Table of Content

1 Introduction **1**

1.1 Analyzing Memory Usage . . . 3

1.2 Visualizing Memory Consumption . . . 4

1.3 Understanding the Problem of Visualizing Memory Usage . . . 5

1.4 Our Proposal . . . 6

1.4.1 Research goals . . . 6

1.5 Contributions . . . 6

1.6 Vismep Overview . . . 7

1.7 Scope and Limitations . . . 8

1.8 Related Publications . . . 9

1.9 Thesis Outline . . . 10

2 Software Visualizations to Analyze Memory Consumption **11**

2.1 Introduction . . . 11

2.2 Methodology . . . 12

2.2.1 Research Questions . . . 13

2.2.2 Search Strategy . . . 14

2.2.3 Inclusion & Exclusion Criteria . . . 16

2.2.4 Quality Assessment . . . 17

2.2.5 Data Extraction . . . 18

2.2.6 Data Analysis . . . 19

2.3 Results . . . 21
2.3.1 RQ1: Problems Domain . . . 23
2.3.2 RQ2: Data . . . 28
2.3.3 RQ3: Visual Representation . . . 31
2.3.4 RQ4: Evaluation . . . 38
2.3.5 RQ5: Availability . . . 39
2.4 Discussion and Open Challenges . . . 41
2.5 Related Work . . . 43
2.6 Threats to validity . . . 45
2.7 Summary . . . 46

3 Visualizing Memory Consumption with Vismep 48

3.1 Introduction . . . 48
3.2 Related Work . . . 50
3.2.1 Memory Consumption Analysis in Python . . . 50
3.2.2 Studies on Software Visualization for Memory Usage Analysis . . . 52
3.2.3 Software Visualization Evaluation . . . 52
3.3 Vismep . . . 53
3.3.1 Overview . . . 53
3.3.2 Vismep In a Nutshell: Exploring a Pandas Issue . . . 55
3.3.3 Call graph view . . . 55
3.3.4 Source Code View . . . 57
3.3.5 Sub Call Graph View . . . 58
3.3.6 Scatter Plot View . . . 58
3.3.7 Interactions . . . 59
3.4 Methodology . . . 60
3.4.1 Research Questions . . . 61
3.4.2 Participants & Applications . . . 61

3.4.3 Procedure . . . 63
3.4.4 Data Collection and Transcription . . . 65
3.4.5 Data Analysis . . . 66
3.5 Results . . . 66
3.5.1 RQ1.1: Information needs . . . 67
3.5.2 RQ1.2: Use of Vismep . . . 68
3.5.3 RQ2.1: Cognitive Load . . . 72
3.5.4 RQ2.2: Perception of usability . . . 72
3.5.5 RQ2.3: Perception of Vismep features . . . 73
3.6 Discussion . . . 75
3.7 Threats to validity . . . 76
3.8 Summary . . . 77

4 Answering and Asking Questions During Memory Consumption Analysis 79

4.1 Introduction . . . 80
4.2 Related Work . . . 81
4.3 Methodology . . . 82
4.3.1 Research Questions . . . 82
4.3.2 Memory Profiler Tools . . . 83
4.3.3 Participants & Applications . . . 86
4.3.4 Procedure . . . 88
4.3.5 Data Collection and Transcription . . . 90
4.3.6 Data Analysis . . . 90
4.4 Results: What Questions do Python Programmers Ask During Memory Usage Analysis? . . . 92
4.4.1 Understanding Static Structure, Intent and Implementation . . . 93
4.4.2 Understanding Control Flow . . . 95
4.4.3 Discovering Memory Usage in a Single Point of Time . . . 95

4.4.4 Comparing and Contrasting Memory Usage . . . 96
4.4.5 Discovering Memory Events . . . 97
4.5 Results: How do Python Programmers Answer These Questions Using Vismep and Tracemalloc? . . . 98
4.5.1 Understanding Static Structure and Implementation . . . 98
4.5.2 Understanding Control Flow . . . 100
4.5.3 Discovering Memory Usage at a Single Point of Time . . . 101
4.5.4 Comparing and Contrasting Memory Usage . . . 102
4.5.5 Discovering Memory Events . . . 104
4.5.6 Unanswered questions . . . 105
4.5.7 Suggestions . . . 107
4.6 Discussion . . . 108
4.6.1 Questions asked by participants . . . 108
4.6.2 Answering questions . . . 110
4.7 Threats to validity . . . 112
4.8 Summary . . . 113

5 Conclusions **115**
5.1 Dissertation Contributions . . . 115
5.2 Limitations . . . 118
5.3 Empirical Foundation Impact . . . 122
5.4 Future Work . . . 123

Bibliography **139**

Annexes **140**

A Search String for Digital Libraries **141**

B Perception of Vismep and Tracemalloc **142**

B.1 Cognitive Load 142
B.2 Usability 143