ABSTRACT
In pair programming, two software developers work on their code together in front of a single workstation, one typing, the other commenting. This frequently involves pointing to code on the screen, annotating it verbally, or sketching on paper or a nearby whiteboard, little of which is captured in the source code for later reference. CodeGraffiti lets pair programmers simultaneously write their code, and annotate it with ephemeral and persistent sketches on screen using touch or pen input. We integrated CodeGraffiti into the Xcode software development environment, to study how these techniques may improve the pair programming workflow.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors

Keywords: Pair programming, code annotation, pen input

INTRODUCTION
In pair programming, two developers share one workstation: while the driver edits the code, the navigator observes his work, with roles swapped frequently. The navigator cannot perform any editing, but has to communicate her thoughts to the driver who then edits the code, making the team more aware of design decisions, pitfalls, and mistakes. This extreme collaboration technique has been shown to significantly lower development times and coding error rates [2].

However, this communication happens not just verbally or through written code. By pointing, gesturing, sketching diagrams and scribbling annotations, programmers explain graphical properties to each other, test ideas, or visualize complex software structures. Current IDEs rely on keyboard and mouse input to create syntactic content such as code, and offer little support for graphical content. Thus, programmers have to express documentation and other semantic content either textually, in external programs, or physical artifacts: Automated tools like Doxygen (see doxygen.org) that parse textual comments in the code are widespread but unsuitable for capturing quick annotations or graphical content. Graphics created in separate pen-based applications offer greater expressiveness, but require mode switches, and do not link sketches to code. Physical artifacts such as whiteboards or paper offer quick creation of highly expressive, informal notes, but outside the IDE. Such notes are also easily thrown away or wiped from the board, being captured digitally only if they seem valuable enough.

Other professions such as manuscript editors often use editing marks to communicate revisions and opinions [3, 6], which has also been proposed for teachers when reviewing code [4, 5]. CodeGraffiti extends graphical input for general semantics [1] in the IDE. It places sketches, documentation, explanations on structure and design decisions directly in line with the code. This lets pair programmers communicate graphically right in the IDE. Our hypotheses are that this lets programming teams communicate graphical ideas more effectively, that they retain more sketches for documentation than via physical artifacts, and that sketches are integrated better into code structures.

INTERACTION DESIGN
Our design rationale is to give the navigator a way to support team conversation by sketching directly on the shared screen (Fig. 1). Sketching (Fig. 2) and annotating should be as easy as picking up a pen to draw or write on paper or a white-
board. The driver is still the only person entering syntactical
code (Fig. 1). The navigator enters semantic graphics that
do not compile, making it easy to quickly jot down a sketch,
explain a design idea or point out a typo to the driver. Similar
to copy editor marks, annotations provide information to
a word or line using underlining, exclamation marks, or cir-
cirling. Sketches (Fig. 2) are broader in scope and may refer
to multiple points, e.g., to highlight a software design pattern.
Hand-drawn sketches and annotations look appropriately in-
formal, and can be adapted easily as design decisions change.

A common focus is considered essential to maintain the
higher quality of pair-programmed code. Therefore, despite
separate text and sketching cursors, we decided not to allow
the navigator to scroll to a different part of the code. By shar-
ing the same view, neither member can wander off and work
on separate tasks or even files.

The IDE links graphics within code bodies persistently to one
or more anchors in the text. It also links anchors visually to
the graphics so that sketch and code can provide explanations
for each other. These graphics show up for every program-
mer who opens the code base with CodeGraffiti installed, and
can become a permanent part of the software documentation
over time.

We also allow ink over interface widgets, reference docu-
mentation, and other screen elements not related to source
code for illustration and gesturing purposes. Missing this
link to source code, however, they are treated as ephemeral,
fading out after five seconds.

**PROTOTYPE**
We implemented CodeGraffiti in two parts: a server running
as a plug-in in the IDE, and clients for various input modal-
ities. The plug-in was written for Xcode¹, the free, native
development IDE for Apple devices. It accepts input from
three clients:
- finger painting gestures on iPad and iPhone (Fig. 3a),
- pen input on a graphics tablet (Fig. 3b),
- pen input on a tablet display (Fig. 3c).

The server stores sketches in a companion file to each source
file, and keeps a table linking them to anchors in the text. This
way, users without the plug-in do not see any artifacts,
and CodeGraffiti integrates well into revision control sys-
tems. As lines are inserted, anchors move to another file,
or referenced variables are renamed, the IDE updates sketch
positions accordingly. When the text anchor is removed the
sketch becomes uncoupled, and the programmer can reattach
it to a different position.

An interesting challenge is that the driver might scroll the
view while the navigator is sketching. If both share only one
physical display (Fig. 3b), this is unlikely. If the navigator
has a mirrored display (Fig. 3a,c), we wait until she finishes
drawing and then snap it to the driver’s new view.

**SUMMARY and FUTURE WORK**
We presented a rationale and prototype for simple and inte-
grated sketching in pair programming. While designed with
pair programming in mind, a single programmer or code re-
viewer can also benefit from the sketching facilities provided.

Our next steps are to deploy CodeGraffiti to both single
and pair programmers, and explore how sketching input is
adopted, and how it fits into the workflows of single pro-
grammers, pair programmers, and code reviewers. We also
hope to learn how the three input modalities compare for dif-
derent tasks. Finally, preliminary tests already indicated that
the second cursor might be distracting to the driver. To al-
leviate this problem we plan to fade out the pen cursor if it
moves near the main cursor.

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