EECS 598. Program Synthesis: Techniques and Applications

Lecture 1: Introduction

Xinyu Wang

Logistics: Course staff

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  - Canvas
- No TA

Introduce yourself

- Name?
- What program? What year?
- What areas in CS are you interested in?

Logistics: Course mode

- Mode: Hybrid but to COVID (some components in-person, other components online)
  - In-person lectures: 1014 DOW
  - Online lectures: Zoom (check course webpage!)
    - 75-90mins with 3mins break
    - Ask questions during lecture: unmute yourself and ask
    - Non-urgent questions/comments: type in chat
  - Recordings available after class
  - Mode will be available at least 1 week prior to class (check schedule online!)
  - Office hours: T/TH 4:30-5:30pm eastern time (Zoom)

Logistics: Course structure

- Research-oriented seminar class
  - Reading papers, presentations, discussions
  - Lectures on basics and general landscape

Logistics: Course structure (cont'd)

- Content: Program synthesis techniques & applications
- Four modules
  - Module 1: Programming-by-Example Techniques
  - Module 2: More techniques
  - Module 3: More applications
  - Module 4: Final Project Presentations

Logistics: Course structure (cont'd)

- Module 1: Programming-by-Example Techniques
  - A set of fundamental ideas/techniques underlying many program synthesizers
  - After this module, you should be familiar with all these techniques
- Module 2: More techniques
  - A set of more advanced techniques
  - You should be able to solve many problems using these techniques
- Module 3: Applications
  - Interesting applications that combine different techniques

Logistics: What do you need to do?

- Paper presentation(s): 1-2 papers/student, depending on how many students enrolled
- Paper reviews: at most 2 reviews per week
- Participation: discuss, ask questions, brainstorm new ideas, …
- Final project: team (1-2 people), proposal, checkpoints, final report, final presentation

Logistics: Paper presentation

- Identify 1-2 papers you want to present
  - Send to instructor
  - If not, you may get any paper
- Prepare (e.g., slides, demo, thoughts, ideas, discuss with others)
- Present (45m talk + 30m QA)
  - Thorough (45m is quite a long time)
  - Give high-level ideas as well as important lower-level technical details
  - Introduce necessary background

Logistics: Paper reviews

- Write a review (template available on course page)
  - A short summary, pros, cons
  - Questions
  - Thoughts

- Send to instructor via email **by midnight the day before class**

Logistics: Participation

- Attend
- Ask questions (don’t be shy!)
- Express your opinions
- Connect to your research
- Your ideas
- …

Logistics: Final project

- Find a teammate (solo is also okay; but if more than 3, check with instructor)
  - Sooner than later!
- Generate ideas
  - Sooner than later!
- Write proposal
- Checkpoints: Progress report
- Final presentation
- Final report

Logistics: Final project (cont'd)

- Different kinds of final projects
  - Extend/improve a technique in a paper
  - Apply an existing synthesis framework to a new problem domain
  - Develop a new synthesis technique for an existing problem
  - Develop a new synthesis technique for a new problem
  - …
- Grading of final project is based on: originality, completeness, scope

Logistics: Final project (cont'd)

- Proposal
  - 1-2 pages, like an introduction, also include a timeline and a sketch of solution
  - need to convince me your problem is worth solving and is technically challenging
  - also need to convince me you are able to solve it within 2 months (at least partially)

Logistics: Final project (cont'd)

- Checkpoints
  - Nothing but a progress report
  - A partial final report that is gradually more complete over time

Logistics: Final project (cont'd)

- Final project report
  - 6-8 pages, structured like a conference paper
  - Include:
    - Introduction — why this project
    - Motivating example — illustrate how your technique works concretely
    - Technical details — make sure to first give high-level idea before showing details
    - Evaluation — how it works in practice
    - Related work — how your idea relates to existing work

Logistics: Grading

- Paper presentation: 20%
- Paper reviews: 30% (2% x 15)
- Participation: 5%
- Final project: 45%
  - Proposal: 5%
  - Checkpoints: 16% (8% x 2)
  - Final project presentation: 12%
  - Final project report: 12%

What is this course about?

- This course is about program synthesis, including both techniques and applications
  - Techniques: general synthesis algorithms not necessarily tied to a specific application
  - Applications: novel application of program synthesis techniques

- Beyond acquiring knowledge about program synthesis, also:
  - PL thinking
  - Writing, presentation, …

You should take this course

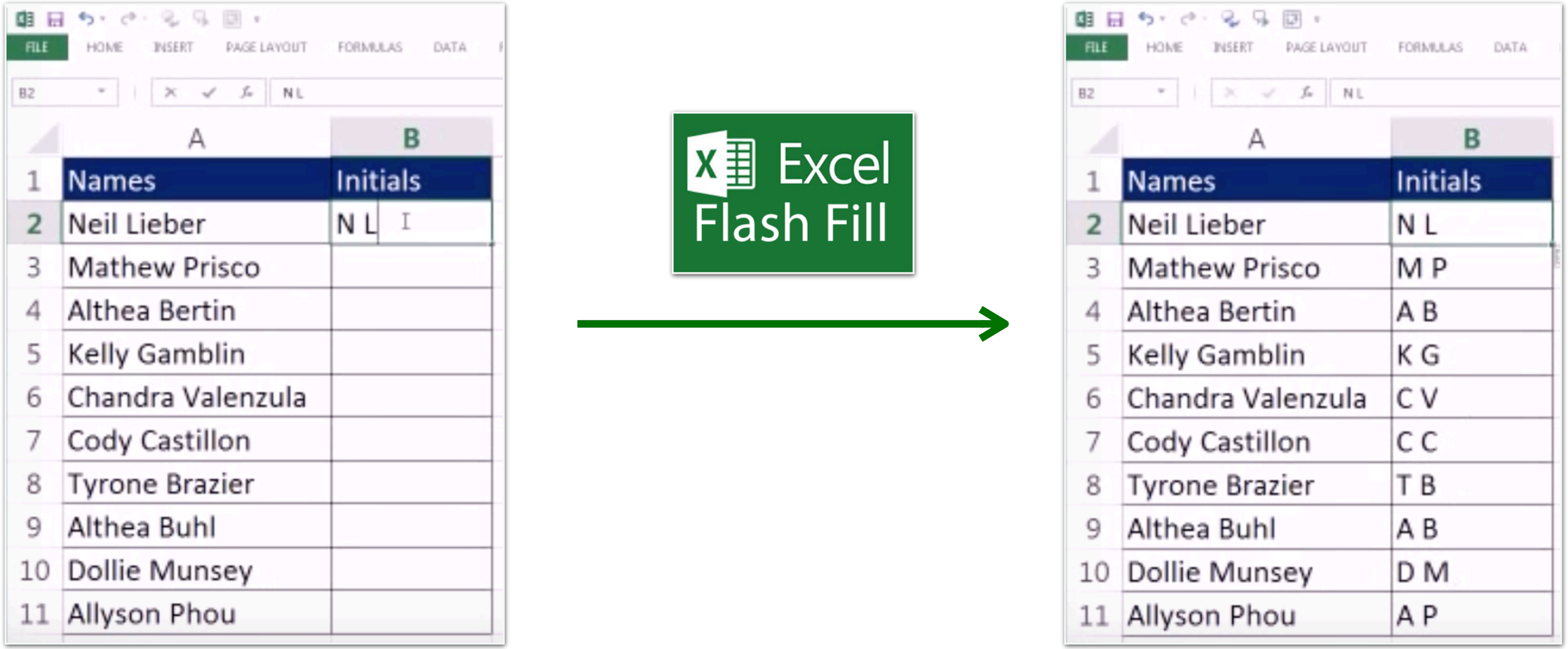
- .. if you are doing or plan to do research in program synthesis
- .. if you are interested in programming languages research
- .. if you plan to explore possibilities of applying PL in your own research
- .. if you just want to learn about the topic!

What is “program synthesis”?

- What is “program”?
  - C/C++/Java/Python…
  - Haskell/ML/OCaml/Lisp/…
  - SQL/Datalog/…
  - …
- Synthesis from what?
  - Input-output examples
  - Natural language
  - Demonstrations
  - …

Example 1: FlashFill [Gulwani et al. 11]

- Synthesize Excel macros for string processing from input-output examples (video)

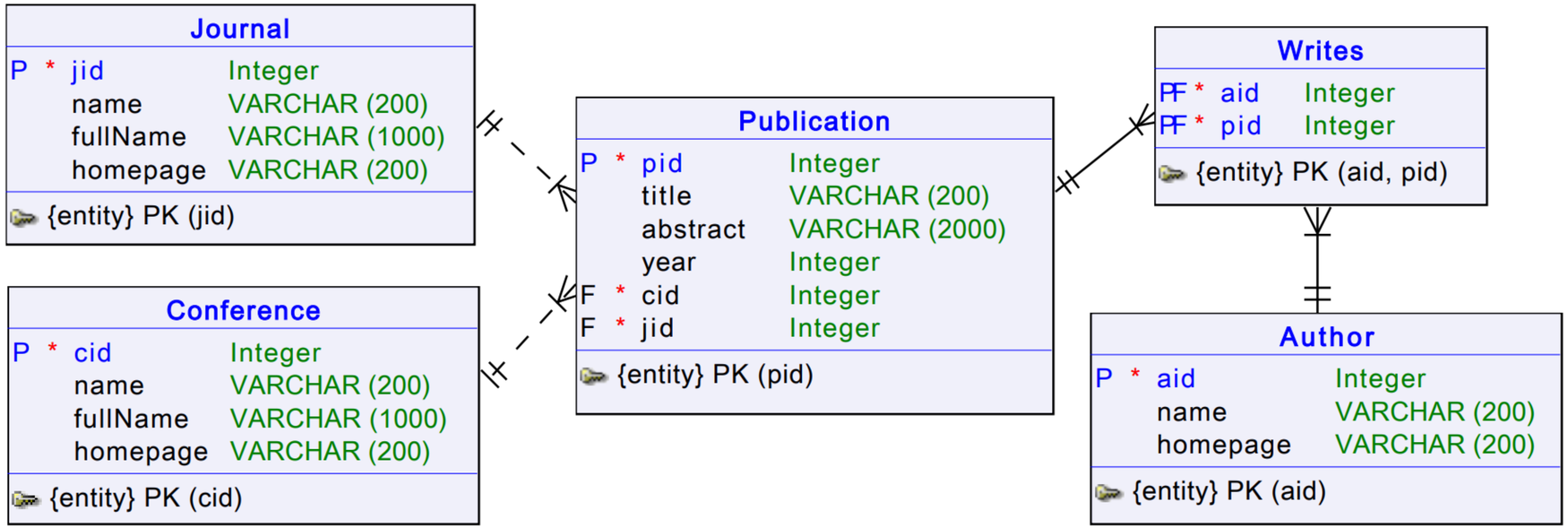


Example 2: SQLizer [Yaghmazadeh et al. 17]

- Synthesize SQL queries from natural language (given schema)

NL: *"Find the number of papers in OOPSLA 2010"*

Schema:

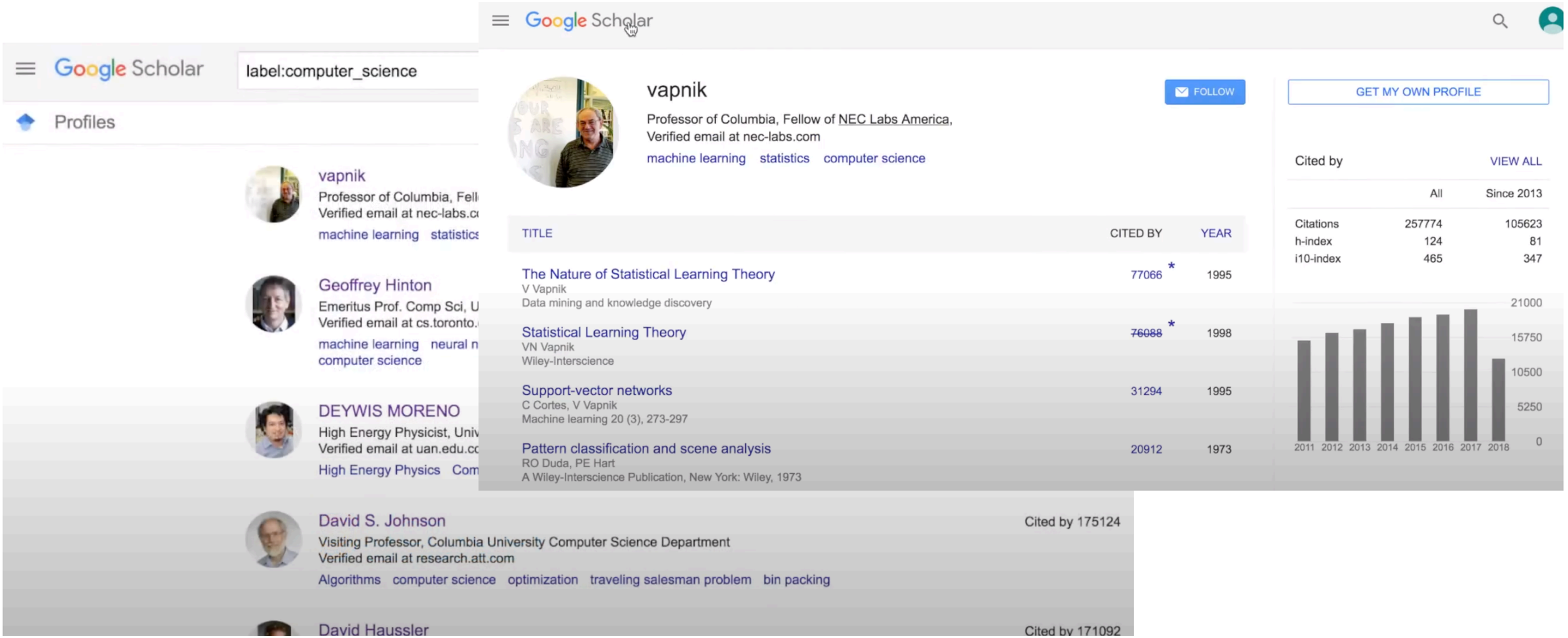


SQL query:

```
SELECT count(Publication.pid)
FROM Publication JOIN Conference ON Publication.cid = Conference.cid
WHERE Conference.name = "OOPSLA" AND Publication.year = 2010
```

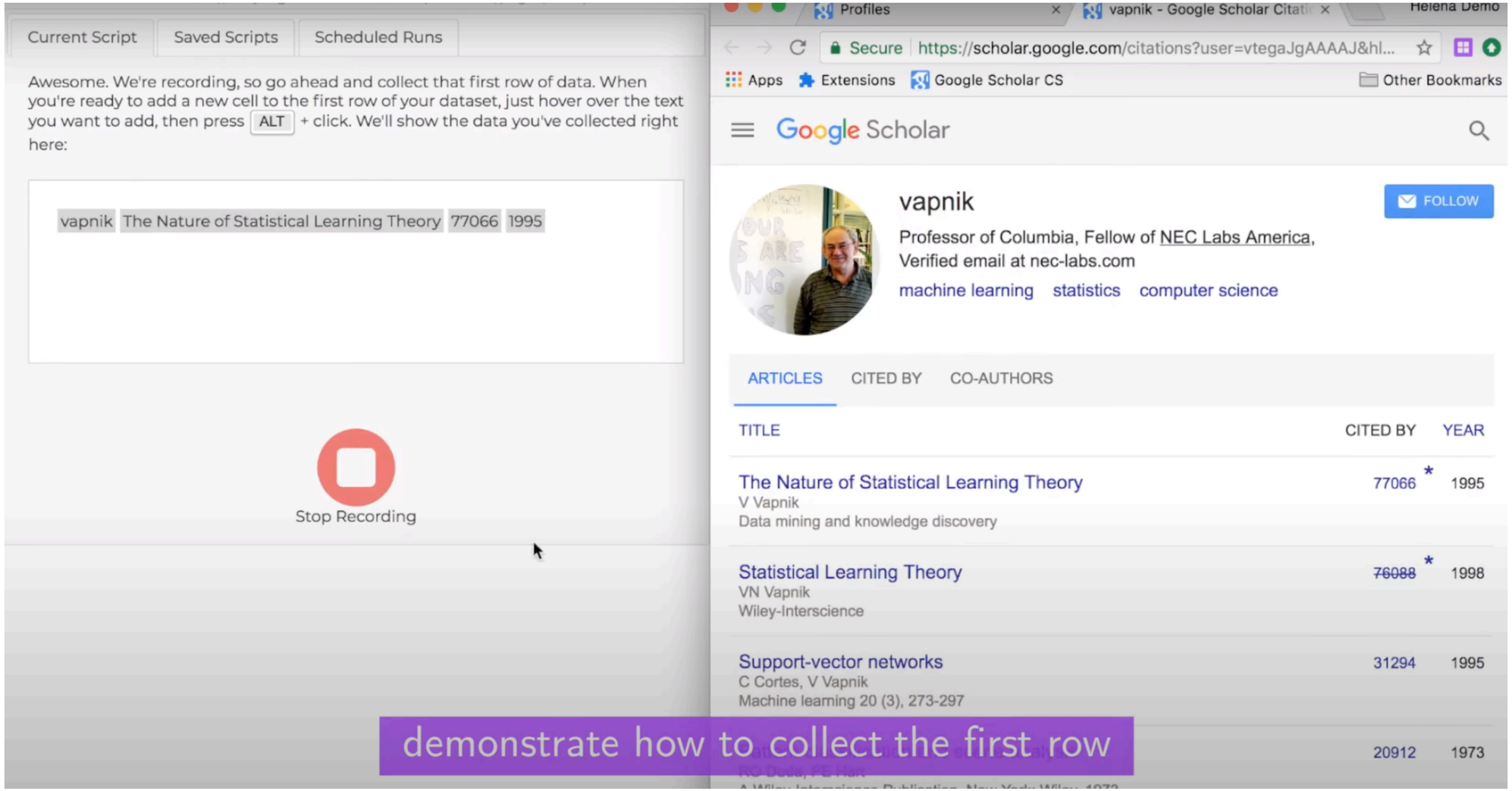
Example 3: Rousillon [Chasins et al. 18]

- Synthesize web scraping scripts from example demonstrations (video)



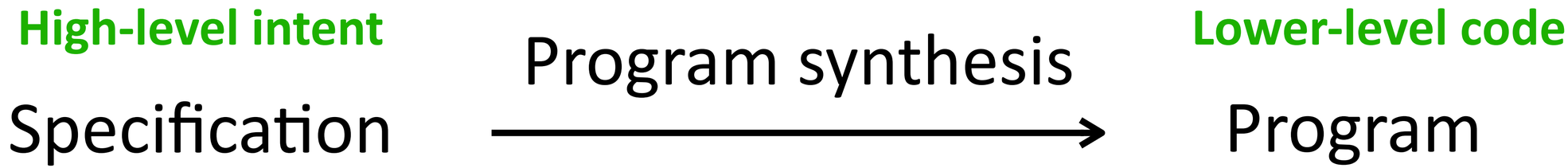
Example 3: Rousillon [Chasins et al. 18] (cont'd)

- Synthesize web scraping scripts from example demonstrations (video)



What is “program synthesis”?

- “Program Synthesis correspond to a class of techniques that are able to generate a program from a collection of artifacts that establish semantic and syntactic requirements for the generated code.” [1]



[1] http://people.csail.mit.edu/asolar/SynthesisCourse/Lecture1.htm

Program Synthesis vs. Machine Learning/Deep Learning

- ML/DL is also program synthesis?
  - ML/DL: data is spec, model is program, try to learn a model that matches data
  - At a high-level, yes
  - But in this class, no, at least not the focus
    - Definitions of “programs” are very different (e.g., grammar vs. neural nets)
    - Data is noisy whereas spec is less noisy (but there is a trend in program synthesis to tolerate noise in spec)
    - Typically continuous in ML/DL vs. discrete search space in program synthesis
    - The line is getting blurry

Program Synthesis vs. Compilers

- Program synthesizers are compilers? Compilers are synthesizers?
  - Compilers also convert high-level intent (code) to lower-level code
  - At a high-level, yes
  - But in this class, no, at least not the focus
    - Compilers translate (well, not really nowadays) whereas synthesizers discover
    - Compilers apply predefined transformations (again, not really nowadays) whereas synthesizers perform search
    - The line is getting blurry

Working definition of program synthesis in this course

High-level intent

Specification

I/O examples, demonstrations, natural language, reference implementation, etc.

Program synthesis

Typically involves search

Lower-level code

Program

In some programming language (grammar + semantics)

Why program synthesis?

- Many useful applications
  - E.g., FlashFill in Excel
- Technically challenging
  - Exponential search space (or even undecidable)
- Cool
  - Intersection of many areas: PL, AI, FM, systems, logics, …

Three pillars of program synthesis [Gottschlich et al. 18]

- Intention
  - How do users specify their goals?
  - Examples, demonstrations, NL, …, or their combinations!
  - Challenges: under-specified, ambiguous, unstructured
- Invention
  - How to find the right solution?
  - Search-based, representation-based, learning-based, …, and their combinations!
  - Challenges: scalability, ambiguity
- Adaptation
  - How to find the right solution, not starting from scratch?
  - Bug fixes, patches, extension to new hardwares, …
  - Challenges: analyzing, learning, scalability

This course

- Module 1: Techniques for example-based specs
  - Representation-based techniques (both top-down and bottom-up)
  - Search-based techniques (both top-down and bottom-up)
  - Using deduction to guide search and prune search space

  Invention

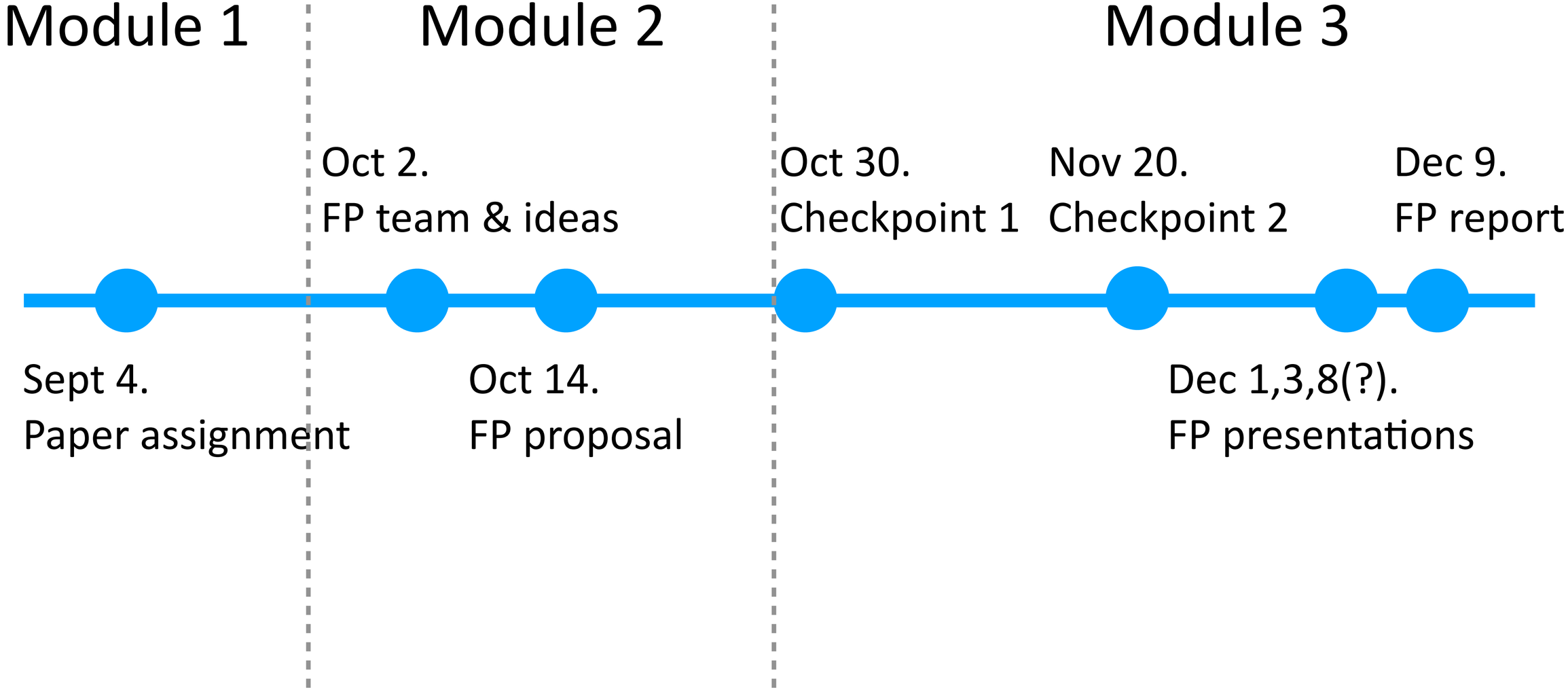
- Module 2: Techniques for specs beyond just examples
  - Specs: reference implementation, types, NL, multi-modal
  - Techniques: CEGIS, ML/DL-based, combinations, interactive

  Intention
  Invention

- Module 3: Applications
  - Super-optimizations, SE, web, DB, security, graphics, arch, …

  Intention
  Invention
  adaptation

Timeline (still tentative)



Summary of this lecture

- Program synthesis is cool
- You should take this class and learn about it
- You will learn a lot from this class

Next lecture (Sept 3)

- Syntax-guided synthesis
  - Popular framework for program synthesis

- Representation-based techniques
  - Top-down: FlashFill [Gulwani11], Sept 8
  - Bottom-up: Dace [Wang17], Sept 10

- Search-based techniques
  - Top-down: L2 [Feser15], Sept 15
  - Bottom-up: Optional readings of Sept 15 — [Udupa13], [Albarghouthi13]

Survey (optional)

- Send me a brief email with:
  - Name
  - I am a [CS/__] [PhD/Masters/undergrad] in year [1/2/3/4/5/…]
  - Write one reason why you are taking this class or one thing you want to get out of it
  - One thing you would like the instructor to do in this class
  - One fun fact about you, or what you like to do in your spare time, or whatever