

# Development of an Educational Tool for ReTI as a VS Code Extension

Bachelorproject for the B. Sc. Informatik at University of Freiburg

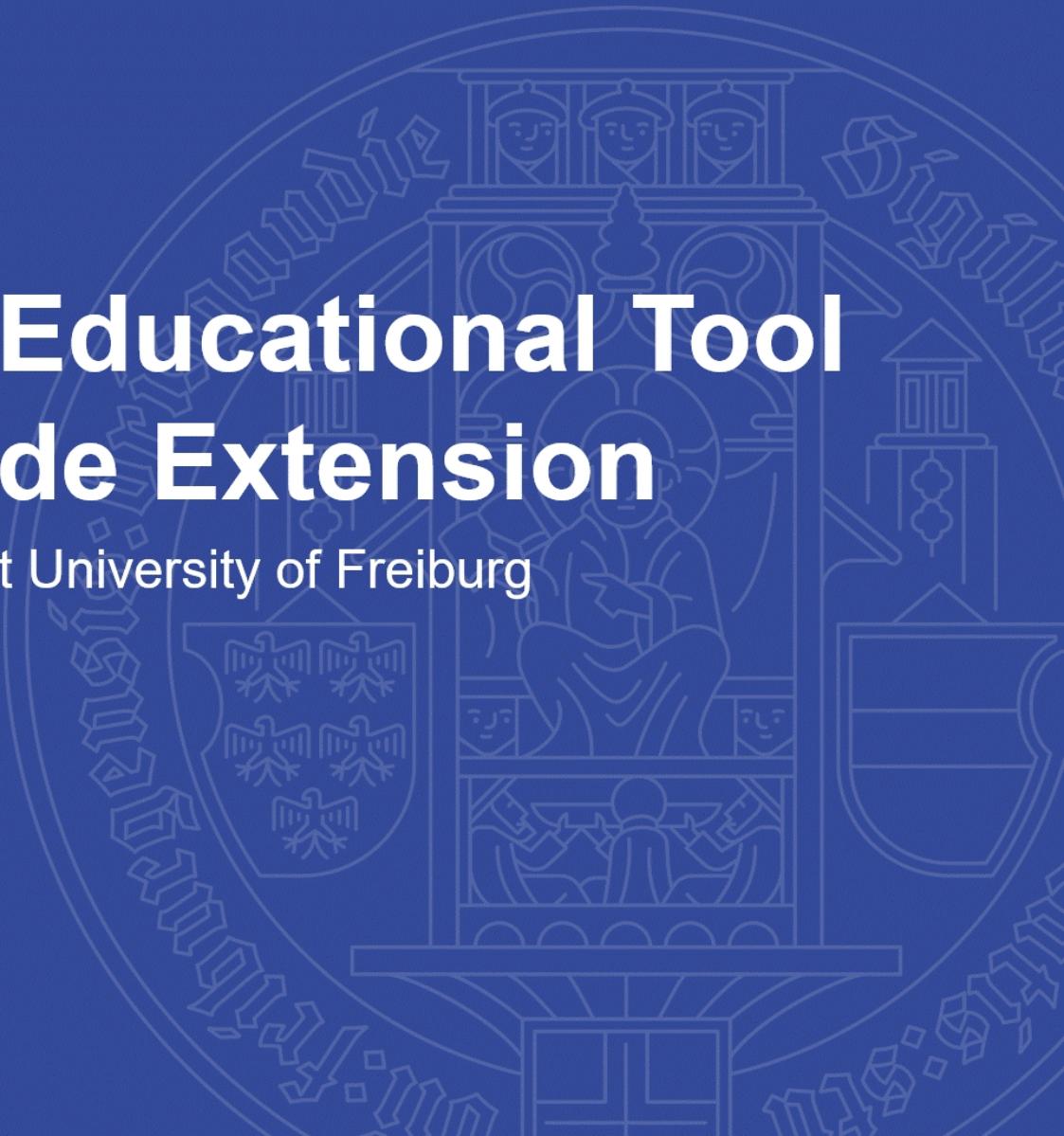
Presenter: Malte Pullich

Chair of Computer Architecture

Examiner: Prof. Dr. Armin Biere

Adviser: M. Sc. Tobias Faller

Freiburg, 16.07.2025



# Agenda

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- 1. Motivation:** State of the Art and Usage
- 2. Background:** ReTI Architecture and Language
- 3. Approach:** Improving on Interactivity and Adding Features
- 4. Results:** Improvement on existing Features, new Features
- 5. Conclusion:** Goals Reached & Future Work

# Motivation

```
root@Malte-Laptop:/mnt/c/BachelorprojektBiere/reticode# vim mul.reti
root@Malte-Laptop:/mnt/c/BachelorprojektBiere/reticode# ./asreti mul.reti | ./emreti -s
STEPS   PC      CODE     IN1      IN2      ACC      INSTRUCTION ACTION
1       00000000 71000001 00000000 00000000 00000000 LOADI IN1 1  IN1 = 0x1
2       00000001 72000001 00000001 00000000 00000000 LOADI IN2 1  IN2 = 0x1
3       00000002 bb000000 00000001 00000001 00000000 MOVE IN2 ACC ACC = IN2 = 0x1
4       00000003 f000000a 00000001 00000001 00000001 JUMP<= 10  no jump as 1 = [0x1] = ACC > 0
5       00000004 b7000000 00000001 00000001 00000001 MOVE IN1 ACC ACC = IN1 = 0x1
6       00000005 2f000001 00000001 00000001 00000001 ADD ACC 1  ACC = ACC + M(<0x1>) = ACC + [0x0] = 1 + 0 = 1 = [0x1]
emreti: warning: continuing after reading uninitialized 'data[0x1]' (use '-i' so squelch such messages, or '-g' to stop)
7       00000006 80000001 00000001 00000001 00000001 STORE 1  M(<1>) = M(0x1) = 0x1
8       00000007 43000000 00000001 00000001 00000001 LOAD ACC 0  ACC = M(<0x0>) = M(0x0) = 0x0
emreti: warning: continuing after reading uninitialized 'data[0x0]' (use '-i' so squelch such messages, or '-g' to stop)
9       00000008 0f000001 00000001 00000001 00000000 ADDI ACC 1  ACC = ACC + [0x1] = 0 + 1 = 1 = [0x1]
10      00000009 80000000 00000001 00000001 00000001 STORE 0  M(<0>) = M(0x0) = 0x1
11      0000000a bb000000 00000001 00000001 00000001 MOVE IN2 ACC ACC = IN2 = 0x1
12      0000000b 2b000000 00000001 00000001 00000001 SUB ACC 0  ACC = ACC - M(<0x0>) = ACC - [0x1] = 1 - 1 = 0 = [0x0]
13      0000000c f8fffff7 00000001 00000001 00000000 JUMP -9  PC = PC + [0xfffffff7] = 12 - 9 = 3 = 0x3
14      00000003 f000000a 00000001 00000001 00000000 JUMP<= 10  PC = PC + [0xa] = 3 + 10 = 13 = 0xd as 0 = [0x0] = ACC <= 0
15      0000000d f8000000 00000001 00000001 00000000 JUMP 0    PC = PC + [0x0] = 13 + 0 = 13 = 0xd
15      0000000d f8000000 00000001 00000001 00000000 <infinite-loop>
ADDRESS  DATA     BYTES    ASCII    UNSIGNED      SIGNED
00000000 00000001 01 00 00 00 ....      1          1
00000001 00000001 01 00 00 00 ....      1          1
```

Fig. 1: Screenshot of running an example ReTI-Program with Emulator by Prof. Dr. Biere [1]

**Goal:** Improve accessibility and responsiveness to provide a better educational experience.

# ReTi-Architecture

```
JUMP<= 12
  LOAD IN1 2
  LOAD ACC 3
  STORE 2
  ADD IN1 3
  MOVE IN1 ACC
  STORE 3
  ADDI ACC 1
  STORE 1
; Check if i <
  LOAD ACC 0
  SUB ACC 1
JUMP -11
NOP
```

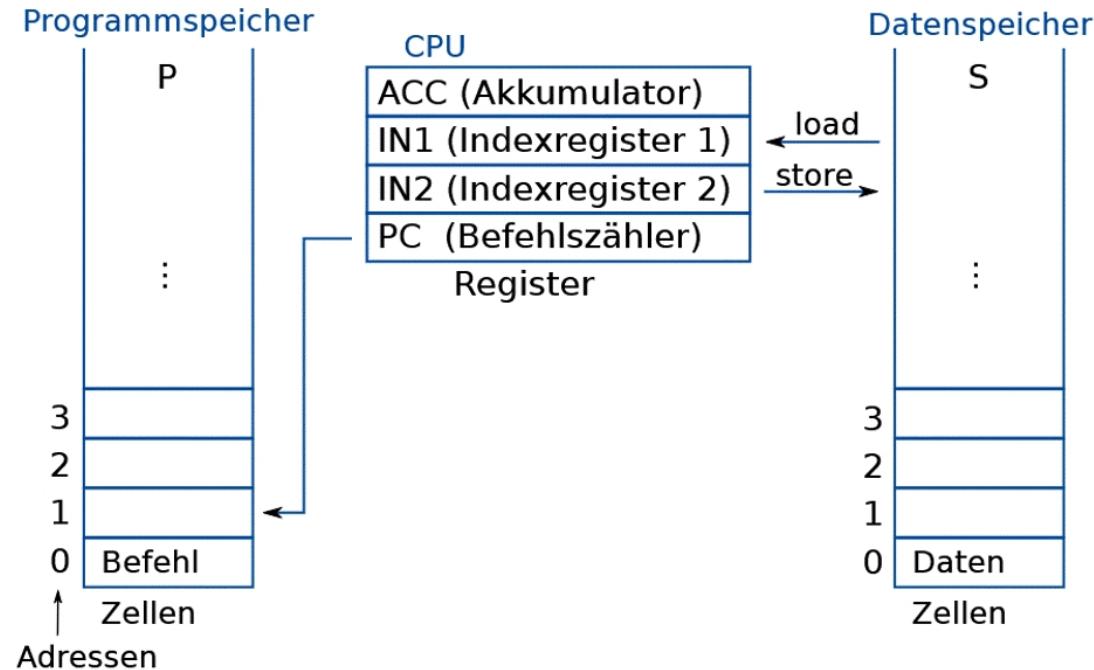


Fig: 2 Excerpt of a ReTI example program that calculates the Fibonacci number of 5

Fig 3: ReTI architecture [2]

# Approach

**Goal:** Improve accessibility and responsiveness to provide a better educational experience.

**Build upon current features:**

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- Rebuild a Website for the Quiz

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- VS Code Extension API

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- Most used IDE

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- VS Code Extension API
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- VS Code Webview → Easy integration of Quiz-Website

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- Integrate Emulator, Assembler, Disassembler

# Approach

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### Quiz:

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- Add Explanation to Result for each Question

## Additional features:

### Implement as VS Code Extension:

- VS Code Extension API
- Most used IDE
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## Additional features:

### Debugger:

- Improves programming flow
- Enables experimentation
- Microsoft Debug-Adapter-Protocol

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## Additional features:

### Debugger:

- Improves programming flow
- Enables experimentation
- Microsoft Debug-Adapter-Protocol

### Language Server:

- Syntax Highlighting, Inline errors, Tooltips
- Microsoft Language-Server-Protocol

# Results

## Integration of Old Features

```
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eti
root@Malte-Laptop:/mnt/c/BachelorprojektBiere/retilode# ./asreti
mul.reti | ./emreti -s
STEPS PC      CODE   IN1    IN2    ACC    INSTRUCTION
 ACTION
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C ACC = IN2 = 0x1
4     00000003 f000000a 00000001 00000001 00000001 JUMP<= 10
no jump as 1 = [0x1] = ACC > 0
5     00000004 b7000000 00000001 00000001 00000001 MOVE IN1 AC
C ACC = IN1 = 0x1
6     00000005 2f000001 00000001 00000001 00000001 ADD ACC 1
ACC = ACC + M(<0x1>) = ACC + [0x01] = 1 + 0 = 1 = [0x1]
```

Fig 3: Example Usage of the ReTI Emulation by Prof. Dr. Biere [1]

```
15     0000000d f8000000 00000001 00000001 00000000 JUMP 0
PC = PC + [0x0] = 13 + 0 = 13 = 0xd
15     0000000d f8000000 00000001 00000000 <infinite-loop>
ADDRESS DATA    BYTES   ASCII  UNSIGNED   SIGNED
00000000 00000001 01 00 00 00 ....      1       1
00000001 00000001 01 00 00 00 ....      1       1
```

Fig 4: Output of the ReTI Emulation by Prof. Dr. Biere [1]

```
mul.reti x Emulate Ctrl+Alt+E
mul.reti
1 ; A simple multiplication routine
2 ; Initialize m and n
3 LOADI IN1 9 ; Initialize m and save in IN1
4 LOADI IN2 10 ; Initialize n and save in IN2
5 ; Result will be stored in M<1>, Expected: 90
6 MOVE IN2 ACC
7
8 ; i will be stored in M<0>
9 ; LOOP
10 JUMP<= 10
11 MOVE IN1 ACC ; ACC = m
12 ADD ACC 1 ; ACC := m + m * (i - 1)
13 STORE 1
14 ; Increasing the counter variable
15 LOAD ACC 0 ; ACC := i
16 ADDI ACC 1
17 STORE 0
18 MOVE IN2 ACC ; ACC := IN2 := n
19 SUB ACC 0 ; ACC := n - i
20 JUMP -9
21 JUMP 0
```

Fig 5: Example Usage of the ReTI Emulation in VS Code

Emulation finished.

PC: 20

IN1: 5

IN2: 3

ACC: 268435455

Data:

0: 73000005

1: 80000000

2: 73000002

3: 80000001

4: 73000001

5: 80000003

6: 72000003

7: f000000c

8: 41000002

9: 43000003

10: 80000002

11: 2d000003

12: 17000000

Fig 3: Output of Emulation in VS Code

# Results

## Integration of Old Features - Quiz

```
ReTI Machine Code Quiz Version 0.0.3-rc.3
retiquiz 6974014193005616977 16
Enter hexadecimal digits as an answer or
space ' ' to skip a question or 'q' to qui
t.
For irrelevant '*' in the machine code use
'0'.
Asking 16 questions.
INSTRUCTION ; PC CODE
LOADIN1 PC 10 ; 00000000 5000000a ✓
SUB IN1 -18 ; 00000001 29fffffe X
    expected e in 29fffffe at I[7:4]
STORE 8 ; 00000002 80000000
```

Fig 6: Screenshot of the old ReTI Quiz opened in Terminal

The screenshot shows the ReTI Quiz extension running in the Visual Studio Code interface. The title bar indicates the file is named "mul.reti" and the extension is "ReTI Quiz". The main area is titled "ReTI Quiz" with a lightbulb icon. It displays a table of 5 questions:

Code	Hexadecimal	Result	Action
LOADI IN2 13	7F00000D	✗	Check
LOADIN2 IN1 6	61000006	✓	Check
JUMPz 6	D8000006	✓	Check
LOADI ACC 8	73000_08		Check
STOREIN1 12	_000000C		Check

Below the table, there is an "Explanation:" section with the message "Incorrect! The correct value was: 2." A detailed assembly table is shown:

Type	Mode	*	Destination	Immediate
LOAD	I		IN2	13
0	1	1	0	0
			1	0
				000000000000000000000000000000001101
		7	2	00000D
				LOADI IN2 13

Fig 7: Screenshot of the new ReTI Quiz opened in VS Code

# Results

## New Features – Language Server

```
5      MOVE
6      Usage: MOVE S D
7      ; i
8      ; LO
9      JUMP Moves content of the first register to the second register.
10
11     MOVE IN1 ACC    ; ACC = m
12     ADD ACC 1       ; ACC := m + m * (i - 1)
13     STORE -5        Immediate will be treated as unsigned. Negative numbers might not be
14     ; Increasing the counter variable
15     LOAD ACC 0      ; ACC := i
16     ADDI ACC 1
17     STORE ACC 0      Too many operands. STORE instruction only takes one operand.
18     JU      Unknown instruction JU.
19     MO ↗ JUMP
20     SU ↗ JUMP<
21     JUMP - ↗ JUMP=
22     JUMP 0 ↗ JUMP>
          ↗ JUMP≠
          ↗ JUMP≤
          ↗ JUMP≥
```

JUMP i  
Increases the program counter

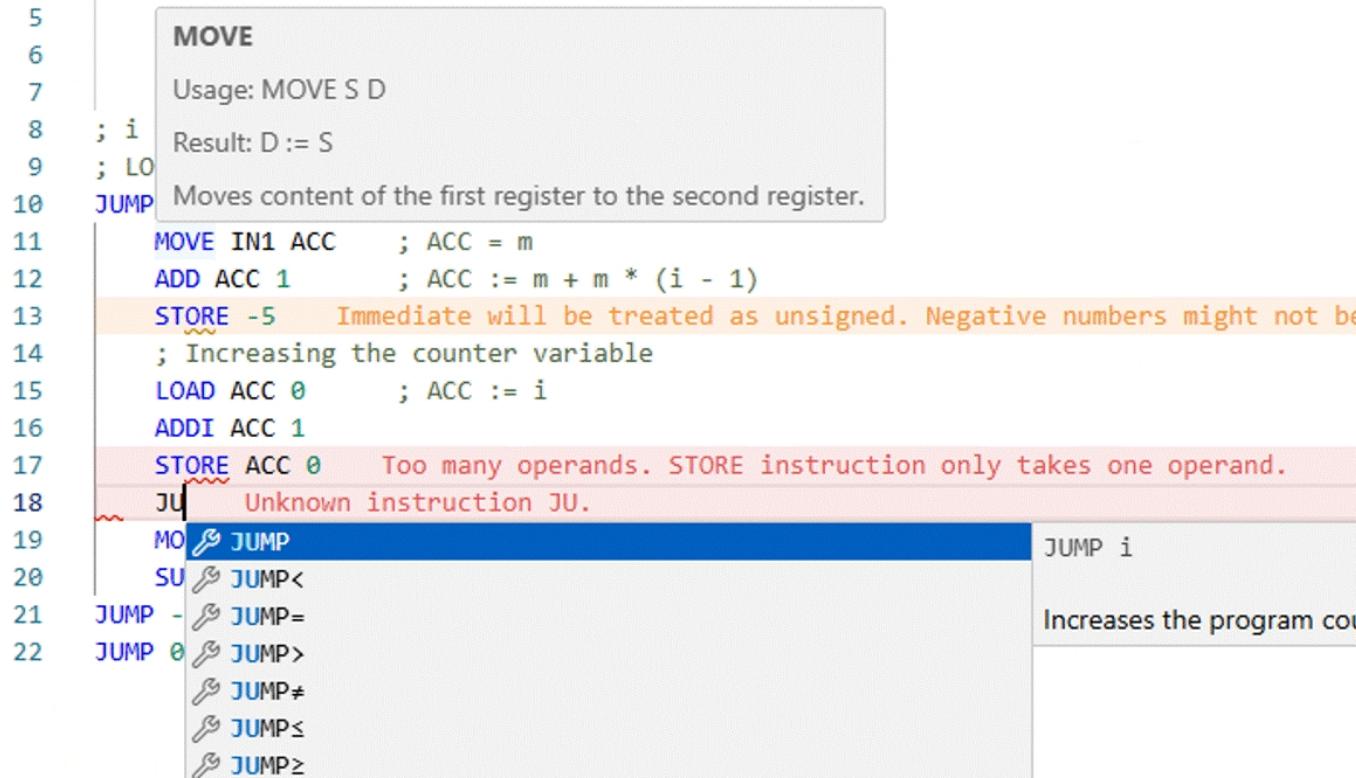
A screenshot of a code editor in VS Code demonstrating Language Server Protocol (LSP) features. The code is written in a assembly-like language. Several lines of code are highlighted with different colors: blue for instructions like MOVE, ADD, and STORE, green for comments, and red for errors (e.g., 'Too many operands'). Tooltips are shown above some lines, such as 'Immediate will be treated as unsigned. Negative numbers might not be' for the STORE instruction at line 13. A completion dropdown is open at the bottom of the editor, showing various jump instructions starting with 'JUMP' and their corresponding symbols (e.g., >, <, =, ≠, ≤, ≥). The tooltip for 'JUMP i' indicates it 'Increases the program counter'.

Fig 8: Screenshot from VS Code highlighting LSP Features

### Features:

- Syntax Highlighting
- Tooltips
- Realtime compilation and checking
- Autocomplete suggestions

# Results

## New Features – Debugger

The screenshot shows a debugger interface for a ReTI assembly program named `fibonacci.reti`. The assembly code is as follows:

```
1 ; Initialization
2 LOADI ACC 5      ; Initiate n = 5, Expected result in M<3> = F(5) = 5
3 STORE 0          ; Store n in M<0>
4 LOADI ACC 2      ; Initiate i = 2 since F(0) = 0, F(1) = 1
5 STORE 1          ; Store i in M<1>
6 ; F(n-1) will be stored in M<2>, since its 0 no intialization is needed
7 ; F(n) will be stored in M<3>
8 LOADI ACC 1
9 STORE 3
10 LOADI IN2 3     ; IN2 will save the offset for the used variables
11
12 ; LOOP
13 JUMP<= 12       ; Skip over the loop if n - i <= 0, meaning i > 0
14 LOAD IN1 2       ; LOAD F(n-1) into IN1
15 LOAD ACC 3       ; LOAD F(n) into IN1
16 STORE 2          ; store F(n) in M<2> since in the next iteration it is F(n-1)
17 ADD IN1 3        ; calculate F(n+1)
18 MOVE IN1 ACC ;
19 STORE 3          ; M<3> now holds F(n+1) which in the next iteration will be F(n)
20 ADDI ACC 1        ; increase i
21 STORE 1          ; STORE new value of i in M<1>
22 ; Check if i < n for JUMP condition
23 LOAD ACC 0
24 SUB ACC 1        ; ACC = n - M<1> = n - i, will be positive as long as n > i
25 JUMP -11         ; JUMP back to the start of the loop
26 NOP
27 JUMP 0
```

The left sidebar displays the **VARIABLES** and **WATCH** panes. The **VARIABLES** pane shows register values: `ACC = 2`, `IN1 = 2`, `IN2 = 3`, and `PC = 18`. The **WATCH** pane shows memory locations: `0 = 5`, `1 = 3`, `2 = 1`, `3 = 2`, and `4 = 0`. The assembly code window has a toolbar at the top with icons for step, run, and breakpoints.

Fig 9: Screenshot of running ReTI-Debug session

### Features:

- Reading and writing register values
- Reading memory
- Breakpoints
- Stepping

# Results

## New Features – Debugger, Stepping

fibonacci.reti

The screenshot shows a debugger interface with assembly code for calculating the nth Fibonacci number. The code uses registers ACC, IN1, and IN2, and memory locations M<0>, M<1>, and M<2>. The assembly instructions include LOADI, STORE, ADDI, MOVE, and JUMP. A tooltip provides comments for each instruction. The code starts with initialization, enters a loop where it calculates F(n) based on F(n-1) and F(n), increments i, and checks if i < n to continue the loop. The assembly code is as follows:

```
1 ; Initialization
2     LOADI ACC 5      ; Initiate n = 5, Expected result in M<3> = F(5) = 5
3     STORE 0          ; Store n in M<0>
4     LOADI ACC 2      ; Initiate i = 2 since F(0) = 0, F(1) = 1
5     STORE 1          ; Store i in M<1>
6     ; F(n-1) will be stored in M<2>, since its 0 no intialization is needed
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18    MOVE IN1 ACC
19    STORE 3          ; M<3> now holds F(n+1) which in the next iteration will be F(n)
20    ADDI ACC 1        ; increase i
21    STORE 1          ; STORE new value of i in M<1>
22    ; Check if i < n for JUMP condition
23    LOAD ACC 0
24    SUB ACC 1        ; ACC = n - M<1> = n - i, will be positive as long as n > i
25    JUMP -11          ; JUMP back to the start of the loop
26    NOP
```

Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

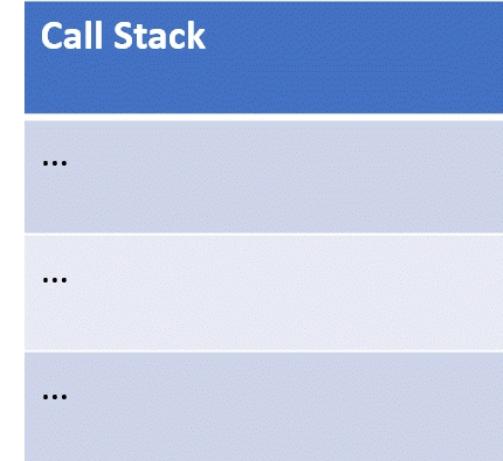


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti

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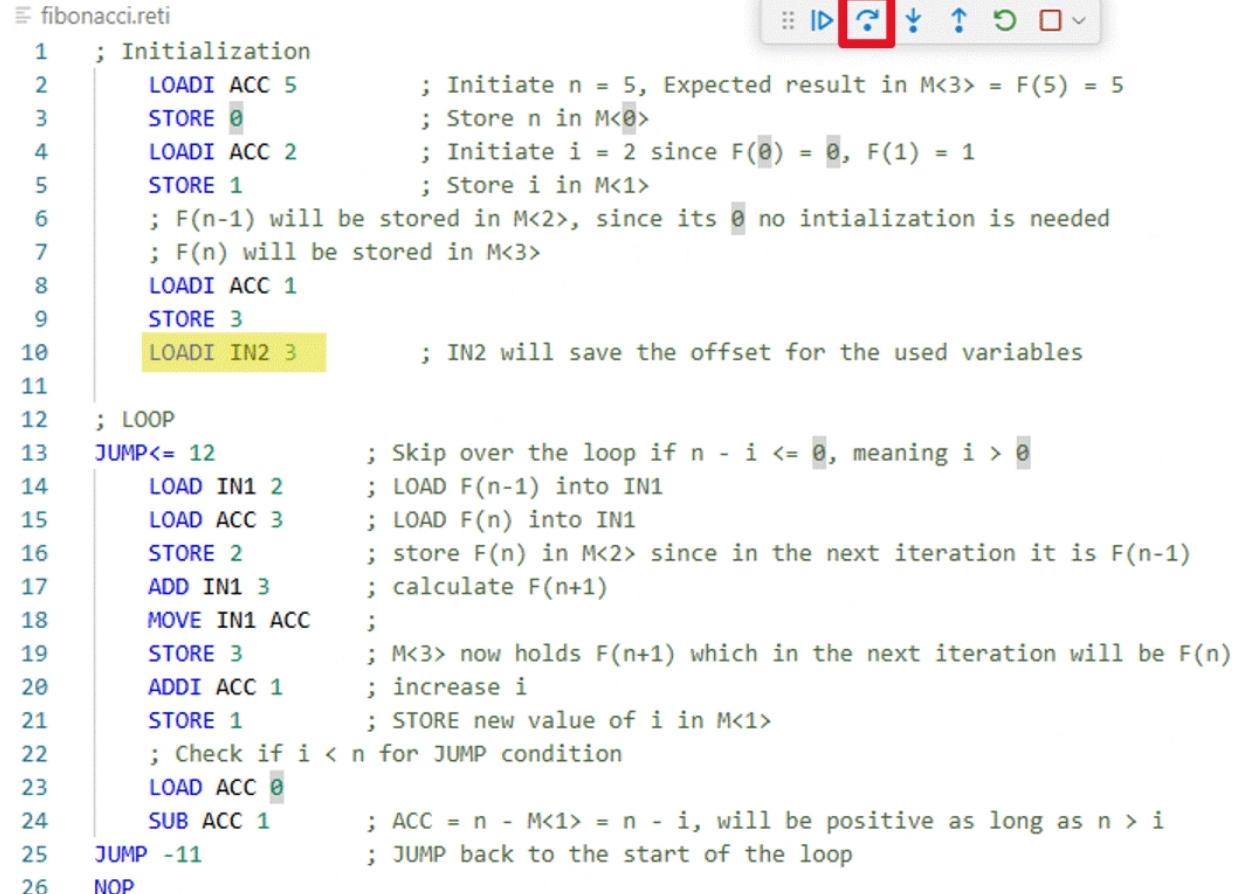


Fig. 10: Screenshot of running ReTI-Debug session

## Call Stack

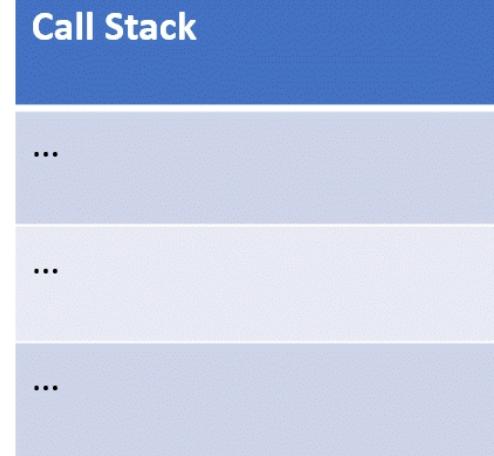
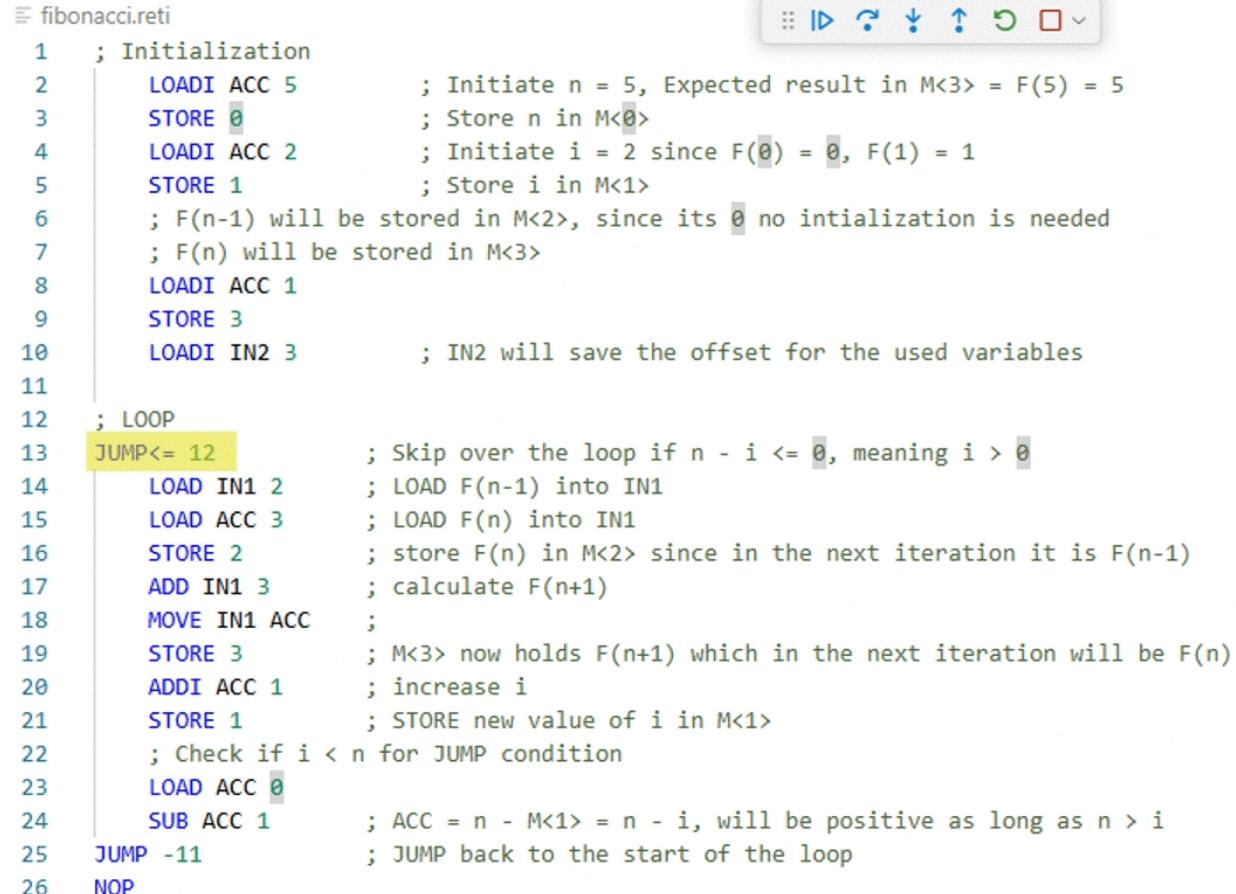


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fibonacci.reti



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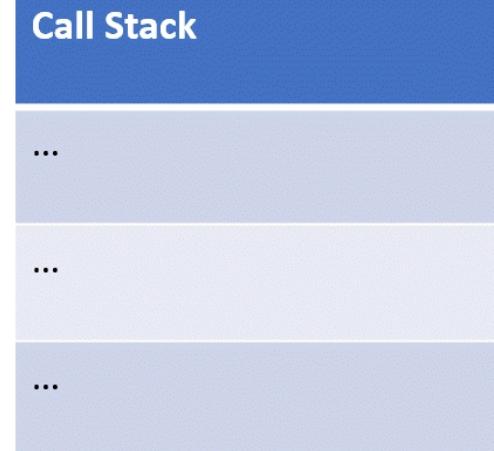


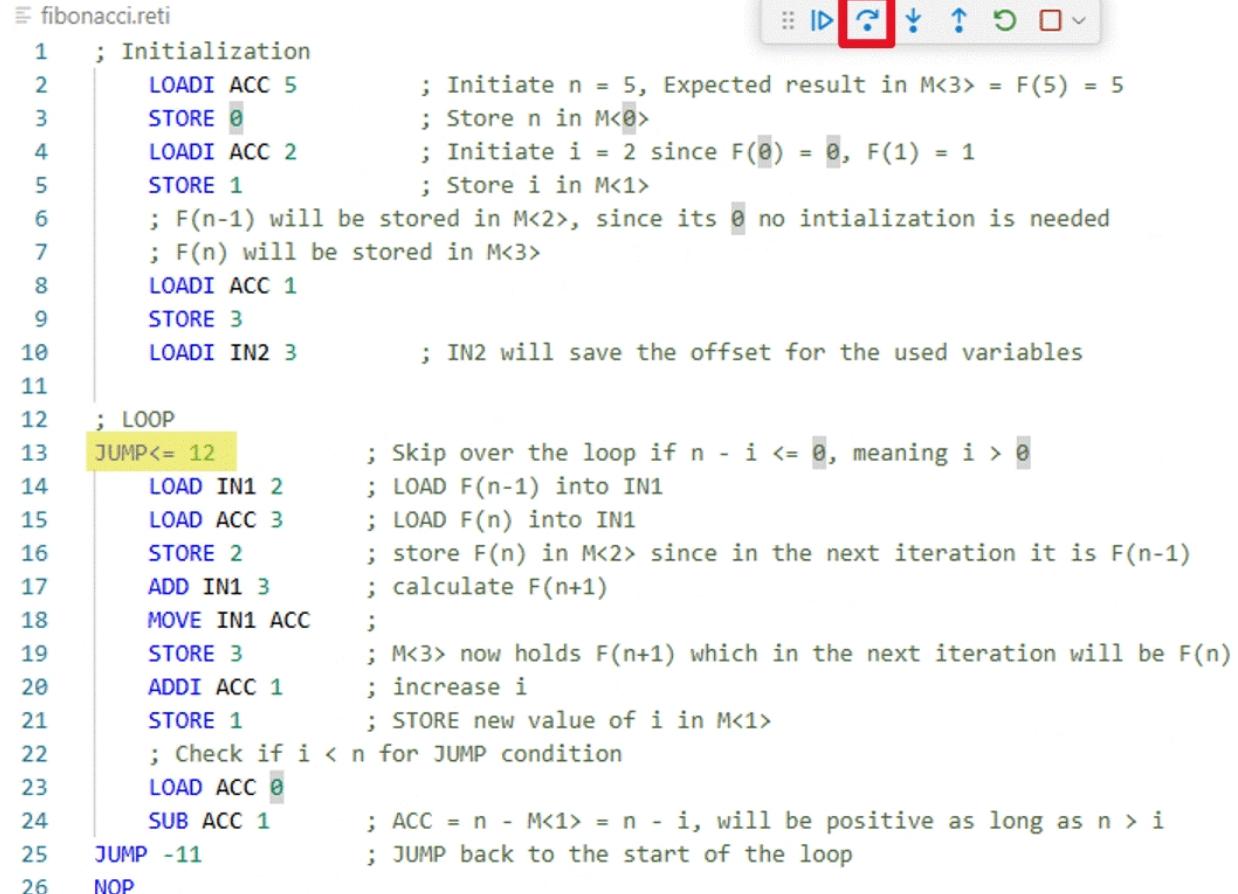
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## New Features – Debugger, Stepping

fibonacci.reti

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```



The screenshot shows a debugger interface with a toolbar at the top containing several icons: play, step, break, and others. The assembly code for the fibonacci.reti program is displayed below the toolbar. Line 13, 'JUMP<= 12', is highlighted with a yellow background. The code implements the Fibonacci sequence calculation using a loop and accumulators.

Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

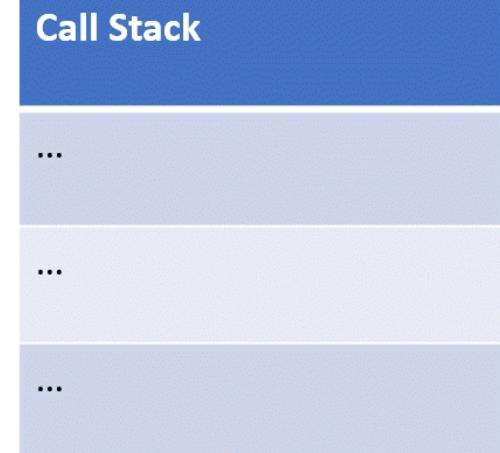
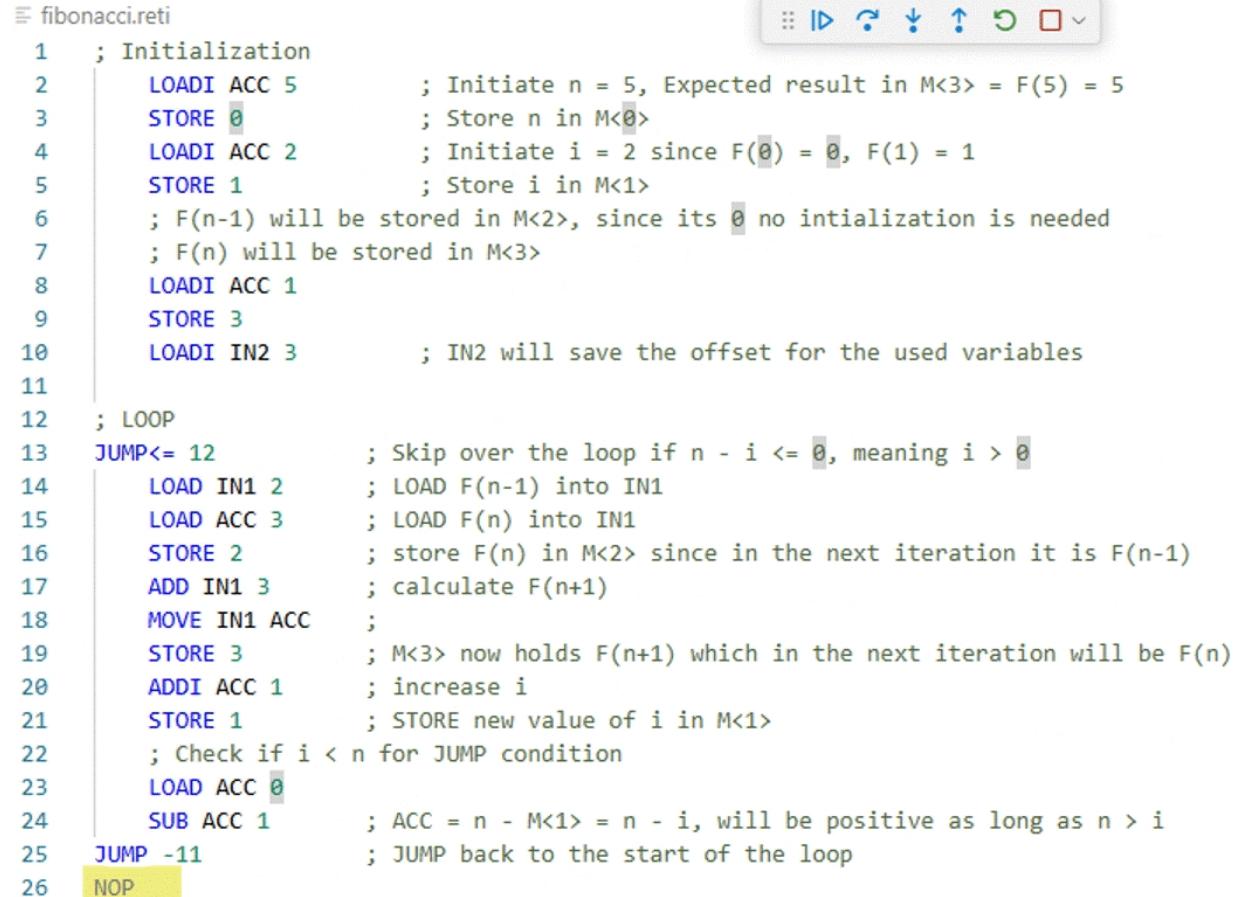


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fibonacci.reti



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24 SUB ACC 1        ; ACC = n - M<1> = n - i, will be positive as long as n > i
25 JUMP -11         ; JUMP back to the start of the loop
26 NOP
```

Fig. 10: Screenshot of running ReTI-Debug session

## Call Stack

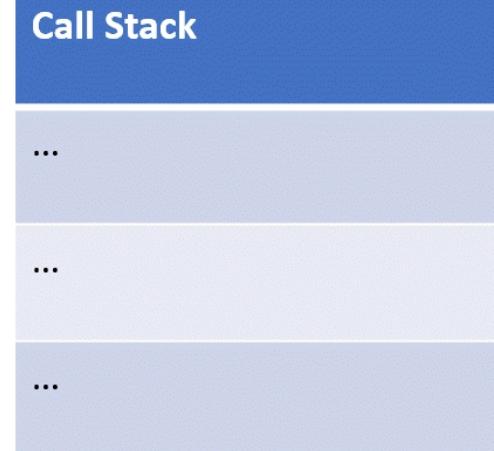


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti

The screenshot shows a debugger interface with assembly code for calculating the nth Fibonacci number. The code uses registers ACC and IN1, and memory locations M<0>, M<1>, and M<2>. It initializes n=5, i=2, and stores intermediate results in M<0> and M<1>. A loop calculates F(n) by adding F(n-1) and F(n-2), then stores the result in M<2>. The loop condition checks if i < n. The code ends with a NOP instruction.

```
1 ; Initialization
2      LOADI ACC 5      ; Initiate n = 5, Expected result in M<3> = F(5) = 5
3      STORE 0          ; Store n in M<0>
4      LOADI ACC 2      ; Initiate i = 2 since F(0) = 0, F(1) = 1
5      STORE 1          ; Store i in M<1>
6      ; F(n-1) will be stored in M<2>, since its 0 no intialization is needed
7      ; F(n) will be stored in M<3>
8      LOADI ACC 1
9      STORE 3
10     LOADI IN2 3      ; IN2 will save the offset for the used variables
11
12 ; LOOP
13 JUMP<= 12          ; Skip over the loop if n - i <= 0, meaning i > 0
14     LOAD IN1 2        ; LOAD F(n-1) into IN1
15     LOAD ACC 3        ; LOAD F(n) into IN1
16     STORE 2          ; store F(n) in M<2> since in the next iteration it is F(n-1)
17     ADD IN1 3         ; calculate F(n+1)
18     MOVE IN1 ACC
19     STORE 3          ; M<3> now holds F(n+1) which in the next iteration will be F(n)
20     ADDI ACC 1        ; increase i
21     STORE 1          ; STORE new value of i in M<1>
22     ; Check if i < n for JUMP condition
23     LOAD ACC 0
24     SUB ACC 1        ; ACC = n - M<1> = n - i, will be positive as long as n > i
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26 NOP
```

Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

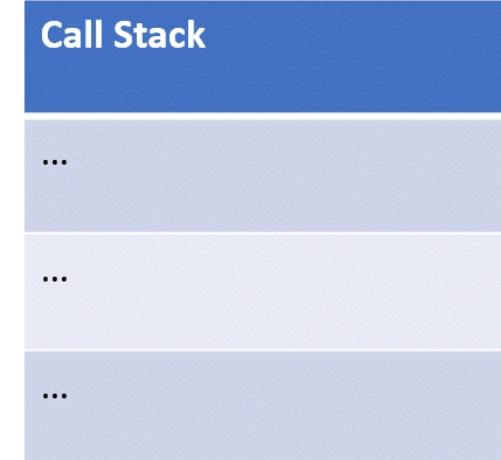
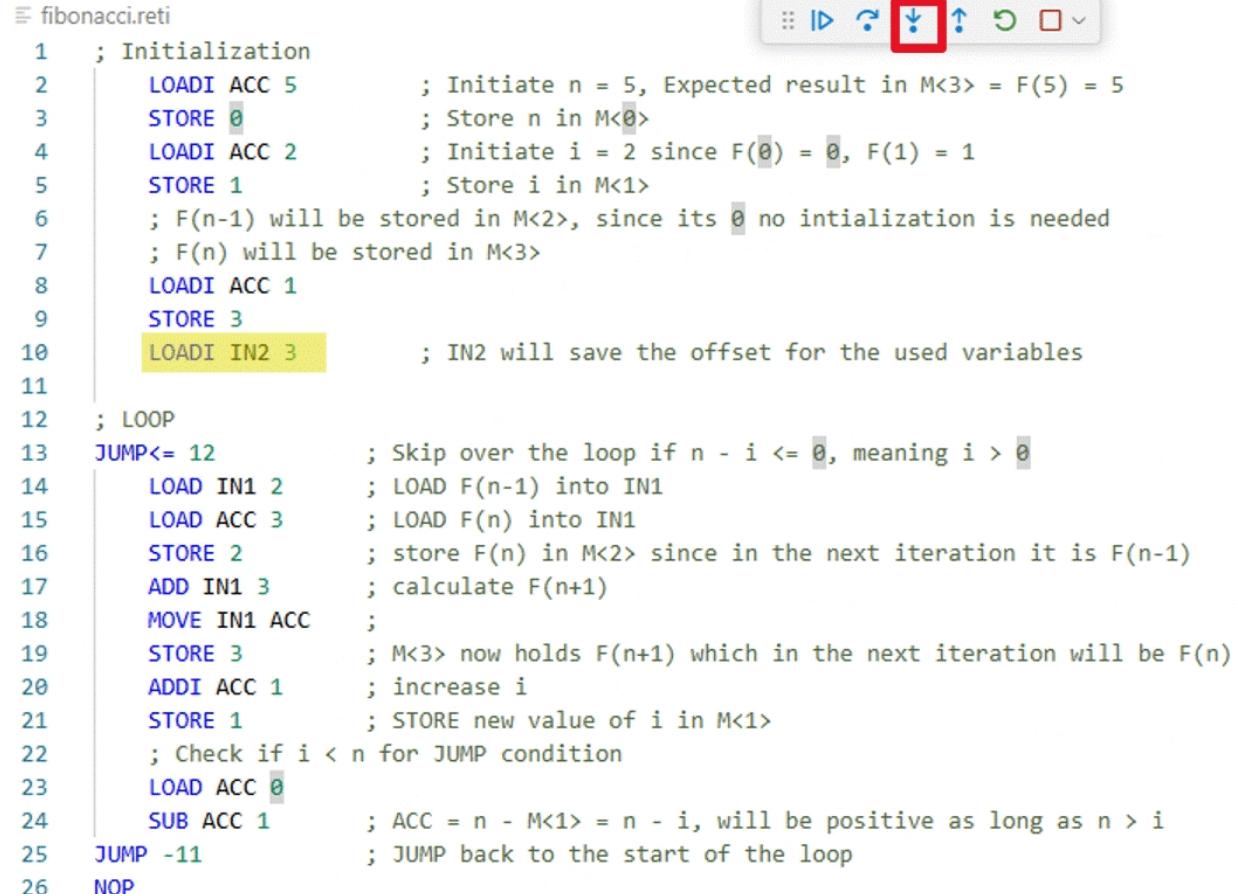


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti



The screenshot shows a debugger interface with the file "fibonacci.reti" open. The assembly code is as follows:

```
1 ; Initialization
2 LOADI ACC 5      ; Initiate n = 5, Expected result in M<3> = F(5) = 5
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4 LOADI ACC 2      ; Initiate i = 2 since F(0) = 0, F(1) = 1
5 STORE 1          ; Store i in M<1>
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7 ; F(n) will be stored in M<3>
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17 ADD IN1 3         ; calculate F(n+1)
18 MOVE IN1 ACC      ;
19 STORE 3          ; M<3> now holds F(n+1) which in the next iteration will be F(n)
20 ADDI ACC 1        ; increase i
21 STORE 1          ; STORE new value of i in M<1>
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25 JUMP -11         ; JUMP back to the start of the loop
26 NOP
```

The toolbar at the top right includes icons for step, run, and other debugger functions. Line 10, "LOADI IN2 3", is highlighted with a yellow background.

Fig. 10: Screenshot of running ReTI-Debug session

## Call Stack

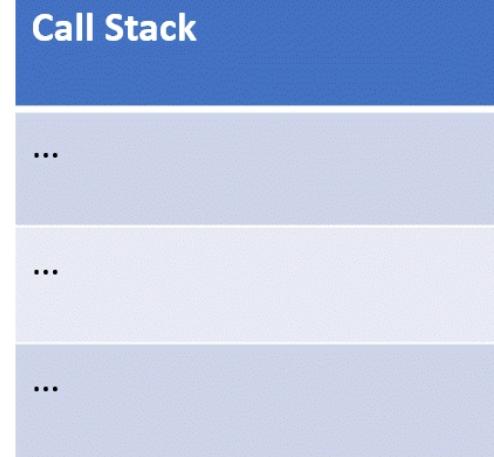


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti

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Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

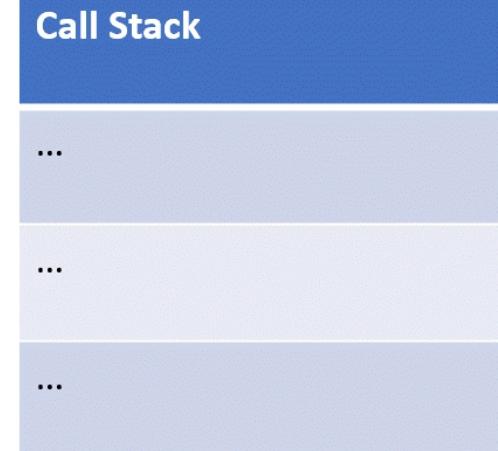
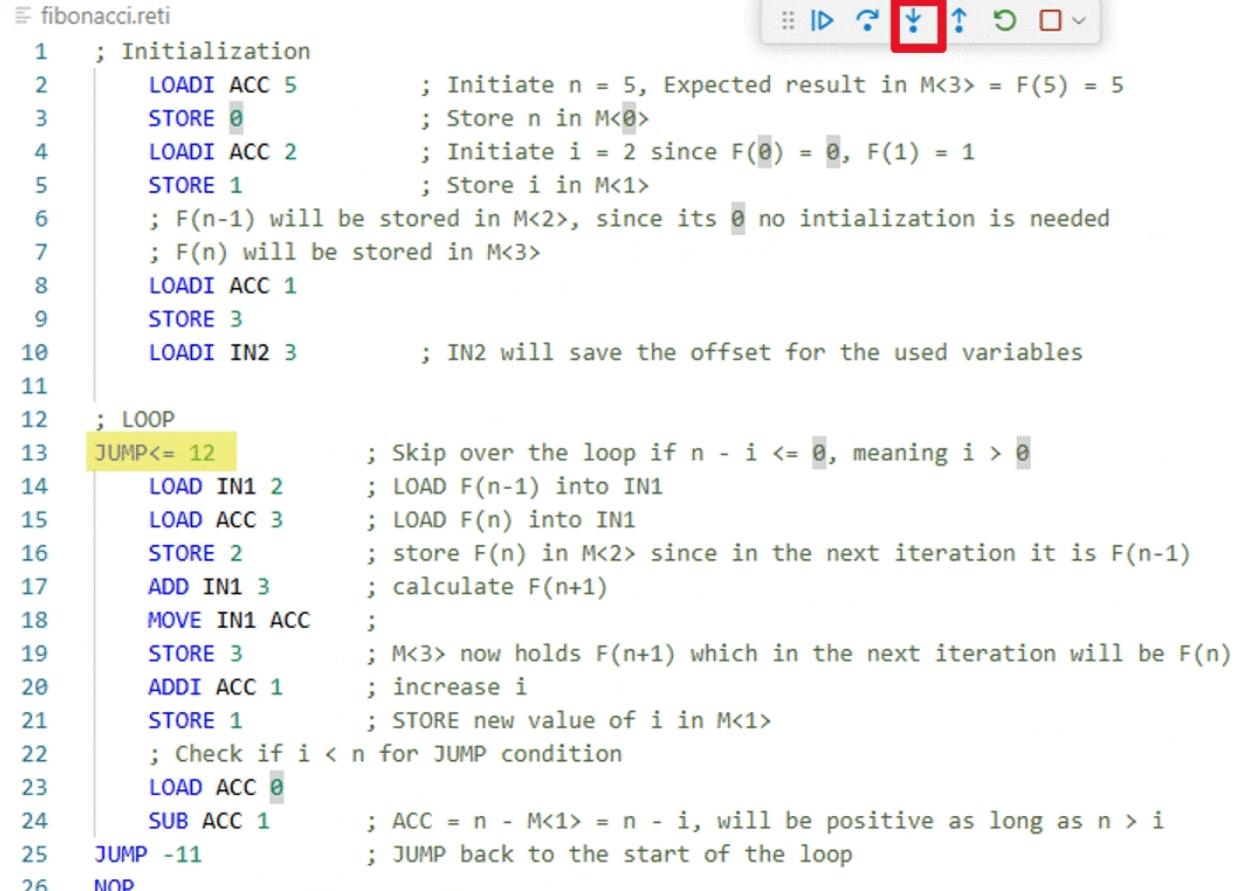


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti



The screenshot shows a debugger interface with the file "fibonacci.reti" open. The assembly code is as follows:

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25 JUMP -11         ; JUMP back to the start of the loop
26 NOP
```

The toolbar at the top right includes icons for step, run, and other debugger functions. The line number 13 is highlighted with a yellow background.

Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

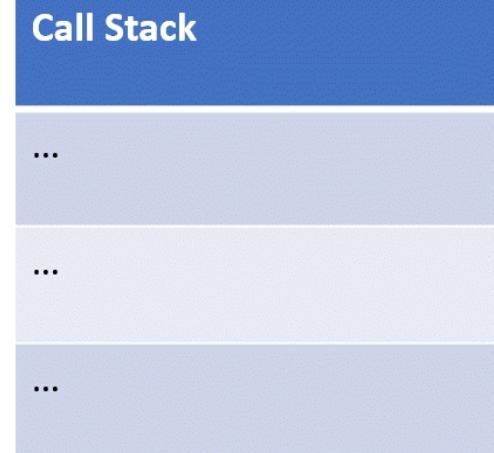


Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

fibonacci.reti

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Fig. 10: Screenshot of running ReTI-Debug session

## Call Stack

19

...

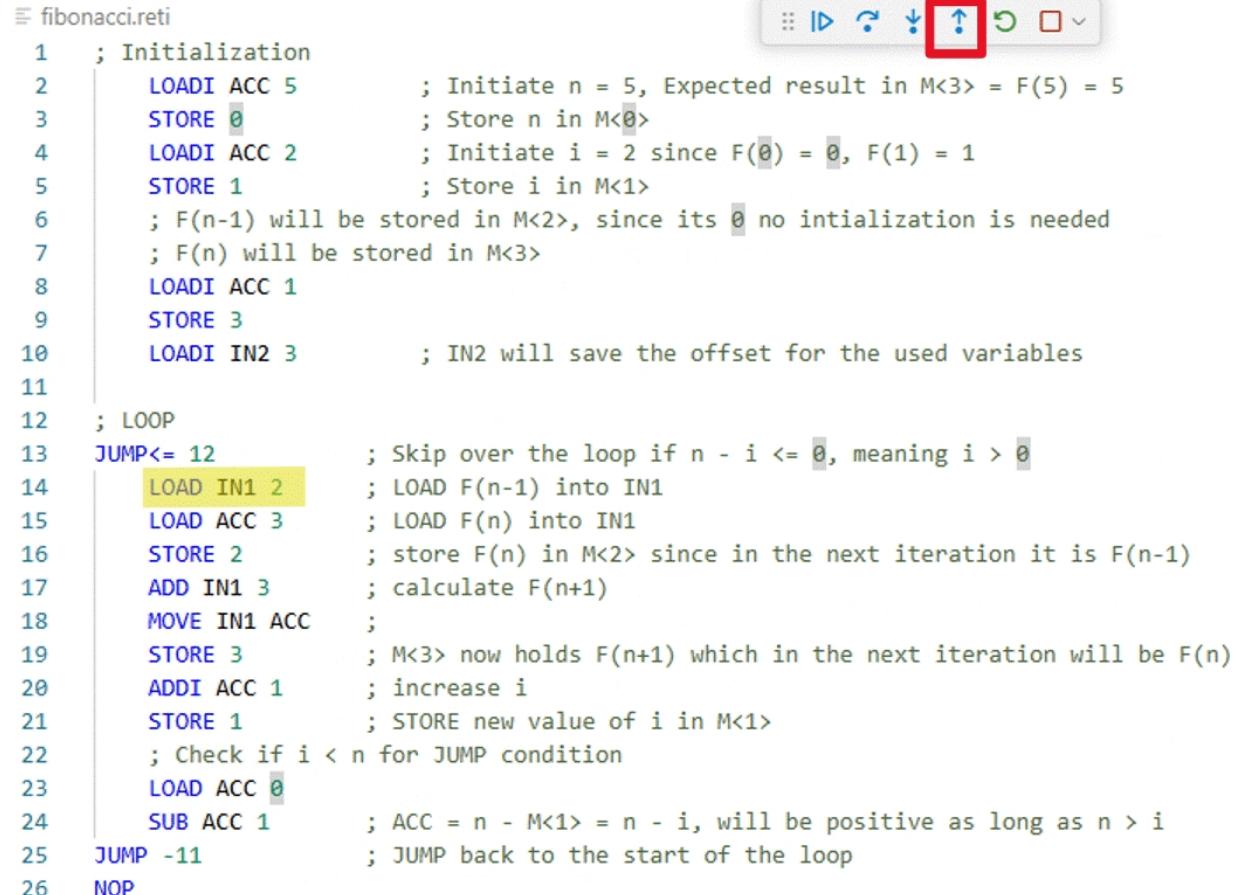
...

Fig. 3: Visual representation of the call stack

# Results

## New Features – Debugger, Stepping

```
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The screenshot shows a debugger interface with assembly code for calculating Fibonacci numbers. The toolbar at the top includes icons for step, run, and other debugger functions. A red box highlights the step-up arrow icon.

Fig. 10: Screenshot of running ReTI-Debug session

## Call Stack

19

...

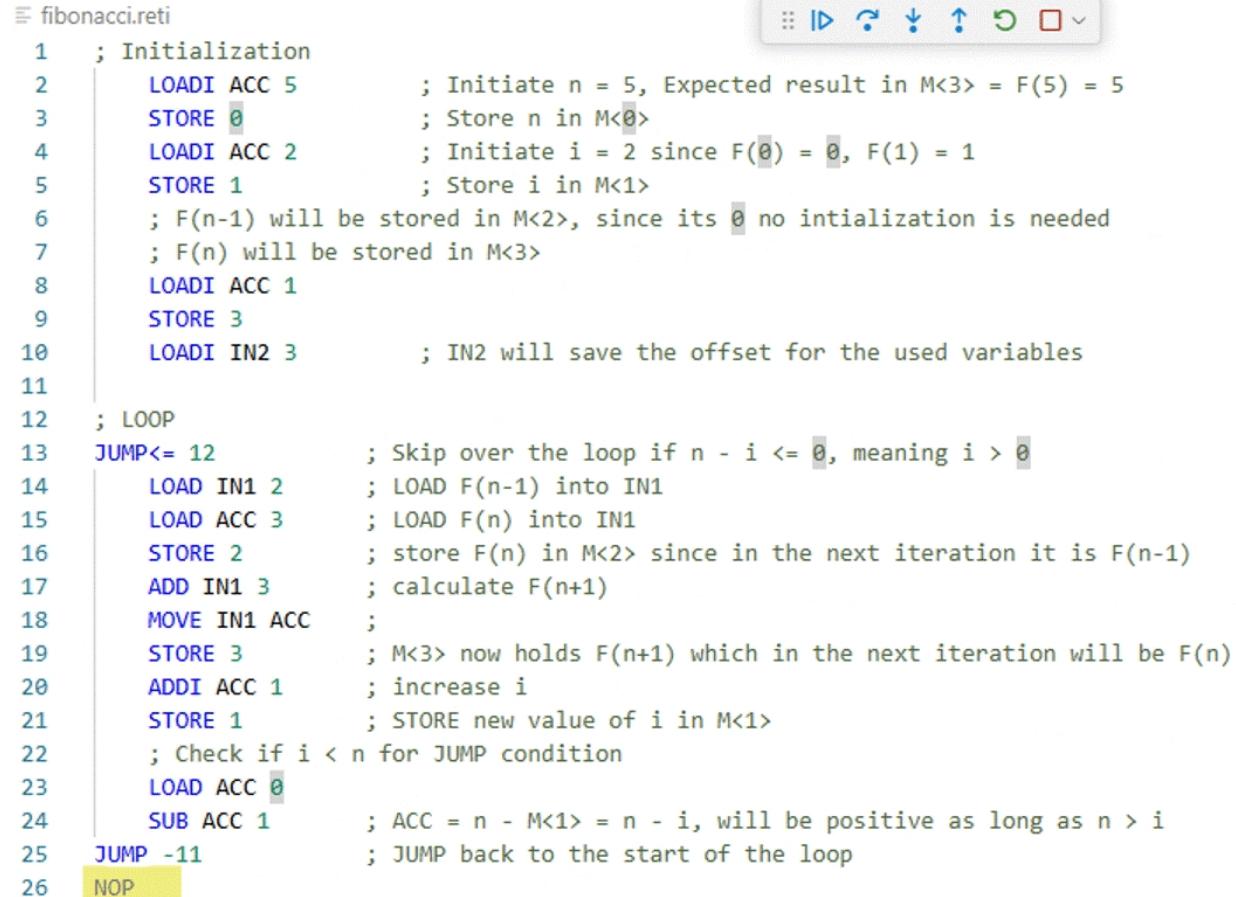
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```

Fig. 10: Screenshot of running ReTI-Debug session

Call Stack

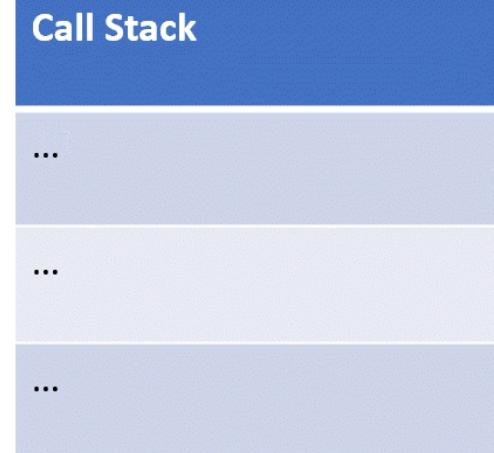


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# Conclusion

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- Quiz more accessible both as website and in the extension

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# Conclusion

## Goals Reached

- Quiz more accessible both as website and in the extension
- More Feedback in Quiz
- All features (Assembler, Quiz, Emulator, RanReTi, Disassembler) accessible through extension
- Extension provides familiar programming workflow
- Debugger and Language Server offer
  - Syntax Highlighting
  - Realtime Compilation
  - Code Completion Suggestions
  - Executing Code and Inspecting/Manipulating ReTI State

# Conclusion

## Limitations & Future Work

- **Improve Memory View:**
  - Using “watch expression” is cumbersome
- **Expand to other versions of ReTI**
- **Add datapaths visualization:**

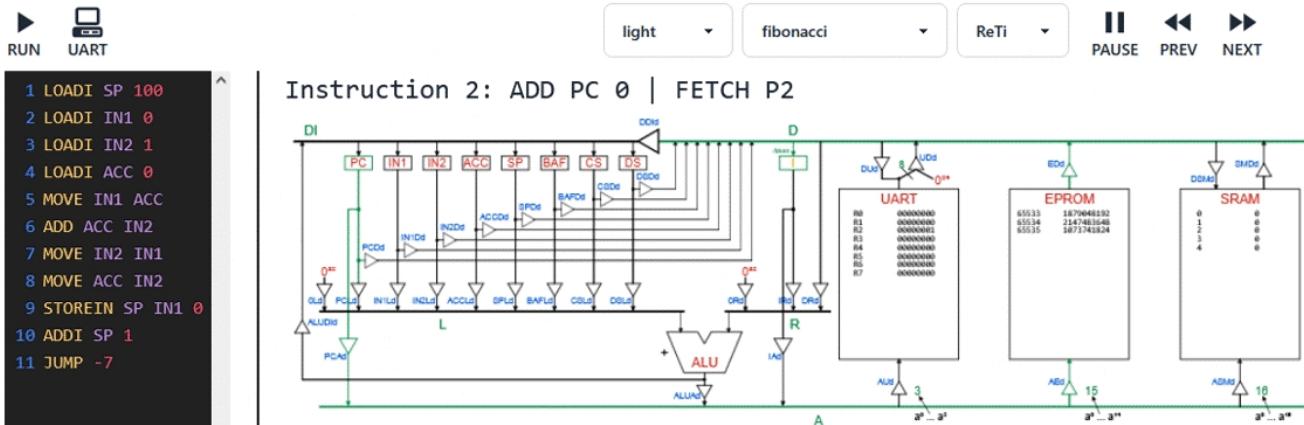


Fig. 11: Screenshot of ReTI-Emulator with Datapath-Visualization [3]

- Same project also provides Pico-C to ReTI compiler

# Extra: Language-Server-Protocol

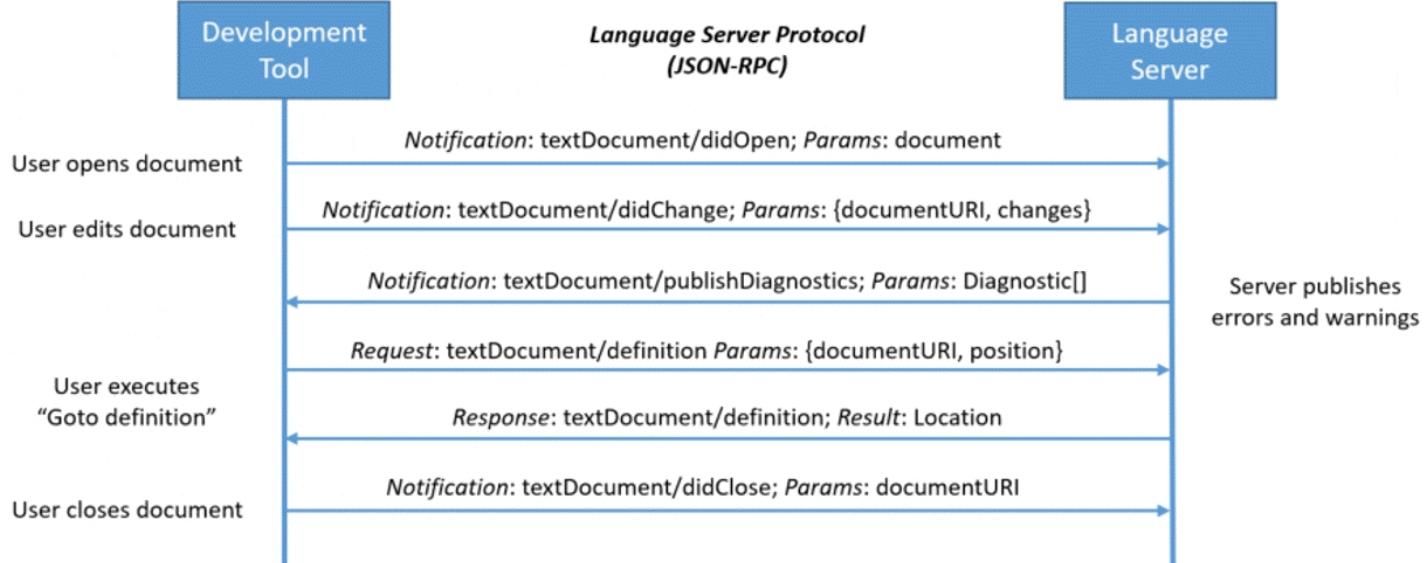


Fig. 12: Example for Communication between Tool and Server in the Language-Server-Protocol [4]

# Extra: Debug-Adapter-Protocol

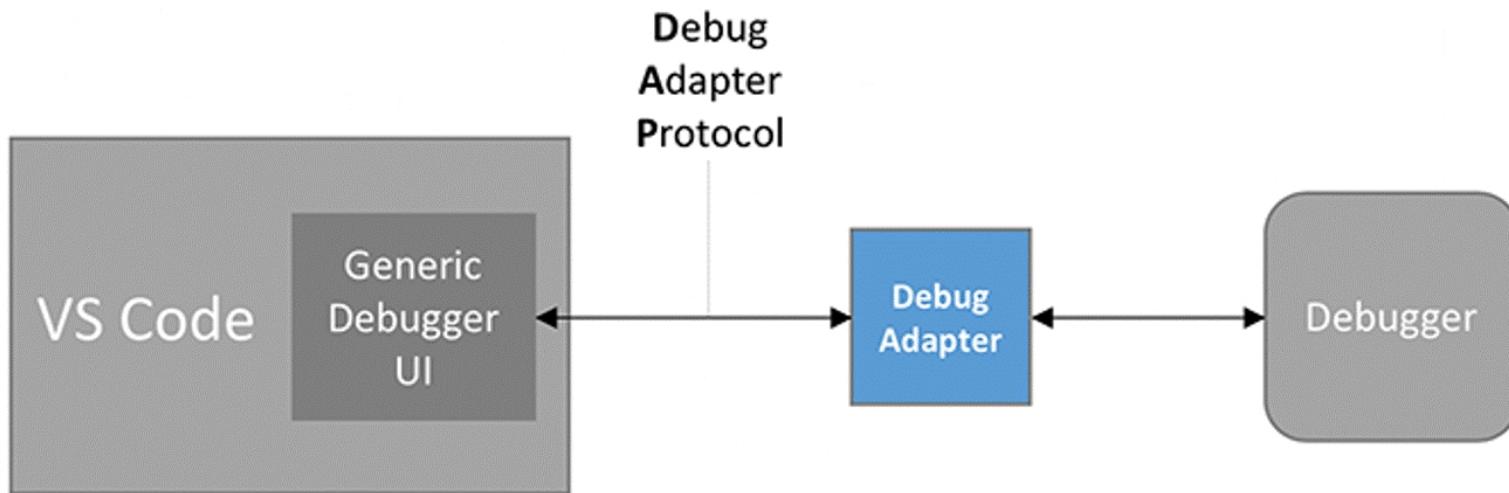


Fig. 13: VS Code Debug Architecture [5]

# References

- [1]: Screenshots taken of Reticode by Prof. Dr. Armin Biere, <https://github.com/arminbiere/reticode>
- [2]: Technische Informatik – Kapitel 2 – Kodierung, Prof. Dr. Armin Biere, University of Freiburg, SS 2024
- [3]: Screenshots taken of ReTI-Emulator, [github.com/michel-giehl/Reti-Emulator](https://github.com/michel-giehl/Reti-Emulator)
- [4]: Microsoft *Language Server Protocol - Sequence Diagram*. Retrieved 13. July 2025, from <https://microsoft.github.io/language-server-protocol/overviews/lsp/overview/>
- [5]: Microsoft. *VS Code Debug Architecture*. Retrieved 13. July 2025, from <https://code.visualstudio.com/api/extension-guides/debugger-extension>