Program Synthesis

MPhil ACS module P342 - Alan Blackwell
You do the rest!
Principles of program synthesis, from HCI perspective

- The user experience of ML-based synthesis:
  - The user says: “Here is an example of what I want to do”
  - Followed by: “You do the rest”

- System response: “OK, I’ll do others the same way”
  - How does it know what “others” are?
  - How does it know what “the same way” is?

- Usability issues:
  - How to specify applicability?
  - How to control generalisation?
  - How to understand what was inferred?
  - How to modify the synthesised program?
Classic programming by example

- Keyboard macros – demo in Emacs

- Get a plain text file containing semi-structured text
- `<Ctrl+x>` ( starts macro recording
- Perhaps search for context, cut and paste, add text …
- Remember to go to known location (e.g. start of next line)
- `<Ctrl+x>` ) ends recording
- `<Ctrl+x>` e plays back once
- `<ESC> 1 0 0 <Ctrl+x>` e repeats 100 time
Value proposition

- The next generation of AI: “Intelligent tools”
- If a user knows how to perform a task on a computer, that should be sufficient to create a program to perform the task.
  - Early research aimed to achieve “programming in the user interface”
- Macro recorders are one model, but they are “too literal”
  - Do only what they are shown (no generalisation)
  - Unable to adjust for different cases (no inference)
- Other models:
  - Automation of repetitive activities
  - Creation of custom applications
- Machine learning problem is to create a model of user intent
  - Ideally informed by prior likelihood – from this user, and other users
Eager
Classic mixed-initiative programming by example

- Allen Cypher’s “Eager” created at Apple research in 1990
  - Implemented as extension to Hypercard (event capture + injection)
  - Machine learning implemented in LISP

- Scenario – create a script to produce a list of subject lines from messages
Subject: a necessary evil...
From: tmiller

Allen,
I'd rather not do all of
this paper work, but it will
be worth it in the end.
Terry

---

a) copy first subject

b) type "1. " and paste subject
c) go to next message

Subject: a necessary evil...
From: jmiller

Allen,
I'd rather not do all of this paper work, but it will be worth it in the end.
Jim

---
d) copy second subject

Subject: Lost folders
From: Taylor2

This is a reminder to all to look once again for those red folders I left in the conference room.
-Peter
e) type "2." and paste subject

f) Eager appears
1. a necessary evil...
2. Lost folders

• Subjects •

Next Text: "3."

g) anticipate typing "3."

Edit
Undo %Z
Cut %H
Copy %C
Paste Text %U
Clear

New Card %N
Delete Card
Cut Card
Copy Card

Text Style... %T
Background %B
Icon... %I

h) anticipate paste
i) anticipate going to next message

Subject: Where were you?
From: JONES3
Allen -
I had expected to see you
lunch yesterday. What
happened?
Mike

j) user clicks on Eager

Subject: Experiment
From: Robinson
Dear Allen,
I have the data on the
all subjects. Stop by!

End
k) finish the task

l) Eager finishes
Programming by demonstration in the graphics domain

- Classic example: David Kurlander’s Chimera
  - Infers constraints via heuristics, from snapshots of drawing editor state
  - Users can generalise a “graphical macro” in editable history of operations
  - https://youtu.be/JbrJQW25ekI?t=7m7s

- D. Kurlander *Graphical Editing by Example* (1993)
Toon Talk
Ken Kahn’s ToonTalk – user control of generalisation
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This robot will set things up for another robot.
Ken Kahn’s ToonTalk – user control of generalisation
Ken Kahn’s ToonTalk – user control of generalisation
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Generalising a constraint with Dusty

Dusty (a)  Dusty (b)
Generalising a constraint with Dusty
Generalisation
Why is the generalisation step so significant?

- Generalisation from examples is fundamental to mental abstraction
  - Repetition of concrete instances (i.e. direct manipulation) does not require abstraction
  - Any automated action (i.e. programming) does require abstraction

- So program synthesis requires the user to conceptualise their problem in an abstract way
  - Programming by example is a strategy for achieving this …
  - … the user can become comfortable with individual cases, while
  - … the system formulates abstractions at the same time the user does.

- Essential that user & system can “discuss” what they are concluding:
  - So is this what you want me to do?
  - No, here is a case where you should do something else.
  - Oh, I see, so like this?
The Attention Investment model of abstraction use

- Programming is not like direct manipulation, so the standard rules of usability (Shneiderman’s direct manipulation principles) do not apply:
  - Incremental action
  - Fully visible state
  - Immediate feedback
  - Easily reversible actions

- Making abstractions is cognitively hard, because actions take place in the future, and they apply to multiple potential contexts.
  - Automating repetitive actions does save time and (mental) effort
  - But formulating and refining abstractions costs time and mental effort!
  - What leads a user to approach their tasks in this way?
    - Richard Potter’s “Just In Time Programming”
    - Rosson and Carroll’s “Paradox of the Active User”
    - Bainbridge’s “Ironies of Automation”
    - Burnett’s “Surprise, Explain, Reward” (cf mixed-initiative design strategies, including Clippy)
"I spend a lot of time on this task. I should write a program automating it!"

**Theoretical View:**
- Writing Code
- Work on Original Task
- Automation Takes Over
- Free Time

**Reality:**
- Writing Code
- Debugging
- Rethinking
- Ongoing Development
- No Time for Original Task Anymore
Swyn: inferring regexps to generalise text macros
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wibble wobble tries to nobble
wibbre wobble tries to nobble
wibble wobble tries to nobble
wibble wobble tries to nobble
wibble wobble tries to nobble
wibble wobble tries to nobble
wibble wobble tries to nobble
wibble wobble tries to nobble
wibbble wubble tries to nobble
wibbbbbbble tries to trouble
wibbne wobble tries to nobble
Swyn: inferring regexps to generalise text macros
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Explaining the inference to end-users

- \((0|0044)1223[356][0–9]+\)

- Find one of the following:
  - a) either the sequence “0”
  - b) the sequence “0044”

- followed by the sequence “1223”

- followed by
  - any one of these characters: “3” or “5” or “6”

- followed by at least one, possibly more, of the following:
  - any one of these characters: any one from “0” to “9”
Structured text editing as an ML application

- Aimed at the kind of things people did with sed/awk/perl
  - Many automated text operations involved regexps
  - But users found these the hardest thing to understand …
  - … research agenda for machine learning: sed/awk/perl/swyn

- Similar goals to Witten and Mo’s TELS (1989)
  - Learning Text Editing Tasks from Examples
  - See Cypher book chapter 8

  - Recursive language model “Structured Prediction by Partial Match”
  - Prior expectation based on harvested corpus of regular expressions
Example applications
We’ve had intelligent code editors since 1978

- **The Programmer’s Assistant: Knowledge-Based Emacs (KB-Emacs)**
  - PhD project of Charles Rich at MIT
  - Aimed to recognise cognitive plan elements within source code

- **However, most programmer-assist features in IDEs were implemented using context-aware heuristics rather than AI models:**
  - Syntax-directed editing
  - Auto-complete of standard constructs
  - Refactoring
  - Inference from identifier names (e.g. follow x=x+1; with y=y+1;)
  - Navigate-by-completion for library APIs

- **This is one area where LLMs (e.g. GitHub CoPilot) will have massive effects!**
  - Ask Advait. (Or Michael Lee?)
Working in a data-centric paradigm: FlashFill for Excel

- Building on this paper by Sumit Gulwani (MSR Redmond)

- Live Demo
  - Paste a list of semi-structured text data into the left column
  - Type an example transform result in top cell to the right, then <Enter>
  - Press <Ctrl+E>

- “Synthesises a program from input-output examples”
  - How do you choose the examples?
  - How do you know what will happen?
  - Using this ‘program’ as a component of a larger system is still a research topic
Visualising abstract structure: Data Noodles

- https://www.youtube.com/watch?v=hyCVBxfx7VE

- Applies a transformation paradigm
  - Directed search for fold/unfold transforms that will achieve the demonstrated result

- Search procedure uses off-the-shelf program synthesis toolkit
  - PROSE SDK from Gulwani team at MSR Redmond

- Custom-built front-end
  - The “spreadsheet” is purely for familiarity of presentation
    - No actual spreadsheet calculation is performed
  - Drag-and-drop target previews allow user to anticipate inference
  - Noodles preserve and visualise the demonstrated actions
    - Allow reasoning about causality from example to synthesised program
    - Potentially support modification/correction of examples