Lecture 29:

- IR code generation (wrap up)
- Programming language paradigms

Announcements:

- HW-6 out
- Quiz 7 Fri: VM (trace instructions), code generation

(10) General rvalue path and lvalue expressions

- load the variable value (e.g., the `p` in `p.x.y.z`)
- repeatedly add a `GETF` instruction for remaining path (e.g., `x`, `y`, and `z`)
- for array access, generate index code and use `GETI`
- for assignment statements, last instruction is a `SETF` or `SETI`

(a) Simple example of non-array rvalue

```
struct Node {
  int val;
  Node next;
}

void main() {
  Node p = new Node(3, null);
  int x = p.val;
}
```

```
Frame main
   0: ALLOCS()  // new Node
   1: DUP()
   2: PUSH(3)
   3: SETF(val)
   4: DUP()
   5: PUSH(None)
   6: SETF(next)
   7: STORE(0)  // p
   8: LOAD(0)
   9: GETF(val)
   10: STORE(1)  // x
   11: PUSH(None)
   12: RET()
```

(b) Simple example of lvalue ...

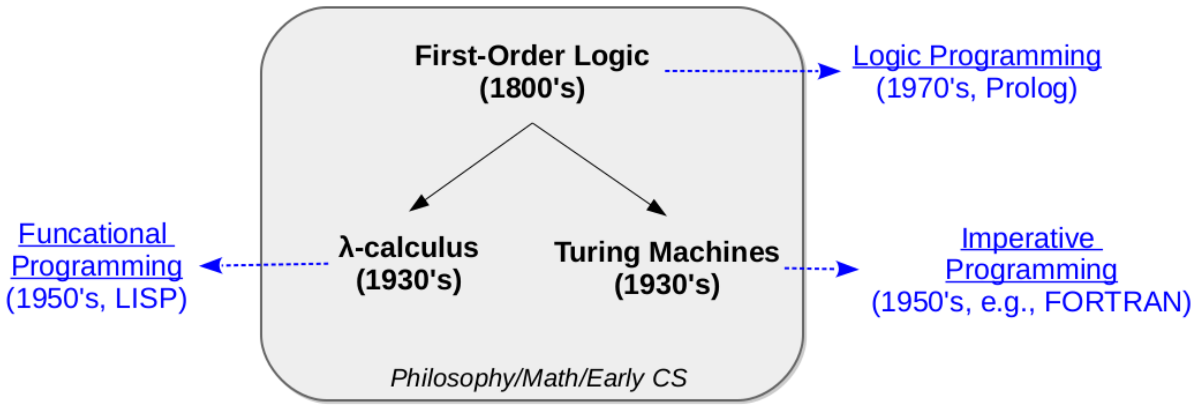
```
struct Node {
  int val;
  Node next;
}

void main() {
  Node p = new Node(3, null);
  // circular linked list!
  p.next = new Node(0, p);
  p.next.val = 4;
}
```

```
Frame main
   0: ALLOCS()  // new Node
   1: DUP()
   2: PUSH(3)
   3: SETF(val)
   4: DUP()
   5: PUSH(None)
   6: SETF(next)
   7: STORE(0)  // p
   8: LOAD(0)
   9: ALLOCS()  // new Node
   10: DUP()
   11: PUSH(0)
   12: SETF(val)
   13: DUP()
   14: LOAD(0)
   15: SETF(next)
   16: SETF(next)
   17: LOAD(0)
   18: GETF(next)
   19: PUSH(4)
   20: SETF(val)
   21: PUSH(None)
   22: RET()
```

Left as an exercise:

- expressions (evaluated left to right; except for >= and >)
- if statements (similar to loops, but more jumps to keep track of)
- array access (similar to field access, but use `GETI`, `SETI`, gen index code)

Programming Language Paradigms



Imperative vs Declarative Languages

> **Imperative Languages**: Programmers specify how to solve the problem and the system carries out the steps
>
> **Declarative Languages**: Programmers specify what the solution should look like and the system determines how best to compute the solution

Logic and Functional languages are generally considered (more) declarative

- compared to object-oriented & procedural languages (C/C++/Python/Java/etc.)
- largely has to do with the underlying models of computation used

There are other ways languages are categorized as well

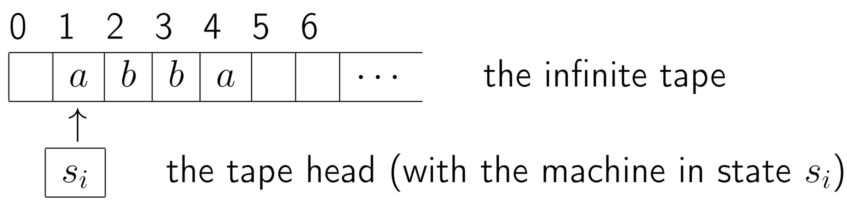
- e.g., script-based, object-oriented, dynamic vs static typing, memory-safety

From Turing Machines to Imperative Programming

Turing Machines:

1. ***infinite tape*** divided into memory cells (one symbol per cell)
2. ***read/write head*** that can move left/right one cell at a time
3. ***state register*** that stores the current state of the machine
4. ***state transition table***:
   curr state + curr head symbol → write symbol + new state + move head

Example: replace a's with b's



Transition Table: (where s_1 is start symbol, s_2 is halt symbol)

Current State	Current Symbol	New Symbol	New State	Direction
s_1	a	b	s_1	Right
s_1	b	b	s_1	Right
s_1	Blank	Blank	s_2	Left

Turing Machines are imperative ...

- they specify how the computation should be carried out (very low level)
- inspiration for RAM machines (read from mem, do op, write to mem)
- where higher-level languages abstract from the low-level computation model