playing program written in ANS Forth. The source code consists of several files with an overall size² of 139497 bytes and 4108 lines of code³. This measure is somehow controversial, but since the files contain only a short header and are formatted in the usual manner, it seems appropriate for comparison. The code is organized in a flat structure. There is one directory with 30 files, which contain 663 words. There is only one custom word list defined. Thus the visualization of a word list hierarchy makes obviously little sense and is left out in the following sections.

The other software, I took into consideration, was brew⁴. Brew is a 'playground for evolutionary programming', as the author calls it. Due to its size of 1062857 bytes and 36801 lines of code, this project seem to large to analyze manually in a reasonable time.

For the following figures, I used a snapshot of an execution trace. Since the calculations of the computer-moves produce a huge amount of word executions, the example trace, was created by making only the player-move: *d2 d3 m* . The snapshot contains all word executions after and including the execution of the word *m*. It consists of 4709 word executions. 4.1 and 4.2 show the state of the game before and after entering *d2 d3 m* .

¹Brainless version 0.1.2 is used, the source code can be obtained on <http://sourceforge.net/projects/forth-brainless/>

²The command to calculate the size was *find . -name '*.fs' -maxdepth 1 | xargs wc -l*

³The command used to count the lines of code, was *find . -name '*.fs' -maxdepth 1 | xargs wc -l*

⁴brew version 0.2.0 was used. The source code can be obtained on <http://www.roberteppecht.ch/beer/index.html>

```

      A B C D E F G H
8  r n b q k b n r 8
7  p p p p p p p 7
6
5
4
3
2  P P P P P P P 2
1  R N B Q K B N R 1
   A B C D E F G H
White moves.
If startled, type 'help'!Gforth 0.7.0, Copyright (C) 1995-2008 Free Software Fou
ndation, Inc.
Gforth comes with ABSOLUTELY NO WARRANTY; for details type `license'
Type `bye' to exit

```

Figure 4.1: State of the game before entering *d2 d3 m*

```

ndation, Inc.
Gforth comes with ABSOLUTELY NO WARRANTY; for details type `license'
Type `bye' to exit
d2 d3 m d3
      A B C D E F G H
8  r n b q k b n r 8
7  p p p p p p p 7
6
5
4
3      P
2  P P P P P P P 2
1  R N B Q K B N R 1
   A B C D E F G H
Black moves. ok

```

Figure 4.2: State of the game after entering *d2 d3 m*

4.2 The application of the previously presented methods

Hierarchical edge bundles

Figure 4.3 shows the first 100⁵ word executions of the trace snapshot mentioned before in a *hierarchical edge bundle*.

Information murals and massive sequence view

Figures 4.4, 4.5 and 4.6 show the trace snapshot in a *massive sequence view*. It is easy to identify certain steps of the program execution like the drawing part at the end of the trace(interaction with drawing.fs shown in figure 4.5) and the file writing part(interaction from epd.fs at the end of figure 4.5), if one knows the words contained in those files. But it also clearly shows the lack of interactivity. Without filtering, zooming, on-demand information on words(references to source code) and of course expressive naming, it still remains hard to map the sections of the trace to behavior. Besides these concerns, the massive sequence view seems to be well applicable to forth program traces.

High-Level polymetric views

In 4.7 I used circles to represent single words. The radius reflects the number of executions, frequently executed words appear as larger circles. The position(distance from the origin) reflects the number of words executed within the word, fewer sub-word-executions result in a greater distance. If the number of sub executions vary, the maximum was used. The color of a circle reflects the io-behavior of the word. Red means, the word prints to stdout and yellow means it is reading from or writing to a file and the other words are without a fill color.

TODO groSse wörter = performance relevant, wörter die in der mitte sind, sind eher intern komplex, farben: wörter die tatsächlich was sichtbares tun

Method invocation view and taxonomy view

The following view shows the words from which certain memory fields are written or read. It should cover *value*, *variable*, *2variable*, *fvariable* and also memory fields, allocated by custom defining words. Since Brainless makes extensive use of *values* and does not use **variables* at all, the following graphic shows only the values(custom defining words have been omitted as well).

⁵The calculation of the interaction lines consume considerable amount of system resources, which prevents longer traces due to memory limitation.

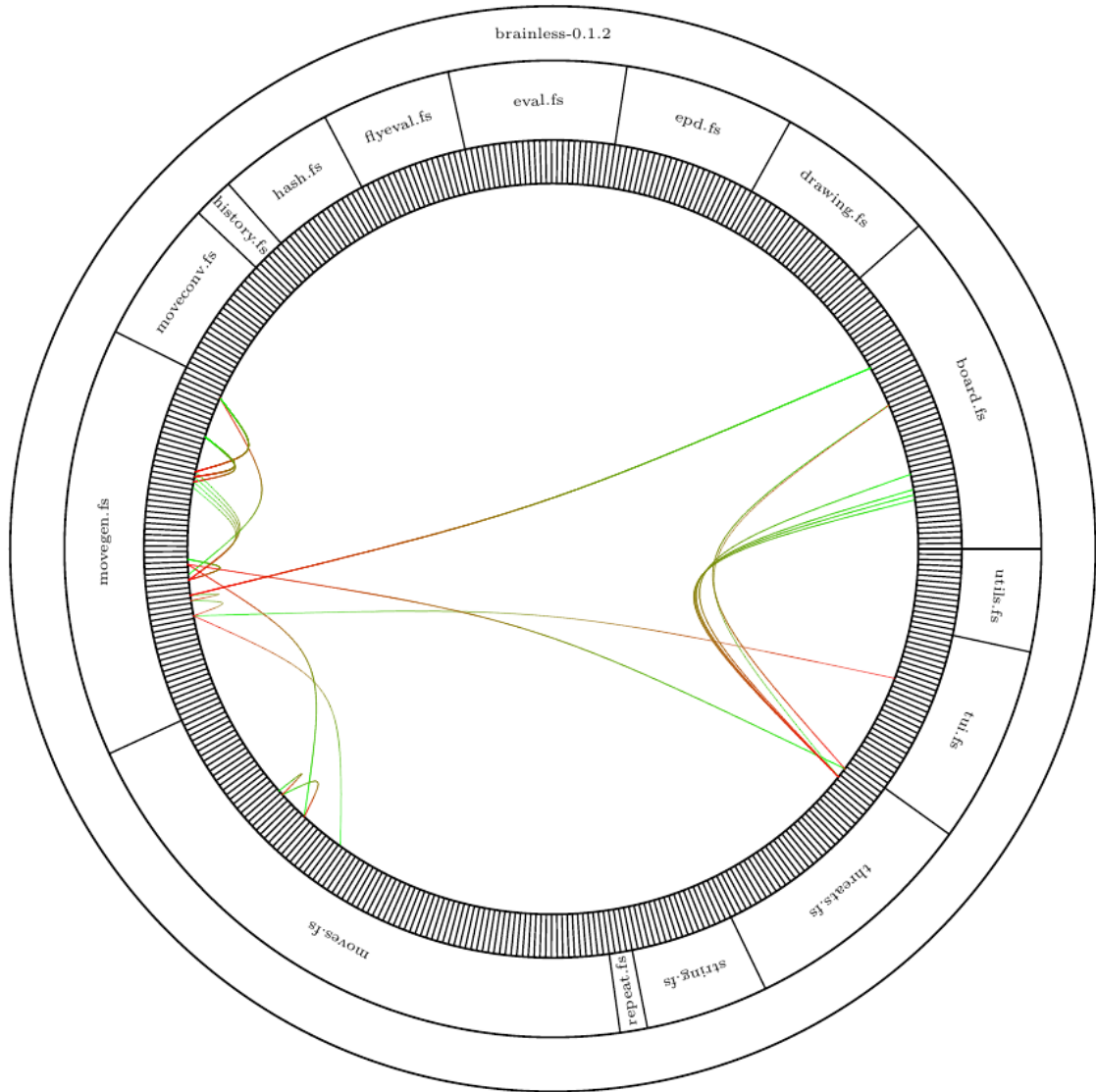


Figure 4.3: Hierarchic edge bundle of a small snapshot of the trace of Brainless after $d2$ $d3$ m

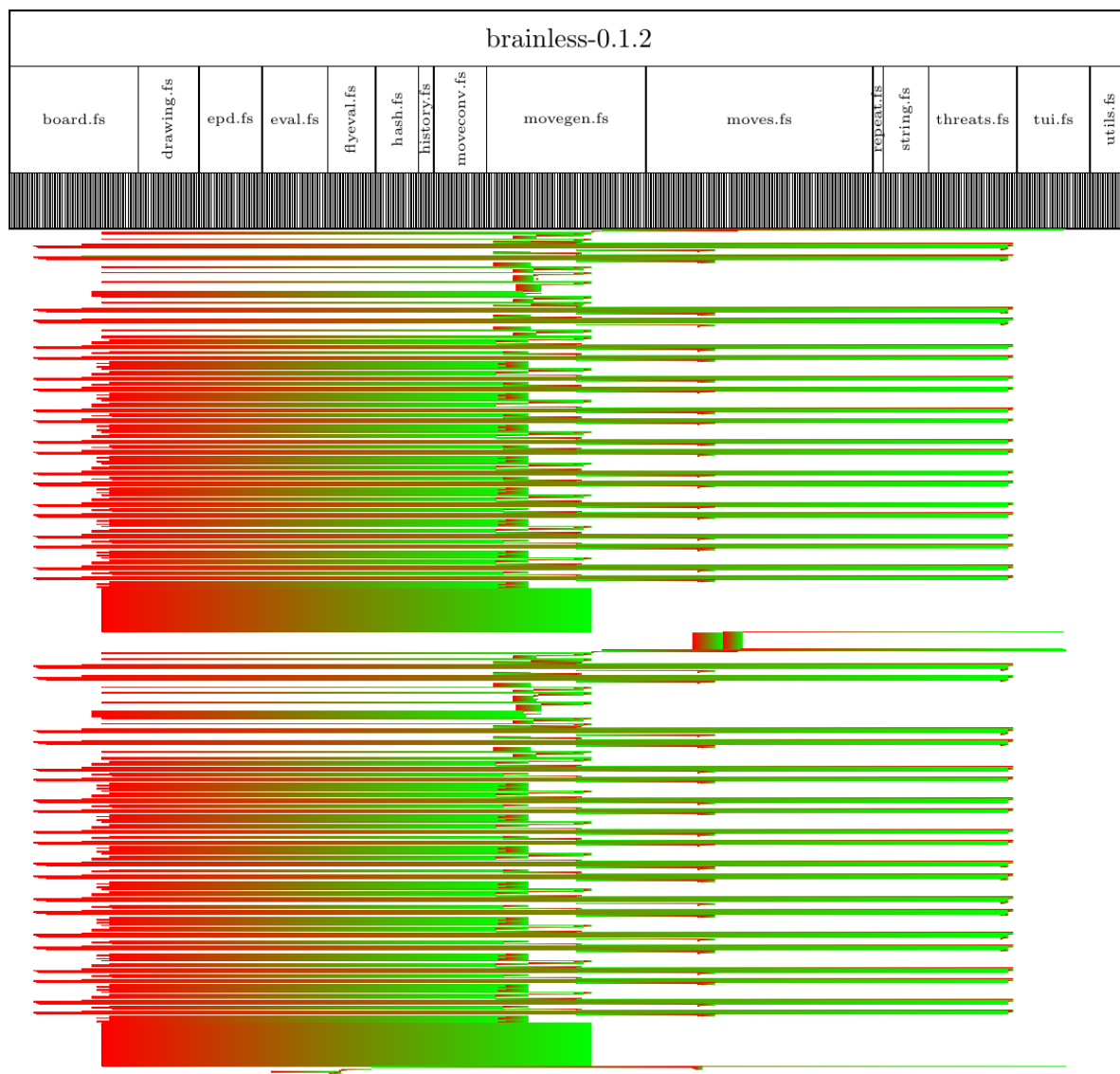


Figure 4.4: Massive sequence view(Part 1) of Brainless after $d2\ d3\ m$

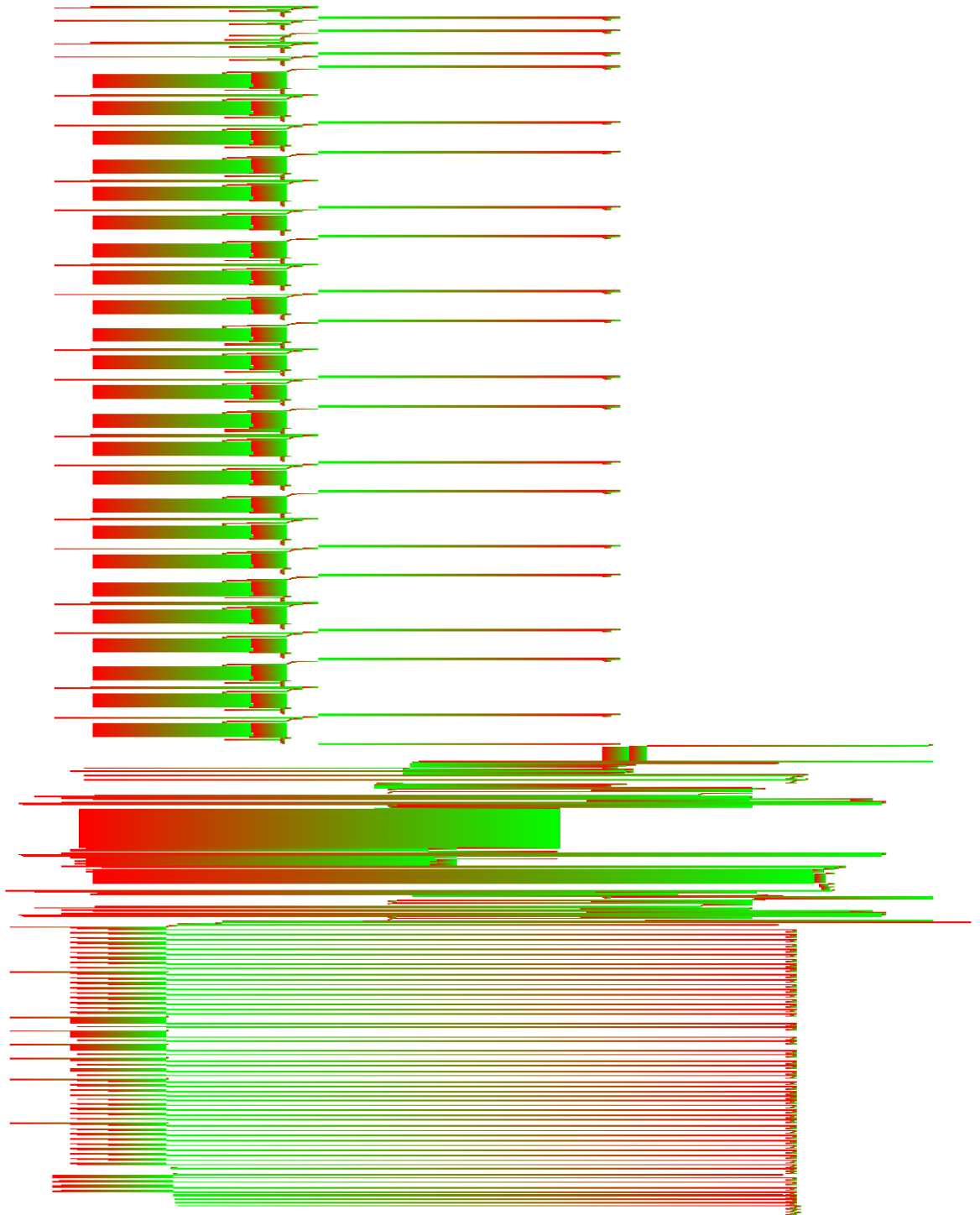


Figure 4.5: Massive sequence view(Part 2) of Brainless after $d2\ d3\ m$

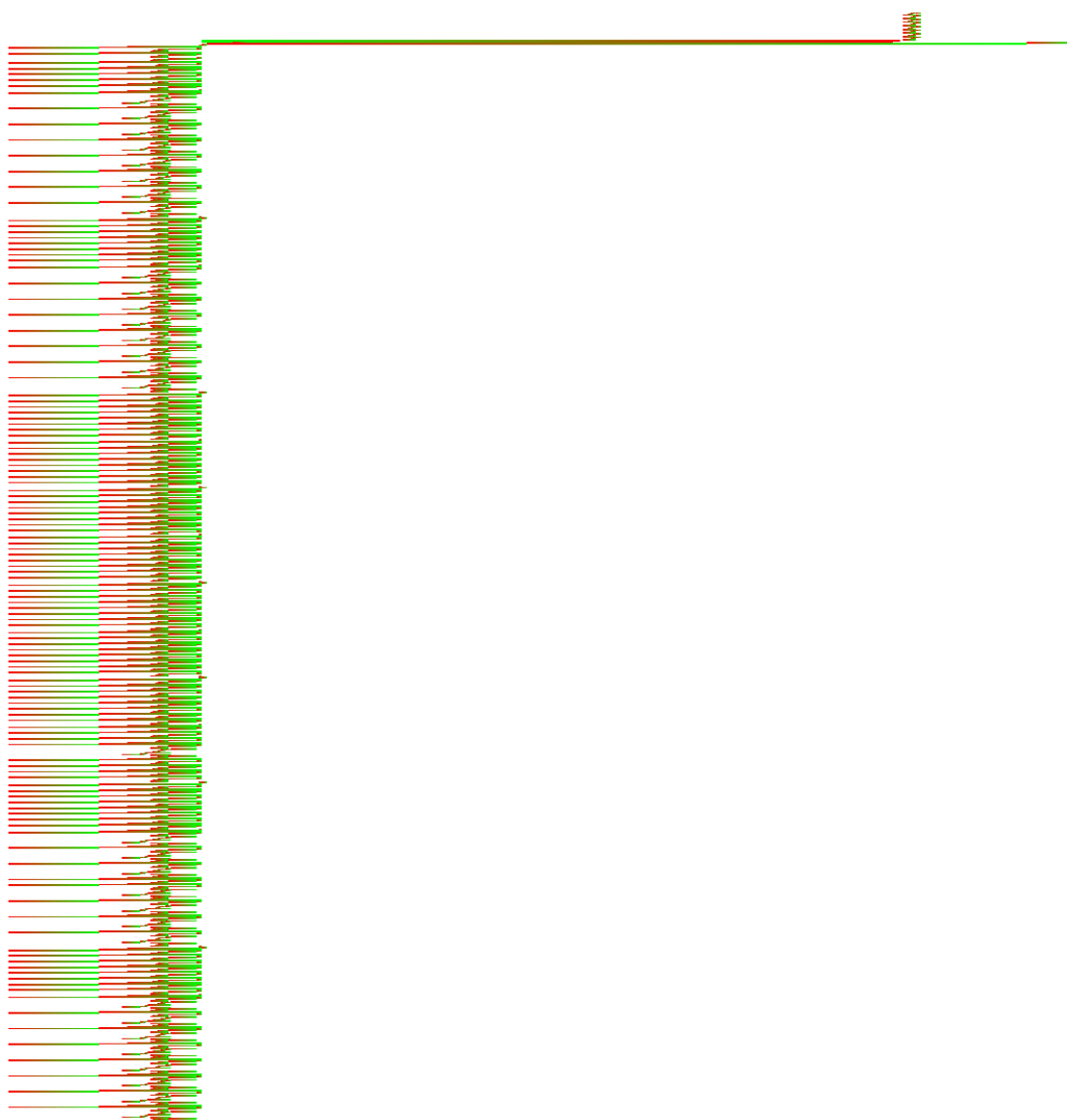
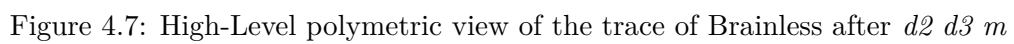


Figure 4.6: Massive sequence view(Part 3) of Brainless after $d2$ $d3$ m



Frequency spectrum analysis

4.3 gfvis - A trace visualization enhancement for Gforth

TODO put this under the matching viz methods!! A very important question in this concern is, how can developers be assisted to write readable code. Experienced developers may do that intuitively, but how can novice developers be encouraged and supported to write readable code. Concatenative languages are flexible enough to produce code very similar to natural languages, but how can this attribute be supported?

One answer is to provide hints based on static analysis.

It is not possible to make every word completely readable and the perceived readability also depends on the experience of the developer. At some point it always comes down to longer combinations of "nip tuck over rot", this is hardly avoidable at the lowest level. Thus, proper documentation of words is essential. Its pretty The obvious, that stack effect comment⁶ in forth, are a must have, but also the behavior of the word should be explained if complex or not very natural to read words⁷. Another advantage of word definition comments is the possibility of automated documentation generation.

Very long word definitions tend increase the amount of brain capacity required to understand its behavior. The way to account this problem is to break down the overall task into manageable pieces. It is called factoring⁸ in context of concatenative languages. An approach could be to place a hint on word definitions which exceed a certain amount of lines or words or different words and suggest further factoring.

Another tool to make code read more natural, is aliasing⁹. By defining aliases for a certain word, its functionality can be used in different contexts and still read very natural. Expressive naming, although obvious, it should be mentioned that assigning expressive and fitting names for words is essential. This applies to any language[does it? cite...].

To understand code, the systematic approach turned out to be most efficient[RCM04]. To ease afford of finding the definition of words used at a certain point, a hyperlink like referencing mechanism can be used[cite the visualization paper with the hyperlink feature].

As stated by Charles D. Moore in [BW09]: "... The challenge there is 1) deciding which words are useful, and 2) remembering them all.", when programs get larger, the amount of words can grow big. Thus it is suggested to have some sort of a dictionary to search the whole vocabulary by name, stack effect comment, word definition documentation and provide a reverence to where they are used. Auto completion can also help a lot in finding words previously defined.

⁶See https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Stack_002dEffect-Comments-Tutorial.html#Stack_002dEffect-Comments-Tutorial

⁷Most notable
G in gforth. See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Comments.html#Comments>

⁸See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Factoring-Tutorial.html#Factoring-Tutorial>

⁹See <https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Aliases.html>

- other data structures and variables should be displayed
 - memory maybe like [Rei95] or [AKG⁺10] but since there is no underlying object orientation and no standardized oo system this would be hard to accomplish
 - fisheye or word cloud like display (tree or sugiyama as of [SWFM97])
- interactive program manipulation: state of the system before a word, after a word and by clicking on the word jumping to its definition or inserting it and there also providing those features
- stepping debugger mode: simply stepping through the whole code word by word
- goal-oriented strategy: the definition of an execution scenario such that only the parts of interest of the software system are analyzed (Koenemann and Robertson, 1991; Zaidman, 2006).
- code analysis and visualization facilities see chapter 2 TODO

4.3.1 software maintenance

- types of maintenance
- find bugs and fix them
- find the right place to implement a new feature.
- find the right place to modify a feature.

4.3.2 program comprehension

- structured approach
- thorough reading is the most efficient[cite]
- about the mental model building
- keeping the mental model up to date
- keeping artifacts up to date

Summary and future work

The pure exploratory approach did not provide any information on the actual impact of the implemented and suggested solutions. The gathering of quantitative data and the formulation of hypotheses remains to be done in further works.

summary of what has been done and the subjective conclusion
only on the implementation or also the suggestions?

5.1 comparison with related work

Quiet some research has been done on the topic of program comprehension in the last decades, but most of it addressed object oriented or procedural languages. Since there is no standard way to model object orientation, it is not possible to implement a general tool for visualization similar to the existing methods, but these methods should be applicable on an object oriented model implemented in forth in general. The research on trace visualization has proven to be very similar for concatenative languages since a program is also a concatenation of words. The most similar existing work is kgforth, a development environment using qt. Although the outline looks promising, it is not in development anymore and I was not yet able to run it.

5.2 discussion of open issues

Concerning the implemented demo, most obvious is the lack of usability. First of all the second window turned out to be rather annoying, it would have been better to include the visualization within the gforth window and record the trace in a standardized data structure in a separate file. Another not yet addressed problem is the scalability of the view, the inefficient use of the screen real estate makes it unusable for very long traces. A possible solution would be to limit the displayed float and data stack depth to a certain number since it is not encouraged to manipulate more than some of the

most upper stack elements. Or limit the depth per word to the number of elements as defined in the stack effect comment. Another improvement would be the implementation of an interactive trace sequence view, like the "massive sequence" view implemented by [CZH⁺08], where in addition nested words as well as the stack state between arbitrary words can be hidden and displayed on demand. The introduction of "watch points" to reduce the visual noise the size of trace file could also address the scale issue. It is also not practical to compare two traces to each other and it is very hard to understand the behavior of large systems. [A visualization of several traces like the massive sequence view where several traces are synchronized by word and differences are visualizes by colors could solve this problem.???might be the same as on long trace for server like software??]

Due to the implementation of the trace recording within the debugger, it is not possible to collect traces of live systems. Neither is performance analysis possible while recording traces/debugging.

- nature of gforth
 - interpretation/compilation mix(how to integrate the adhook changes between modes '[]')
 - implementation within the executing system(??)
 - lack of dynamic information(return stack add -> wordname heuristic)

5.3 further work to be done

- how does software maintenance work in those languages?
- ide
- display of variable content
- display of allocated memory areas
- display of color diff with tooltip of previous values for stacks and memory areas
- (better visualization of loops and control structures) is this even possible?
- (display of the full program as a graph) is this even possible?
- (customizable inspection depth) ?
- type system for forth...see strongforth and the work of greg
- static code analysis
 - v—- see previous chapter —-v
- using a standard data type to store traces

- stack depth per word

TODO: PASST NICHT MEHR

To properly approach the stated problem, the first thing is to understand if and when program understanding is required. Although intuitively obvious, this section will discuss both, since the approach which developers use to understand programs, can be very different during the life cycle of software. Next, the means of understanding programs itself is investigated. Third, the nature of concatenative languages and in particular gforth/forth will be investigated.

kind of an ide development environment

light table ide(js) continuous reverse engineering idea of [MJS⁺00] to provide immediate response of the systems output... although probably not applicable or very time consuming in setup(or not more than integration testing...) for most industrial scale software
eclipse ide(java)

conclusion like what i contributed to the community!!

5.4 further reading

work on program comprehension of concatenative languages good overview of the field [CDPC11] and [Cor09]

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