Program Synthesis

MPhil ACS module P230 - 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 times
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
a) copy first subject

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

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

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

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

d) copy second subject
e) type "2. " and paste subject

f) Eager appears

Subject: Where were you?
From: JONES3

Allen -
I had expected to see you
lunch yesterday. What
happened?

Mike
1. a necessary evil...
2. Lost folders

\[ \text{Subjects} \]

\[ \text{g) anticipate typing "3."} \]

\[ \text{h) anticipate paste} \]
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

1. a necessary evil...
2. Lost folders
3. Where were you?
4. Experiment
5. Meeting
6. We're Open
7. Vacation

some ideas
Chimera
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](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
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Generalising a constraint with Dusty
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."

**Theory:**
- Writing code
- Work on original task
- Automation takes over
- Free time

**Reality:**
- Writing code
- Debugging
- Ongoing development
- Rethinking
- No time for original task anymore

Permanent link to this comic: https://xkcd.com/1319/
Image URL (for hotlinking/embedding): https://imgs.xkcd.com/comics/automation.png
SWYN: See What You Need
Swyn: inferring regexps to generalise text macros
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Communicating inference to the user

- \((0|0044)1223[356][0–9]^+\)

- 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
The *Programmer’s Assistant* project from 1978 onwards

- Implemented as Knowledge-Based Emacs (KB-Emacs)
  - PhD project of Charles Rich at MIT
  - Aimed to recognise cognitive plan elements within source code

- In practice, programmer-assist features in modern IDEs are implemented using 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

- There is significant research inferring more such patterns from code bases, and a few products coming onstream with more generative predictions
  - https://www.tabnine.com
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