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# Causette: User-Controlled Rearrangement of Causal Constructs in a Code Editor

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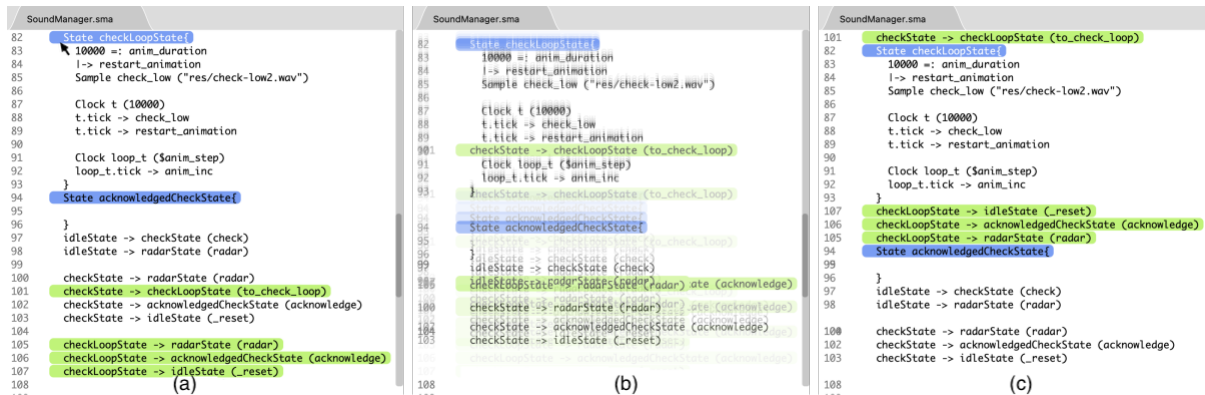


Figure 1: *Interaction 2. Reordering FSMs:* (a) The user hovers over on a declaration of a state (blue) which highlights the in and out transitions (green); (b) the user clicks on the state, and the system animates a rearrangement of the transitions; (c) the new y-ordering of the statements matches the causal relationships being analyzed (in-transitions above state above out-transitions).

## ABSTRACT

Programming interaction usually involves specifying causal relationships such as input events triggering a state change or the propagation of values. Such code may reside in several locations and its execution is driven by multiple causal chains, which hinders the programmer’s ability to understand and fix it. We designed Causette, a set of four novel interaction techniques for a code editor. They consist in rearranging causal constructs on demand to make the code representation consistent with the causal chain being analyzed by the user. We ran an experiment showing that Causette may be more usable than a regular editor for some code understanding tasks. This work suggests that rearranging interaction code may help developers better understand and fix it.

## CCS CONCEPTS

• Human-centered computing → Visualization toolkits; User interface programming; • Software and its engineering → Development frameworks and environments.

## KEYWORDS

Interaction programming, code visualization, causality

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## 1 INTRODUCTION

Programmers of interactive systems e.g. Graphical User Interfaces that react to input events from the keyboard, the mouse, or the touchscreen, face specific challenges due to the interrelated behavior of numerous components and uncontrolled, unpredictable flow of external events [37]. A number of textual programming languages provide dedicated language constructs to tackle the complexity of writing interactive programs. Some of them propose reactive constructs that avoid the need to write code for updating outputs when the inputs of a computation change [64]. Others use traditional object-oriented constructs to describe state-based behavior [1]. Conceptual frameworks, syntaxes and tools have been proposed for user interface development [49], natural programming [50], interaction-oriented programming [40], or web programming [4]. Still, most approaches rely on code split over different source files, each dedicated to the description of interactive behavior at a local level. This breakdown hinders the programmer’s ability to understand interactive behavior. As a consequence, interaction code is hard to debug and maintain.

## 117 The problem: understanding causality

118 We believe that developers should be able to follow and under- 176  
 119 stand the *causal chains* to assess whether the code of an interac- 177  
 120 tion will behave correctly. Following the philosopher of science 178  
 121 W. Salmon [57], we take *causality* as a spatio-temporal process 179  
 122 involving the transmission of “information, structure and causal 180  
 123 influence”. We consider that two processes A and B have a *causal* 181  
 124 *relationship* if A always precedes B and B occurs every time A oc- 182  
 125 curs. In other words, “causality” means that the execution of a piece 183  
 126 of code follows the occurrence of an input event. *Causal chains* are 184  
 127 a set of elementary causal relationships that form a chain. 185

128 General-purpose and interaction-oriented programming lan- 186  
 129 guages provide programmers with “causal programming constructs” 187  
 130 i.e. syntactic expressions that establish a particular causality be- 188  
 131 tween two pieces of code. Some of Java Swing, Qt, SwingStates [2] 189  
 132 or QML APIs and syntaxes can be considered as causal constructs. 190  
 133 With Java Swing, the registering of a listener callback is a causal 191  
 134 construct expressed with `source.addListener(listener)`. With 192  
 135 Qt, the connection between a signal and a slot is expressed with ob- 193  
 136 ject1.signal.connect(object2.slot). With SwingStates, the 194  
 137 transition between two states is expressed with `Transition t` 195  
 138 `= new PressOnShape(BUTTON1, "»menuOn")` while with QML 196  
 139 a transition is expressed with `DSM.SignalTransition {target-` 197  
 140 `State:finalState signal:button.clicked}`. In Smala[40], the 198  
 141 binding between the activation of two processes is expressed with 199  
 142 `p1->p2`, an assignment with `p1:=p2`, a dataflow with `p1=>p2` and 200  
 143 a transition with `s1->s2(event)`. 201

144 Such causal constructs may have been defined by a programmer 202  
 145 with the same source or destination, over multiple code locations. 203  
 146 They thus implicitly form a “causal chain”. The challenge we tackled 204  
 147 here is the programmer’s ability to understand such causal chains. 205  
 148 Since interaction is by nature dependent on external events that 206  
 149 might occur in any order, understanding an FSM requires taking 207  
 150 into account multiple causal chains. Similarly, to understand a data- 208  
 151 flow of connected components, developers must follow the flow of 209  
 152 data across multiple code locations. Few tools have addressed these 210  
 153 difficulties in past work. 211

## 154 Causette

155 Our goal is to better support programmers when they seek to 213  
 156 understand the causal chains involved in interactive programs. Here we 214  
 157 introduce *Causette*<sup>1</sup>, a set of interaction techniques and representa- 215  
 158 tions of textual code. With Causette, a programmer is notably able 216  
 159 to bring together the causal relationships that are far away from 217  
 160 each other in the source code, with a visual ordering consistent 218  
 161 with the conceptual causal order (see fig. 1). Our contributions are: 219

- 162 (1) The elicitation of four design principles (4.2) we relied upon to 220
- 163 design four interactions (4) that rearrange interaction code rep- 221
- 164 resentations to support some interaction programming tasks; 222
- 165 (2) The demonstration of the interactions in relevant scenarios (4); 223
- 166 (3) The evaluation of the interactions with a semi-controlled ex- 224
- 167 periment with 12 professional programmers (5). 225
- 168 226
- 169 227
- 170 228
- 171 229

172 <sup>1</sup>Causette is a pun from the French given name Cosette spelled like Causality, and 230  
 173 evoking “\*-et” HCI terms such as “widget” or “applet”. 231

## 2 RELATED WORK

175 We first introduce the terminology we use. As much as functional 176  
 177 programming is about programming functions that run within a 178  
 179 program that compute results [35], interaction programming is 180  
 181 about programming interactions that run within an interactive 181  
 182 program i.e. that reacts to external events such as human input or 182  
 183 network data reception. Interaction code is the code devoted to the 183  
 184 description of interactive programs. Similarly, as much as object- 184  
 185 oriented programming [31] languages have been designed to suit 185  
 186 the programming of “objects”, interaction-oriented [37] program- 186  
 187 ming languages and frameworks [14, 37, 48] have been designed 187  
 188 by research in three areas: interaction programming and causality, 188  
 189 augmenting textual code, and code representation and animation. 189

### 190 2.1 Interaction programming and causality

191 In the field of interaction-oriented programming, the causal chal- 191  
 192 lenges related to interaction code have been pointed out [14, 37, 47, 192  
 193 48], but few tools have addressed it. The WhyLine debugger [32, 33] 193  
 194 provides developers with answers to a *why?*-question regarding 194  
 195 a phenomenon they perceive on a user interface i.e. a causality 195  
 196 question. Outside the scope of interaction programming, many 196  
 197 papers have studied developers’ needs, particularly when debug- 197  
 198 ging [36, 61, 63] and proposed new debugging methods, notably 198  
 199 in the field of functional reactive programming [58, 59]. However, 199  
 200 few of them have been focusing on the debugging of interaction- 200  
 201 oriented programs or causal relationships. Aside the field of pro- 201  
 202 gramming, some work in information visualization have studied the 202  
 203 representation of causality. This includes the exploration of graphs 203  
 204 and diagrams to visualize causality [22, 23, 62], applied to statistics 204  
 205 or to the modelling of distributed systems. However, typical graph 205  
 206 layouts may not be appropriate to follow the control flow of an 206  
 207 application, as they force the readers to visually hop from node to 207  
 208 node in arbitrary directions. Those limits have been addressed by 208  
 209 tools like DA4Java [53] for Java source code. To make the graph 209  
 210 more readable, a set of features allows to incrementally compose 210  
 211 graphs and remove irrelevant nodes and edges from graphs. 211

### 212 2.2 Augmenting textual code in IDEs

213 Several issues with program understanding motivate work on tex- 213  
 214 tual code augmentation. One issue is related to file-based IDEs. The 214  
 215 literature points out how IDEs lack effective support to browse 215  
 216 complex relationships between source code elements. Developers 216  
 217 are often forced to exploit multiple user interface components at 217  
 218 the same time [34], making the IDE “chaotic” [43]. To prevent time- 218  
 219 consuming navigation between files, CodeBubbles [7, 8, 55, 56] 219  
 220 offers an integrated development environment for Java. With Code- 220  
 221 Bubbles, programmers can build working sets composed of code 221  
 222 fragments (like methods, small classes, notes, documentation, etc.), 222  
 223 displayed in a separate bubble or lightweight window. Programmers 223  
 224 can rearrange the layout of the bubbles to create a logical context. 224  
 225 VSCode offers a functionality called CodeLens [42]: an actionable 225  
 226 contextual information interspersed (from different files) in the 226  
 227 edited code. It differs from Causette in terms of interaction tech- 227  
 228 nique (pop-up window), type of information (e.g. editing history) 228  
 229 and targeted code (imperative code). In the same line of thought, to 229  
 230 230  
 231 231  
 232 232

233 overcome the limits of navigation in IDEs, Hunter [19] is a tool for  
234 the visualization of JavaScript applications that provides a set of  
235 coordinated views that include a node-link diagram that depicts the  
236 dependencies among the components of a system, and a treemap  
237 that helps programmers to orientate when navigating its structure.

238 We used a different strategy to bring related chunks of code  
239 closer, by inserting “remote” code into the currently edited one.  
240 Similarly, “code portals” [9] embed various types of context infor-  
241 mation uniformly into the main source code view in proximity to  
242 the relevant source code. “Fluid source code views” [18] consists of  
243 insertions of relevant remote lines of code in the edited file. The  
244 aim is to provide the programmer with the control and data flow di-  
245 rectly in the edited code, and thereby minimizing navigation. But it  
246 is applied to object-oriented programming and relies on displaying  
247 hierarchies of methods. SimplyHover [29] is a plug-in for Eclipse  
248 that brings the “if” condition next to its “else” counterpart.

249 Theseus is an IDE extension that visualizes the run-time be-  
250 havior of a program within a code editor by displaying real-time  
251 information about how the code actually behaves during execu-  
252 tion [39]. It provides the programmer with the number of calls of  
253 a particular function and a collapsible tree of calls. Like Causette,  
254 Theseus augments the textual code being edited, by displaying the  
255 number of calls to the left of the function header. By contrast, we  
256 target another type of information: the causal activation chain. We  
257 also focused on state activations in an FSM, but used a quantita-  
258 tive representation of activation recency instead of a numerical  
259 representation of the number of calls. We took Theseus evaluation  
260 method as inspiration for the evaluation of Causette.

### 2.3 Code representation and animation

261  
262  
263 Causette builds upon previous work about graphical code repre-  
264 sentations. For example, InterState [51] is a programming language  
265 and environment that supports developers in writing and reusing  
266 user interface code. InterState mixes texts and graphics to represent  
267 interactive behaviors using a combination of FSMs and constraints.  
268 It also provides programmers with a visual notation to facilitate  
269 code navigation and understanding. SwingStates [2] makes a clever  
270 use of Java anonymous inner classes to describe FSMs. However,  
271 the specification of the interactions is done at a local level, and  
272 SwingStates does not offer support for understanding causal chains.

273 From a more theoretical standpoint, source code shares a lot with  
274 a text to be read [54]. There is a distinction made in the literature  
275 between textual and visual information. But it is not clear-cut and  
276 it is not obvious to favor the latter or the former. Visual programs  
277 can even be harder to read than textual programs [26]. The cogni-  
278 tive dimensions of notation is a framework that helps designers  
279 analyze interactive tools, including programming environments  
280 and languages, may they be textual or graphical [6]. The Physics  
281 of Notations framework focuses on the properties of graphical no-  
282 tations [44]. Unifying textual and visual languages shows that both  
283 types have much in common and that both should rely on the ca-  
284 pability of the human visual system [17]. More recent work on  
285 code reading is relevant to Causette. There have been studies on  
286 the way programmers read natural language text and code. Some  
287 results indicate that code reading is less linear [12, 52] than prose  
288 reading because programmer focus on the program execution flow,  
289

290 or that code regularity (same structures repeated time after time)  
291 reduces code reading complexity [30]. The effect of ordering on  
292 comprehension has been studied [30], with a focus on the ordering  
293 of methods. It motivates design principles for Causette, in the sense  
294 that it invites to support the matching between linearity of reading  
295 order and the readability of the execution flow.

296 An environment and language suitable for programming should  
297 allow one to “follow the flow” and “see the state” [10]. The au-  
298 thor designed several interaction techniques and representations  
299 to support those two concerns. However, they involved following  
300 an imperative flow and data states, while Causette targets the in-  
301 teraction flow or the interactive state. The author claims that the  
302 features of the environment are less important than the particular  
303 ways of thinking they support. This is what we strive to do for  
304 interaction programming: provide programmers with interactions  
305 and representations to better apprehend causal relationships.

306 To augment and represent textual code efficiently, we used ani-  
307 mations. Text animations are useful to understand changes of infor-  
308 mation display [16]. Glimpse [21] or Diffamation [15] share with  
309 our work the use of animations in code: they offer animated tran-  
310 sitions to different parts of text (latex markup code and rendered  
311 document in Glimpse, revision history of textual documents in  
312 Diffamation). Glimpse allows users to check and navigate through  
313 the code, without leaving the text editor. However, Glimpse ani-  
314 mates from code to rendering, and not from code to code. Finally,  
315 animations of word-scale graphics within texts also enable to follow  
316 the rearrangement of graphics and make them easier to compare  
317 thanks to a vertical alignment [25].

### 3 THE SMALA LANGUAGE

318  
319  
320  
321 As mentioned in the related work, the problem of describing and  
322 understanding interaction code has been partly addressed with the  
323 design of specific, interaction-oriented textual languages. We used  
324 such a language, SMALA, in the remaining of the paper, as it elimi-  
325 nates some interaction programming problems, like the “spaghetti  
326 of call-backs” [46]. Our interaction techniques were designed for  
327 this language, to overcome the remaining difficulties (the tech-  
328 niques may be applied to other languages or toolkits such as Qt).  
329 This section briefly describes SMALA to help the reader understand  
330 the code examples.

331 SMALA is a textual, interaction-oriented programming language  
332 dedicated to the development of highly interactive software. It takes  
333 inspiration from classical reactive languages such as Lustre [27]  
334 or Esterel [3], notably adding a specific syntax and a seamless  
335 integration of interactive graphics.

336 At the conceptual level, a SMALA program is a declarative speci-  
337 fication of a graph of coupled processes going from a set of event  
338 sources to a set of output processes. Such specification is akin to the  
339 way causal chains are declared in an imperative language/frame-  
340 work such as Java or Qt: adding listeners (Java), or connecting  
341 signals to slots (Qt) is a way to declare a causal chain during the  
342 *initialization* of an interactive program. The execution is triggered  
343 by the occurrence of events that are propagated by an activation  
344 vector, resulting from the sorting of the graph of processes.

345 At the syntactic level, SMALA provides specific operators to define  
346 causal links between processes (listing 1). For example, the arrow  
347

between two processes specifies that each time the left process is activated then the connected process must be activated (binding). More complex control structures exist such as FSMs. An FSM consists in declarations of states, followed by declarations of transitions (listing 2). Each state may include other processes.

The SMALA syntax has been designed to facilitate the development of interactive software. Indeed, the arrow-based notation is a representation of the control flow of an interactive software. The language designers have also reversed the direction of the classical APL assignment operator ( $src =: dst$  instead of  $dst := src$ ) to make it consistent with the directions of other types of flow (binding:  $->$  and data-flow/connector:  $=>$ ). SMALA makes it easy to combine data-flows and FSMs: a data-flow can trigger an FSM transition and an FSM can start or stop a data-flow (as envisioned in [13, 28]).

However, as with Java or C++/Python/Qt programs, the entire causal chain specification can be spread over several files, which makes it difficult to understand. The SMALA FSM also exhibits some scaling issues with a large amount of states and transitions, and with nested FSMs. Even if we believe that dedicated syntax of SMALA is more usable for interaction programming, it is not enough to understand causality.

Listing 1: Binding &amp; Dataflow

```
Clock c1 (500)
Incr inc
c1.tick -> inc.step
//    ^^ binding
// inc is activated every
//    500ms

Double v (0)
inc.state => v
//    ^^ dataflow
// v receives inc value
// every time inc is
//    incremented
```

Listing 2: FSM

```
FillColor f(0,0,0)
Rectangle r(50, 50, 100, 70)
FSM simple_FSM {
  State idle {
    #000000 =: f.value
  }
  State hover {
    #a0a0a0 =: f.value
  }
  State pressed {
    #ff0000 =: f.value
  }
  idle->hover (r.enter)
  hover->idle (r.leave)
  hover->pressed (r.press)
  pressed->hover (r.release)
  //    ^^ transition
}
```

## 4 INTERACTION TECHNIQUES

We devised from the state of the art three requirements for the design of interaction techniques that would support a programmer in understanding interaction code. We devised the design principles to fulfill the requirements. Most design principles and techniques leverage on a textual code editor. Even if some graphical representations can be used to represent data-flow or FSMs, text-based editors are still heavily used as they provide features that are deemed usable by many programmers. Still, we hypothesize that the regular, mostly 1D, textual presentation of causal relationship constructs spread in multiple files does not help programmers to understand the causal chain. We demonstrate the interaction techniques in a concrete way through use cases.

### 4.1 Requirements

The understanding of interaction code poses specific challenges arising from the multiplicity of causal chains across files that split the description of behaviors. We wanted to design interaction techniques directly available in the edited source code file, saving navigation time across files. Although code lines integration within

edited source code is not new, we have not seen such techniques applied to interaction code and causal relationships understanding. Hence, our interaction techniques should support programmers in:

- Understanding the causal dependencies [ReqCausal]
- Backtracking the origin of a causal propagation, overcoming the inconvenience of split code over files [ReqNoSplit]
- Visualizing transitions and states activations dynamically [ReqDynamicCaus]

### 4.2 Design principles

The first design principle that we followed to fulfill [ReqCausal] is to enable the programmer to make the  $y$ -ordering of lines of code consistent with the expected execution ordering [DgnYRearrange]. Reordering is especially important when the programmer wants to apprehend the multiplicity of execution paths due to uncontrolled sequences of external events. It is important to note that reordering only concerns the appearance of the program, not its actual source code, and it does not change its semantics. The representations of code change upon users' request, and can be set back to the original arrangement upon request.

The second design principle we followed to fulfill [ReqNoSplit] is to bring together the causal relationships that are far away from each other in the source code, including in the same file [DgnTogether]. This is especially important when coping with causal relationships that reside in several code locations.

The third design principle is to take advantage of the text representation and of the properties of visual variables from Semiology of Graphics [5] to understand the code and its execution. Notably, the first three interactions reorder the programming constructs to display them like an imperative,  $y$ -ordered control-flow. Note that the first design principle can be considered a special case of the third one, but its importance deserves a proper principle [DgnVisVar].

Finally, the fourth design principle consists in using animations to help the user apprehend the changes of the representations [DgnAnim] [16, 60], especially for [ReqDynamicCaus]. We also took into consideration the guidelines related to animation of lists, as lines of codes can be considered as lists [60].

To the best of our knowledge, [DgnYRearrange] and [DgnTogether] have never been identified and used in past work. [DgnAnim] is not new, but has not been applied to code-to-code transformation. [DgnVisVar] is not new [17], but has never been applied to interaction code. Though following the same design principles, the interaction techniques were not designed to be completely consistent: our goal was to explore a design space and how well the techniques would support program comprehension. Currently, the interactions are implemented in a GUI that enables a programmer to launch a SMALA program and explore its source code with the interactions. Even though the first three interactions may be available statically (e.g. without running the explored source code), our implementation relies on the run-time *initialization* phase of the tree of processes and the reflexive capabilities of the SMALA execution engine. Only the fourth interaction relies on the run-time *execution*. Relying on the execution engine enabled us to prototype the interactions without implementing a static analyzer.

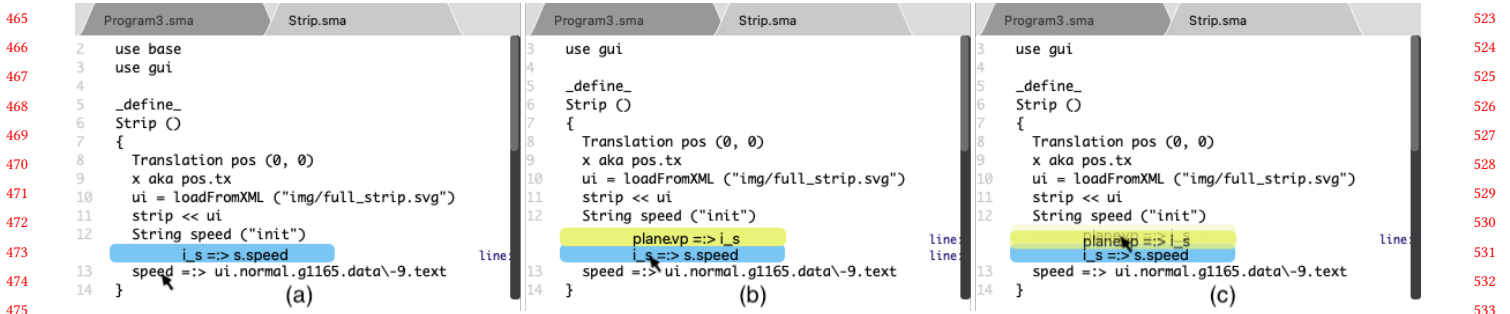


Figure 2: *Interaction 1*. Reordering a data-flow: (a) the user clicks on the left of a connector, an animation inserts the upstream data-flow construct (b) upon click on the new line, an animation inserts the next upstream construct (c) the user clicks on the new line, the system animates the line up-and-down to specify that the beginning of the data-flow has been reached.

### 4.3 Interaction 1: reordering a data-flow

The first interaction technique provides the programmer with means to navigate inside a data-flow and display it like an imperative control-flow. A use case is as follows. The programmer of a drone ground station application is faced with an unexpected behavior while testing interaction code: some text in the graphical interface is not updated as it should be, which is likely the symptom of a broken data-flow. The cause to be identified is a missing connector: the speed of the drone model displayed in the view is not connected to the corresponding data from the bus.

We designed an interaction technique to navigate the data-flow (Figure 2): clicking on a variable on the left-hand side of a data-flow construct summons an animated apparition of the upstream construct that is connected to the said variable. The upstream construct appears in a line of code just above the clicked construct. In a recursive manner, the programmer can click on the summoned lines to display further upstream constructs. If multiple sources are connected on a property, they are all shown using a line each. If there is nothing connected, a short animation quickly bounces the clicked line up and down. Note that the summoned lines may come from the current text file being edited but also from other files. In this case, the source filename is appended to the right of the line as a hyperlink that enables the programmer to jump to the code.

Step-by-step, the programmer is thus able to trace back the absence of a causal construct that should have led to the activation of the line of interest. In our example, we can see that there is nothing connected to the property named *plane.vp*. As such, this cannot be automatically identified as a mistake, since such behavior could have been perfectly legitimate in some applications (in a program, many properties are partially connected). The interaction also works with downstream constructs by clicking on the right side of the arrow, or on the declaration of a property. It is also available for transitions in FSMs: one can explore the chain that leads to or depart from a transition event.

Interaction 1 relies on three design principles to help understand the data-flow: [DgnTogether], [DgnYArrange] and [DgnVisVar]. Compared to a "Jump to Reference" command in a traditional code editor which completely changes the content of the window, or at best provides a transient pop-up on top of the currently edited

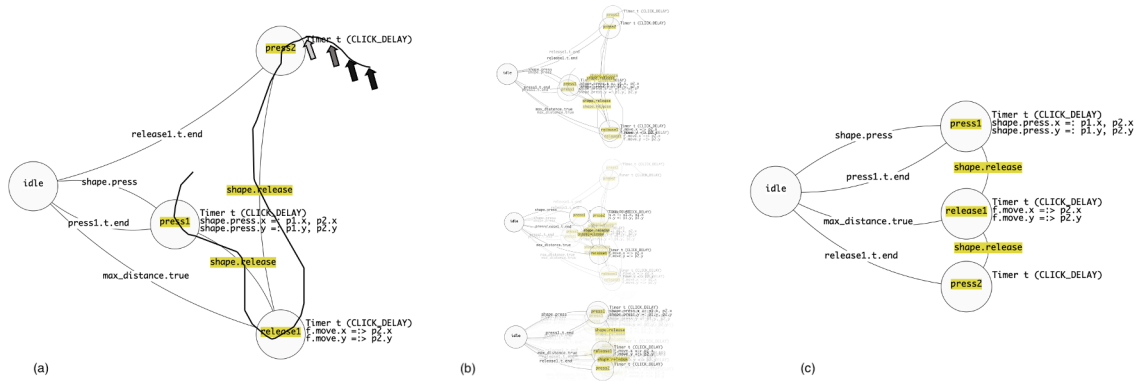
window, the insertion above the lines being read keeps the context in which the programmer tries to understand the code, and displays the lines of code as if they were next to each other. The resulting sequence of lines of code, perceptually ordered in the y-dimension and x-aligned [17], is reminiscent of the sequence of lines of code in an imperative language. However, here the y-dimension of the source code is mapped to the causal relationships (reactive language) instead of the program counter (imperative language), while the x-alignment specifies that all lines belong to a same data-flow (reactive) instead of control-flow (imperative). This makes the causal chain directly visible. The same interaction technique makes it easier to spot a wrong link in the data-flow: the programmer can quickly identify a process wrongly connected to another one.

### 4.4 Interaction 2: reordering textual FSMs

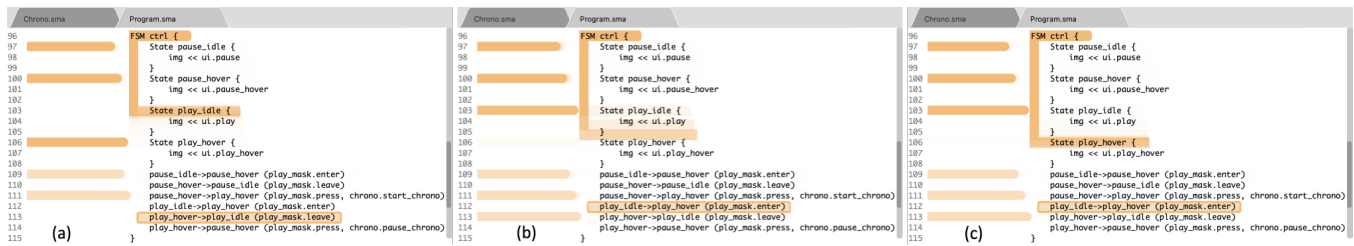
In the example in Figure 1, the FSM has 7 states and 20 transitions. It is thus difficult to apprehend the whole FSM code and understand its behavior given a particular sequence of events. The use-case is as follows: there is a suspicious, transient activation of the check-LoopState state. The user wants to understand the causal events that lead to this state, what the state is activating in turn, and what causes its exiting. However, the current graphical state of the FSM representation makes it difficult to visualize such a sequence as it forces the user to look for the involved transitions and to hop from a line to another in arbitrary directions.

We designed an interaction technique based on the reordering of the elements of an FSM. The programmer can hover over a state, which highlights with a green background the transitions that go into or leave the state. S/he can then click on the state and see a smooth, animated change of the layout of the transitions around the clicked state, to make 'in' transitions lie above the state, and 'out' transitions lie below the state. She can continue exploring the follow-up causal chains by clicking on another state, and see the 'in' and 'out' transitions move around it.

Interaction 2 relies on the same design principles as Interaction 1, but applied to the causal chain related to FSMs (with states, transitions, events) in lieu of data-flows (with variables and operators such as connectors, bindings or assignments). Similarly, the resulting sequence of lines of code, ordered in the y-dimension and x-aligned, is reminiscent of the sequence of lines of code in an



**Figure 3: Interaction 3.** Reordering an FSM given a path selection: (a) starting from a canonical graphical circle-arrow representation of an FSM, the user draws a path through states and transitions according to the causal chain she wants to explore; (b) the system reorders and animates the circles and arrows; (c) the final layout is similar to the corresponding text representation.



**Figure 4: Interaction 4.** Showing in the text editor the activation of states and transitions during execution. (a) The FSM enters state *play idle*, due to activation of the highlighted transition (b) The selected state moves to *play hover* (c) State *play hover* is highlighted and changes in the history sidebars are updated.

imperative language, and allows a developer to better understand the control-flow and its associated causal chain.

Navigation within FSMs and dataflows can be combined. One can rearrange transitions around a state (interaction 2), and click on the process `to_check_loop` that triggers a transition... (interaction 1):  
`check_state -> checkLoopState(to_check_loop)`  
 ... to summon the apparition of an upstream binding:  
`checkSound.t.end -> to_check_loop`  
`check_state-> checkLoopState(to_check_loop)`

### 4.5 Interaction 3: reordering graphical FSMs

The previous interaction techniques are a demonstration of how text-based representations of interaction code could be re-arranged to better follow the control-flow. The use-case from Interaction 2 was concerned with the understanding of the control-flow “around” one particular state. Here the use-case is extended to multiple states.

A popular representation of FSMs relies on circles depicting states and on arrows depicting transitions, annotated with the event that fires a transition. Even if the two representations (“textual code” and “circle-arrow”) seem different, we can smoothly transition from one to another to adapt the view according to the task at hand.

We designed an interaction technique that rearranges the circle-arrow representation (Figure 3). Starting from the circle-and-arrow representation, the user draws a line that passes through states,

transitions and events. The users should specify their gesture according to the particular sequence they want to analyze. After the gesture has been performed, the system animates a rearrangement of the circle-arrow representation. The final arrangement allows the programmer to read from the top to the bottom the causal chain involving a succession of states and events.

Again, such a representation provides the programmer with a sequential reading of the code, which makes causal ordering salient. Remarkably, the final circle-arrow representation is similar to the textual one. This supports the hypothesis that graphical and textual are not so different [17]: the visual representation reuses the assets of the textual one, such as selectivity of the x-dimension (i.e. left alignment [17]) and the ordered perception of the y-dimension to depict the order of the control-flow.

### 4.6 Interaction 4: showing the dynamics of FSMs

The dynamic behavior of FSMs can be hard to understand. The use case is as follows: on a GUI there is a displayed clock, coded with a FSM, which should switch from clock to timer mode upon request on a “play” button. But nothing happens. The programmer wants to check whether the issue is a faulty transition. We designed an animation that highlights the activation of states and transitions during execution (see Figure 4). Each time an FSM enters some state, the state is highlighted and the transition that activated it is both

highlighted and outlined. States might be declared remotely from the declaration of the FSM itself, especially in an embedded FSM. Therefore, the representation also connects the activated state (e.g., `play_hover`) to the parent FSM (e.g., `ctrl`) in which it is declared. As time goes by during execution, the previous activated states and transitions are denoted by horizontal sidebars that progressively fade away and shrink towards the left (see Figure 4), much like a vertical VU-meter in music players. The progressive fading gives the user a sense of the history of activations. This representation also shows whether a state or a transition has been activated at least once. This is particularly useful when the transition between states is very fast.

## 5 EVALUATION

We conducted a study to assess how much more usable would Causette be compared to a traditional text editor. Due to the nature of our research (facilitating some program understanding tasks), we expected that it would be difficult to design a controlled experiment that would be both statistically and practically significant. We expected that measuring the time of completion of a program understanding task would be highly dependent on inter-individual differences. We thus followed the principles of Single-Subject Research [45]. Single-Subject Research involves testing a small number of participants and focusing intensively on the behavior of each individual and measuring strong and consistent effects that have biological or social importance [45]. In the following, we present the results per-subject, instead of aggregated measures of multiple subjects. To design the experiment and report on its results, we followed the principles of Fair Statistical Communication in HCI [20]. In particular, we asked quantitative research questions when suitable, and we stated the effect size.

### 5.1 Research questions

We focused on the following research questions:

- RQ1.** How much would Causette facilitate the understanding of causal structures in interaction code?
- RQ2.** How much would Causette make a difference when given a complex “interactive bug”?
- RQ3.** How much would programmers benefit from insertion of related code lines into the source code being analyzed compared to common methods in text editors (e.g. “find”, “jump to definition”)?

### 5.2 Participants

We recruited 10 participants. All of them were men (more on this in section 6) and were of age 20-25, 1 of age 25-30, 4 of age 30-40. They had at least an M.S in Computer Science or HCI, 3 hold a Ph.D degree. Half of them had more than three years of professional experience in interaction programming with Qt, Javascript or Swing. All of them were proficient in SMALA and were using Sublime Text as an IDE. Sublime Text is a typical textual code editor, with features such as those mentioned in RQ3.

### 5.3 Experimental design

We are aware of the challenges arising in the design of code comprehension tasks and existing work has helped us analyze the limits of our own evaluation study [24]. Our experimental design is inspired

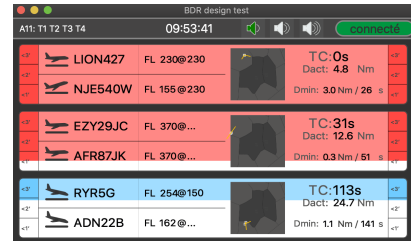


Figure 5: Air Traffic Control app used for the evaluation

by two papers that evaluate new features for IDEs, Theseus [38] and CodeBubbles [8]. We thus conceived a set of tasks related to code comprehension and debugging. We used the code of a real-size application actually in use in Air Traffic Control (ATC). It consists of a GUI that supports air traffic controllers in detecting a conflict between two flights. The source code amounts to approximately 1,000 lines of SMALA spread across 7 files.

Participants were given 6 tasks to complete in total (A to F), those 6 tasks falling into 3 categories (dataflow, value, debug). We designed the tasks within a category to be equivalent in terms of difficulty.

- **Dataflow comprehension questions (A-B):** 2 tasks targeted the understanding of dataflow and required the participants to identify what could trigger the activation of a variable or what the variable could activate down the causal chain.
- **Value questions (C-D):** 2 tasks asked what values a variable could take.
- **Complex comprehension and debugging tasks (E-F):** Finally, 2 tasks involved a complex bug to fix. The tasks require a deeper understanding of the overall behavior of the program.

**E. Missing textual object:** The task involved solving a dataflow problem, where the value of the flight callsign was not correctly connected to the textual property of the GUI. The error was a property naming problem due to a former incorrect *copy/paste*.

**F. Faulty alarm:** The participant was asked to debug a FSM in charge of the sound management of the application. That FSM had an embedded FSM, with 20 transitions and 9 states. We introduced an error in the code, by deleting one transition of the FSM. As a consequence, the FSM ended up stuck in some state *RadarLoopState* and an alarm kept ringing. Participants had to figure that out and fix it.

There were 2 conditions: a control condition with the participants’ usual editor (here Sublime), and a condition with Causette. Sublime is not a full-blown IDE, and we discuss the reasons of choosing it for control condition in section 6. To facilitate within-subjects comparison, each participant was assigned three (from each category) tasks in the control condition and three tasks using Causette. To counterbalance an order effect, half of the participants completed all of their control tasks first, while the other half completed all of their Causette tasks first. The selection of the tasks across categories was randomized.

Before the evaluation, each participant was given a 10 minutes summary of the code: an overview of the architecture and the functions of the app, and the ATC vocabulary to understand identifiers in the code. The code itself did not include any comments. Once



the participant had read the question and was ready to perform the task, a timer was launched. All the interaction techniques were available for each task. Up to seven minutes were allowed for each of the A-B and C-D tasks, while fifteen minutes were allowed for E-F tasks. When participants felt they completed the tasks, they told us, we stopped the task, recorded the duration regardless of the correctness of the answer, and asked for a confidence rate. Participants were also able to give up a task if they felt they could not perform it. If the timer reached the maximum allowed time, we interrupted the task. In total, up to one hour was devoted to the tasks. At the end of the experiment, we made the participants fill a System Usability Scale (SUS) [11] questionnaire on Causette, followed by a 30 minutes interview to get qualitative feedback.

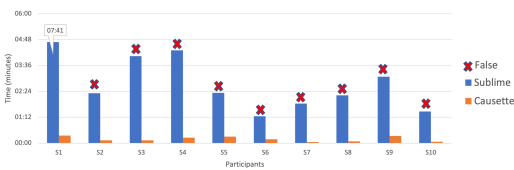


Figure 6: Completion time for the first category of tasks (dataflow questions), comparing control condition (Sublime) and Causette condition. By default, the absence of a red symbol means the answer is correct.

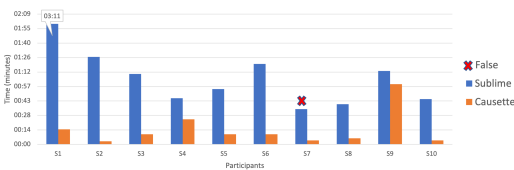


Figure 7: Completion time for the second category of tasks (value questions), comparing control condition (Sublime) and Causette condition.

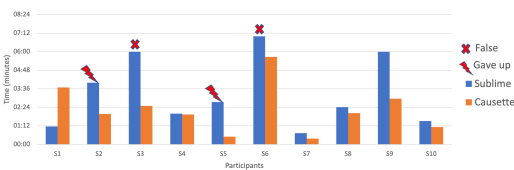


Figure 8: Completion time for the third category of tasks (debugging problems), comparing control condition (Sublime) and Causette condition.

## 5.4 Results

The complete results of the study<sup>2</sup> include completion time, completion success, confidence rate and SUS score. Figures 6, 7, 8 shows the completion time and completion success per participant for each type of tasks and according to the two conditions.

<sup>2</sup>All data anonymously available here: <https://doi.org/10.5281/zenodo.6396517>

5.4.1 *Effectiveness - Degree of achievement.* The participants were all able to correctly complete the tasks in the Causette condition. This contrasts with the completion rate in the Control condition, where many participants could not provide a correct answer or just gave up. In particular, 9 participants out of 10 performed partially correctly the dataflow tasks, as their answers were not exhaustive (they did not mention all paths of the dataflow, and remarkably all but S8 felt confident). Except S1, each participant at least made an error or gave up in the Control condition. 4 participants could not complete the debugging tasks (2 gave incorrect answers, and 2 gave up). This suggests that users are not completely effective with a traditional code editor for these tasks, supporting our analysis of the problems encountered by programmers. This also suggests that our interaction techniques make users more effective than a traditional code editor for all types of task.

Participants were always confident in their answers in the Causette condition. 4 of them (S3, S5, S6, S8) were not confident in some of their answers in the Control condition.

5.4.2 *Efficiency - Time of completion.* Figure 9 represents the time percentage gain per participant and task groups. Except S1 and S4 in debugging tasks, all participants perform their tasks faster in Causette conditions.

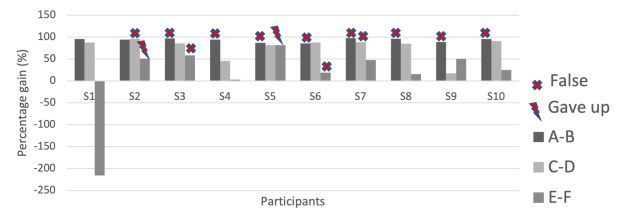


Figure 9: Time percentage gain per participant and per task groups when using Causette compared to Control (Sublime).

In the dataflow tasks, users were able to perform 93% faster with Causette on average. In these tasks, users were only able to answer partially, but we think that the time of completion is meaningful, since they felt they have completed the tasks. Had they resumed the tasks to find out all paths in the dataflow, they would have spent even more time.

In the value tasks, users were able to perform 77% faster with Causette on average.

The results of the debugging tasks are more contrasted. As a reminder, in the control condition, S1 performed better, S4 performed equally, but two participants gave up and two gave incorrect answers. S1 is slower with Causette in the debugging tasks. S1 told us he was familiar with dataflow issues, and less familiar with FSMs bugs, which could explain this outlier. S4 is as fast with Sublime as with Causette. S4 told us he had been focusing on FSMs in his code for two months before the experiment, which could explain his proficiency with Sublime at finding bugs. Except for S1 and S4, the 8 other participants performed faster with Causette. Ignoring incorrect answers, only five participants (S2, S3, S5, S7 and S9) performed significantly faster with Causette with respect to effect size. S6, S8 and S10 performed faster with Causette but with a smaller effect size.

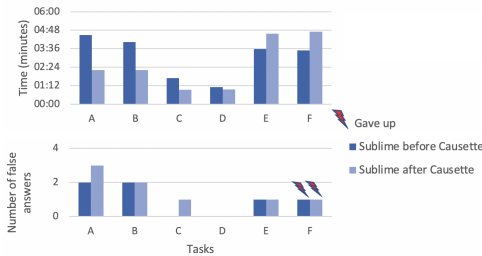
All in all, these results tend to suggest that Causette makes programmers faster at fulfilling the dataflow and value tasks. It may make them faster at debugging with a smaller time gain for half of the participants.

**5.4.3 Satisfaction.** We gathered the SUS scores for Causette only. 7 out of 10 are higher than 90, the remaining 3 (S1, S6, S7) range from 62,5 to 72,5. S1, S6 and S7 thought that they may need the support of a technical person to use Causette (score 3). S7 eventually stated that he would be able to learn to use it quickly. S1 and S6 did not feel very confident (score 3). S1 and S7 thought the system is not well integrated (score 3). S6 did not think he would use it frequently. We present Causette in this paper as a set of interactions, and not as a system. If we polished the interactions as much as we could, the system itself that embeds them is still not very usable. We hypothesize that the comments of S1, S6 and S7 reflect the usability of the system more than the interactions per se.

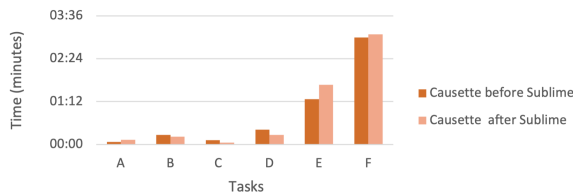
**5.4.4 Internal validity assessment.** We examined whether the design of our experiment exhibits any bias with respect to task equivalence or order (see Figures 10, 11).

In the two conditions, the completion time means between A-B, C-D and E-F tasks tend to confirm that the two tasks within each three categories were of the same difficulty.

In the Causette condition, the order seems to have no effect. There could be an order effect on the completion time of the Sublime condition. It looks as if the use of Causette in a first place had a positive impact on the performances in the Control conditions for the data-flow and value tasks, while it is the opposite for the debugging tasks. However, the computed average times involve at most 3 values, even less when participants gave up or gave an incorrect answer. It is thus difficult to be conclusive or to comment.



**Figure 10: Condition ordering effect: completion time means (upper figure) and answer incorrectness (lower figure) per task in Sublime condition.**



**Figure 11: Condition ordering effect and completion time means per task in Causette condition.**

**5.4.5 Qualitative results.** After each session with a participant, we conducted an interview to get qualitative feedback. Our three research questions RQ1, RQ2, RQ3 target all of the tasks.

**RQ1.** How much would Causette facilitate the understanding of causal structures in interaction code?

Participants mentioned that they felt Causette saved them time to understand the dataflow (all the participants, except S6). The reordering of the in- and out- transitions was also described as time saving (S1, S4, S8, S10). S1 mentioned that he usually needs to draw FSMs when he got confused about the transitioning between states. Participants S1, S8, S10 pointed out that it was interesting to display the current state of an FSM (in the real-time animation of the FSM) instead of printing it in the console.

The issue about the declarative style of interaction code and how it prevents easy causal understanding was brought up: “Because what’s difficult is the declarative aspect, without logical links. You can write it in any order you want.” (S8). S8 also developed an issue for FSMs: “with nested FSMs, after a moment I’m lost in the file, and having something that allows to put logical order between states and transitions, that helps.”

A few participants mentioned that the tool helped them construct or get quick access to a “mental picture” of the causal relationships: “I don’t have to have a mind map all the time [...], there is no need to make drawings.” (S4). Another finding was that 6 out of 10 participants underlined what they felt would be the main use of the tool: to get into someone else’s code or one’s own former project.

The animated insertions were described as presenting the causal relationships effectively. For the dataflow, participants mentioned they felt reassured being provided with a guaranteed, exhaustive list of sources and destinations (S1, S10, S3, S8, S4). S1 and S10 commented on the fact that with a traditional editor, they usually feel unsure whether they figured out completely the dataflow, and they took time to check that the property under study is not dependent on another file or is renamed somewhere else. Such comments are consistent with the confidence rates we measured.

**RQ2.** How much would Causette make a difference when given a complex “interactive bug”?

The two complex comprehension and debugging tasks were commented by some participants as really reminiscent of the problems they usually face. Several comparisons and equivalent use cases were provided. S3 said “it reminds me of many cases [...] : I was creating my graphical objects, but they were aligned at the top left of my interface, and it took me time to understand that I had not initialized their length and height”.

In the debugging task, S5 said he could have answered the last task he gave up in control condition, seeing clearly that the FSM was stuck in a state, but he got tangled up in staying focused on the wrong state. S4 and S7 elaborated on that aspect, saying the FSM animations are useful to locate which state it is blocked in. They found the real time animation and the history bar even more useful “to really see it”. S1, S4, S5, S6 found that reordering FSMs make transition errors more salient.

**RQ3.** How much would programmers benefit from insertion of related code lines into the source code being analyzed?

First, participants brought up that Causette avoids navigating at length: “with the tool we avoid unnecessary navigation. When you use diverse “find” functions, you often end up having too many

occurrences” (S4). This could be supported by the difference in response time we found. Comparisons with search functions in different IDEs were often conducted, to the point where Causette was described as a “super fast search tool” (S5). S2, S3, S4, S5 and S8 liked the simplicity of the triggering of the animated insertion, because it avoided the use of a menu. As one of our participants commented, the interactions involving line insertions might look unusual in the beginning, but it seems easy to get into the habit. Since code is rearranged, it is worth noting users may be disorientated. This was mentioned by one participant: “I clicked unintentionally, and I had trouble finding my way around, I didn’t know what I had clicked on” (S9). This is especially true in interactions with FSMs as the layout may end up very different from the initial arrangement. We used animations to mitigate this aspect. We also provided an “original view” button to get the layout back to its original form. As for the FSM, the real-time animation was appreciated but the reordered FSM animation was also found useful. S1 who liked the graphical FSM underlined that the reordered FSM was very interesting.

## 6 THREATS TO VALIDITY

**Participants.** The number of participants in the experiment is low, and they are all men. We could not avoid this sample bias, as the users of the SMALA language happen to be men. Still, we do not have any plausible hypothesis about the effect of genre on the results of the experiments. As noted by Feitelson [24], the effect of genre is not clear and requires further investigation.

**Size of code.** The application used during the evaluation is 1,000 lines of code only. One can wonder if the interaction techniques would scale to larger code bases. 1,000 lines seem small, but they are written in a specialized, interaction-oriented programming language which is expressive and should not be compared to the size of code written in a general-purpose language such as Java. Still, the FSM of the example has a moderate complex behavior. Scaling up the number of states to a dozen would make it more difficult to perform interaction 3. Besides, our representations have limits: for example, Interaction 1 and 2 only display one causal chain at a time, and do not allow exploring multiple chains simultaneously. But the control condition does not facilitate exploring one causal chain only neither, and we think that it would scale even more badly, as one would have to navigate more files with longer causal chains.

**Tasks.** The tasks only partially represent the programming activity. We are aware that the evaluation has limits and should be complemented with other experiments. In particular, tasks A-B and C-D where the results were the most in favor of Causette, may seem idiosyncratic. However, the tasks represent a typical problem encountered by programmers of interactive programs. We designed the interactions to support solving those problems, hence it is not surprising that the evaluation suggests that Causette offers support. Nevertheless, it had to be demonstrated.

**Control condition.** The choice of a limited set of Sublime Text interactions as the control condition is disputable. Causette is a set of interaction techniques that may have been compared to those of a full-featured IDE. Still, we left the participants choose the Sublime Text interactions they use in their real-world activities. In particular, one can debug program with Sublime Text. However, such a debugger is of little help for the interaction code problems.

**Understanding.** A general pitfall of comprehension evaluation [24] applies to our work: does the study actually tell something about *comprehension*? It could turn out that some participants, especially for task A-B and C-D, found the *correct answers* about the causal chains in code, without properly *understanding* them. Addressing that issue would require further investigation.

**Reading/Writing.** Finally, the study suggests that Causette support code reading, but not code writing. Since developers read 10 times more code than they write [24, 41], our results suggest that at least Causette could be useful. Further work is needed to assess whether Causette could support code writing.

**Generalizability.** The interactions may be too specialized to the particular language we used. Some languages or toolkits provide some of SMALA’s features e.g. Qt’s signal/slot, JavaFX binding, SwingState’s FSMs. We think that most of the interactions could be applied to these features e.g. navigating the chain of signal/slots in Qt or SwingState’s FSMs. However, this necessitates appropriate analysis and introspection tools. For example, one could use the Qt’s MetaObject system to gather dependency information, and use the API provided by some text editors to insert the upstream and downstream signal/slots where a particular connection is created in the code. Similarly, the QML or SwingStates run-times could record the parameters of the transitions and inform Causette. With this, it would be possible to adapt Causette interactions to an editor of Qt code: clicking on `object1.signal` in this line of code...:

```
object1.signal.connect(object2.slot)
...could summon the apparition of an upstream construct above:
object0.signal.connect(object1.slot)
object1.signal.connect(object2.slot)
```

Similarly, since QML and Swingstates provide explicit FSMs syntaxes, an editor of such languages could rearrange the order of transitions as in interaction 2.

## 7 CONCLUSION AND FUTURE WORK

We presented *Causette*, a set of four interaction techniques for a textual and graphical code editor. The interactions rearrange and animate textual code in a way that makes the causal relationships more understandable. An evaluation with professional programmers suggests that Causette may be more usable than a regular text editor for some interaction programming tasks. This work indicates that rearranging interaction code may help developers better understand and fix it. This work can be continued by exploring unanswered questions on scalability, generalization, disorientation, and ecological validity. Instead of running another controlled experiment, we plan to provide our participants with a better, more robust, and more integrated version of our tool and observe its use in practice during a longitudinal study. This should also provide us with new insights on how to best support interaction programmers.

## ACKNOWLEDGMENTS

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