CAFÉ: Automatic Correction and Feedback of Programming Challenges for a CS1 Course

Simon Liénardy, L. Leduc, D. Verpoorten, B. Donnet
Contact: simon.lienardy@uliege.be
Agenda

• Context
• Programming methodology
• CAFÉ
• Preliminary Evaluation
• Conclusion
Context

• Introduction to programming course (CS1)
  – University of Liège, Belgium
  – Open access to the University (and Higher Ed. in general)
    • No background required, esp. in Mathematics
• ~80 Students in CS1
• Programming skills required by following courses:
  – C programming language
  – Algorithmic skills
Programming Methodology

Zone 1
{Invariant}

while (LC) {
    {Invariant ∧ LC}
    Zone 2
    {Invariant}
}

{Invariant ∧ ¬ LC}
Zone 3

Deriving the code:
• Based on Dijkstra, *A Discipline of Programming* (1976)
• Graphical representation
  ➢ Constrains, relationships, properties w.r.t variables
• Strategy to solve the problem
  *(Metacognition [Metcalfe et al. 1994])*
Graphical Loop Invariant: example

Binary search in a sorted array

Value searched: X

A:

\[ \cdot < X \quad \text{To Investigate} \quad \cdot > X \]

Sorted and unmodified
Deriving the code from the Invariant

Zone 1:

\[ 0 \leq X \leq u \]

To Investigate

Sorted and unmodified

Zone 3:

\[ 0 \leq X \leq n-1 \]

To Investigate

Sorted and unmodified
Introducing CAFÉ

- French acronym for Correction Automatique et Feedback des Étudiants
- Students submit on a web platform 5 Challenges of increasing difficulty during the semester
  - Plus Challenge 0 to learn how to submit
- Assessment for Learning oriented [Sambel et al., 2013, Wiliam, 2011]
Challenges?

- Challenge 1
- Challenge 2
- Challenge 3
- Challenge 4
- Challenge 5

Subjects:
- Pointers + Dyn. Alloc.
- Functions + Invariants
- Arrays + Invariants
- Loops + Invariants
- Loops

Timeline:
- September
- October
- November
- December

Mid-Term

Exam
Introducing CAFÉ

Day 1

Instructions → Template → Blackboard → Challenge → CAFÉ

```
int i = 0;
int j = N;
while(i < j)
{

}
```

5/20 + Feedback and Feedforward
Introducing CAFÉ

Day 2

Blackboard

Challenge

12/20

+ Feedback and Feedforward
Introducing CAFÉ

Blackboard

→ Closing the feedback loop [Boud, 2000]

Challenge

Day 3

\[
\text{int } i = 0; \\
\text{int } j = N; \\
\text{while } (i) \\
\text{ } \\
\text{ } \\
\]

19/20 + Feedback and Feedforward
CAFÉ: submitting Graphical Loop Invariant

- Graphical Loop Invariant is the **corner stone** of our methodology
- How to make students work with the Graphical Loop Invariant during the Challenges?
- Blank Graphical Loop Invariant
  - To be filled by the student
  - Bootstrap effect
**CAFÉ: Submitting Graphical Loop Invariant**

(Challenge: compute $C = A \cap B$)

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Part A1</td>
<td></td>
<td>Part A2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Part B1</td>
<td></td>
<td>Part B2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Part C1</td>
<td></td>
<td>Part C2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

And the values 16. to the 17. and to the 18. are in the 19.

1. -> 15. : Replace by variables, constants, numerical values
16. : Replace by “different from”, “common to “, etc.
CAFÉ: Graphical Loop Invariant checking

- Variables present in the Graphical Loop Invariant are in the code too
  - And initialized according to the Invariant
- Array Indices in the Graphical Loop Invariant are used to index arrays
  - Out of Bound check
- Loop Variant correction
- Iterations count (if complexity constrains)
- Unit tests
- Feedback & Feedforward added after correction
Preliminary Evaluation

![Bar chart showing the proportion of submissions for different challenges. The chart is color-coded to indicate the number of submissions: 1 Submission (blue), 2 Submission (orange), 3 Submission (green), and Absence (purple). Each bar represents a different challenge, and the proportions are indicated by the height of the bars.](image)

Feb 5 - ACE2020
Preliminary Evaluation

CAFÉ and Challenges seemed to me a good motivating way to make me work regularly. Totally Agree.

The Challenges enabled me to understand the Loop Invariant determination. Agree.
Conclusion / Future Work

• Challenges: unfeasible w/o CAFÉ
• Yet not self-sufficient
• Deeper Evaluation needed
• Sources: https://github.com/slienardy/CAFE

Thanks for your attention.