# Lecture 3 - Building DSLs

Stanford CS343D (Fall 2021)
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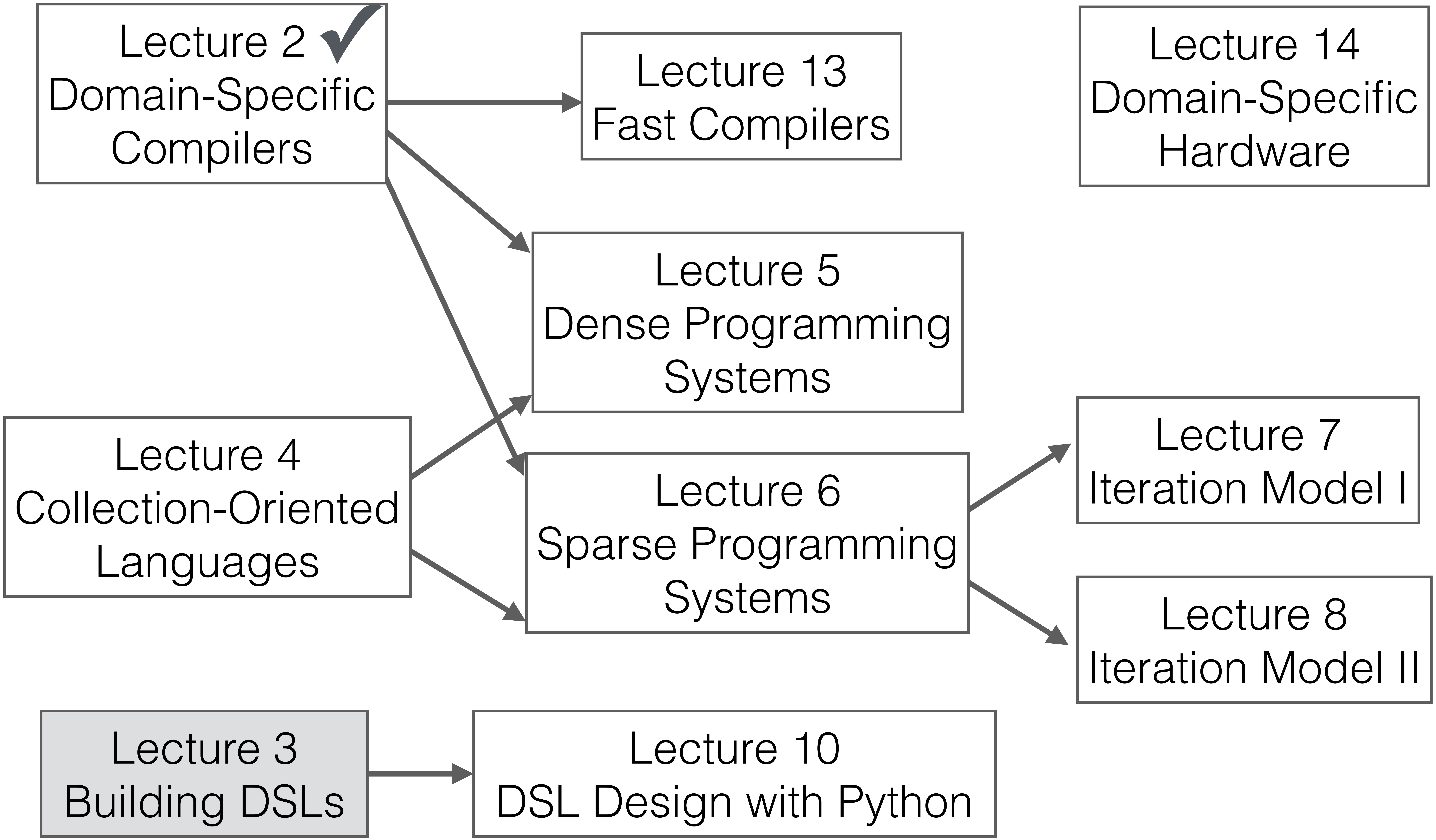
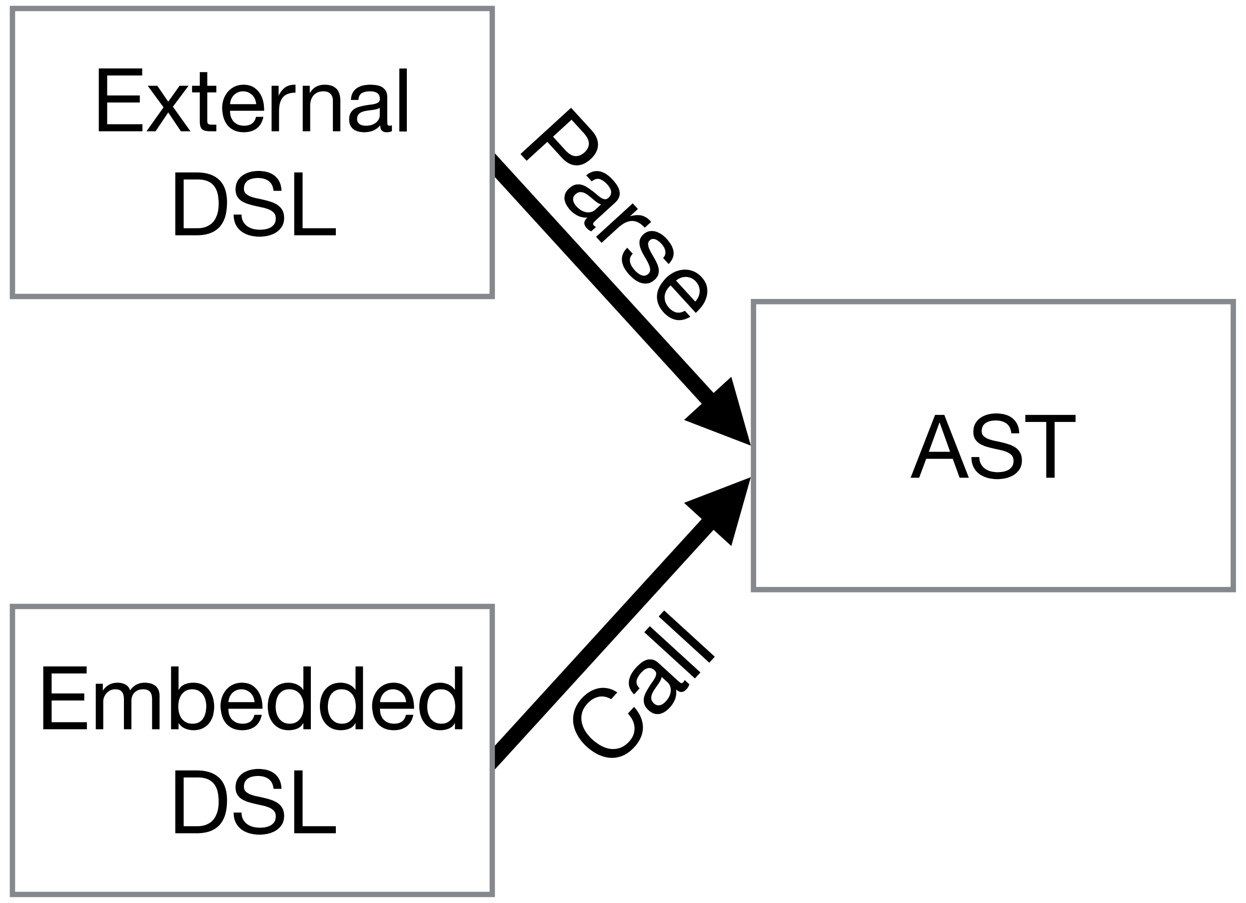
Slides based on lecture by Pat Hanrahan in CS343D Fall 2020

# Lecture Overview



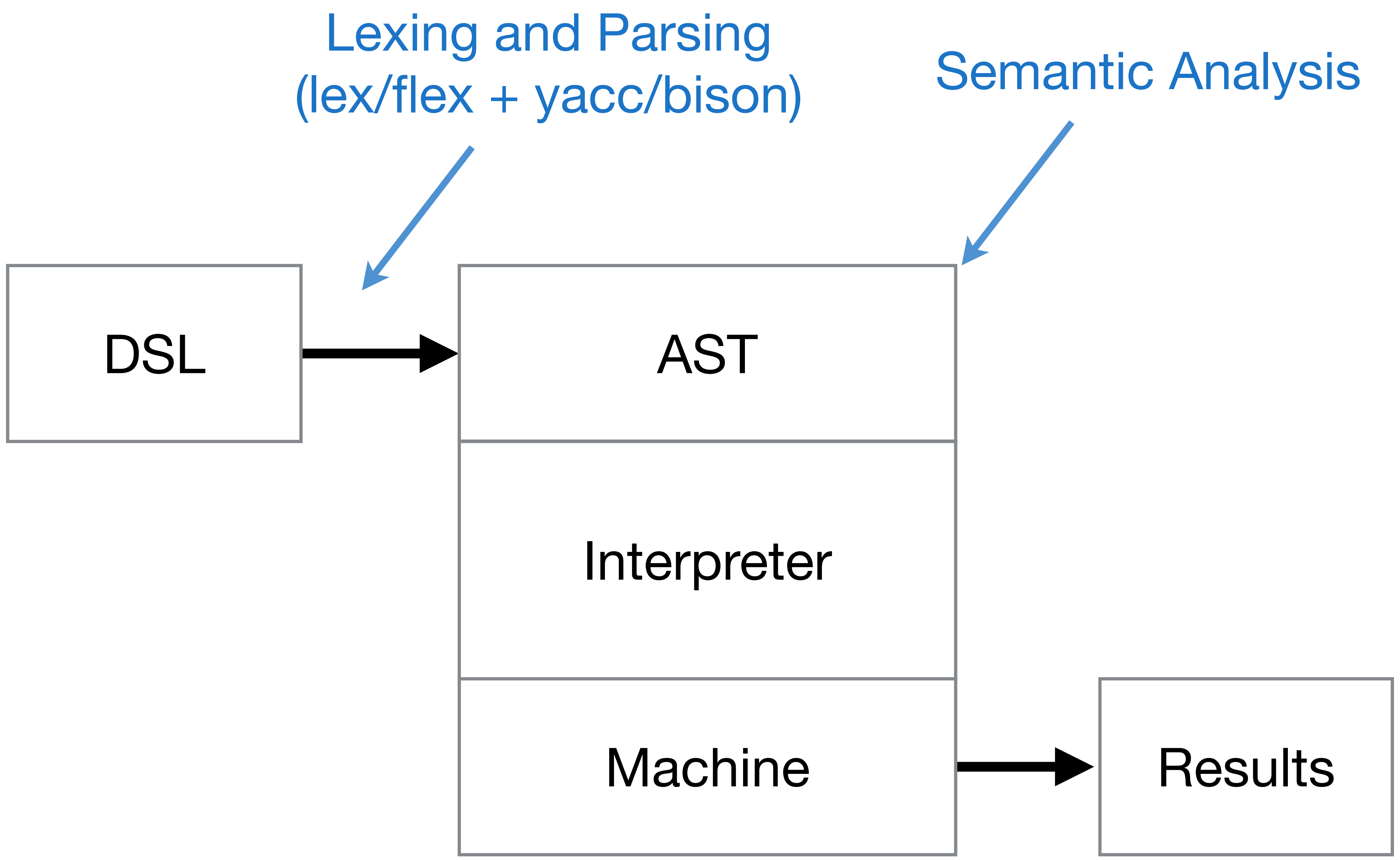
# Types of DSLs — languages or libraries?



# External DSLs

That is, DSLs as textual languages

# External DSLs — Implementation



# External DSLs — Demo

calc.py

lexical analysis
syntactic analysis
interpretation
ASTs

# External DSLs — Advantages and Disadvantages

**Advantages**

+ Flexibility (syntax and semantics)
+ Easy to make a small textual language

**Disadvantages**

- Yet another programming language
- Syntactic cacophony
- Slippery slope towards generality
- Hard to interoperate with other languages
- No tool chain: IDE, debuggers, profilers

# Embedded DSLs

That is, DSLs as a library

# Embedded DSL — Language implemented as a library

**OpenGL**

```
glMatrixMode(GL_PROJECTION);
glPerspective(45.0);

for(;;) {
    glBegin(TRIANGLES);
        glVertex(…);
        glVertex(…);
        …
    glEnd();
}

glSwapBuffers();
```

# Fluent Interfaces — Composable API calls with method chaining

**jquery**

```
<ul>
  <li>One</li>
  <li>Two</li>
  <li>Three</li>
</ul>

// turn first element green
$("li:first").css("color", "green");
```

# Sophisticated data rendering with embedded DSL

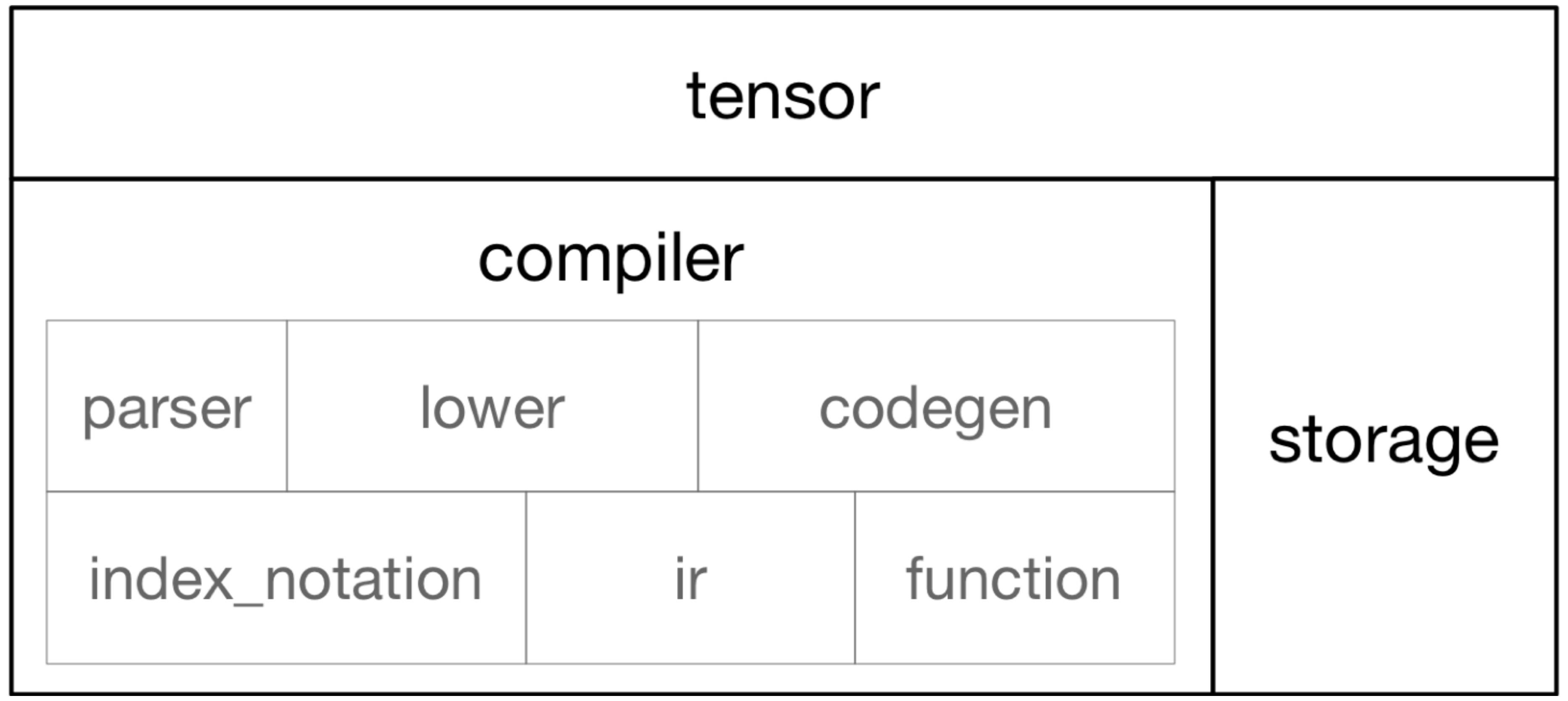
https://www.d3-graph-gallery.com/graph/density_basic.html

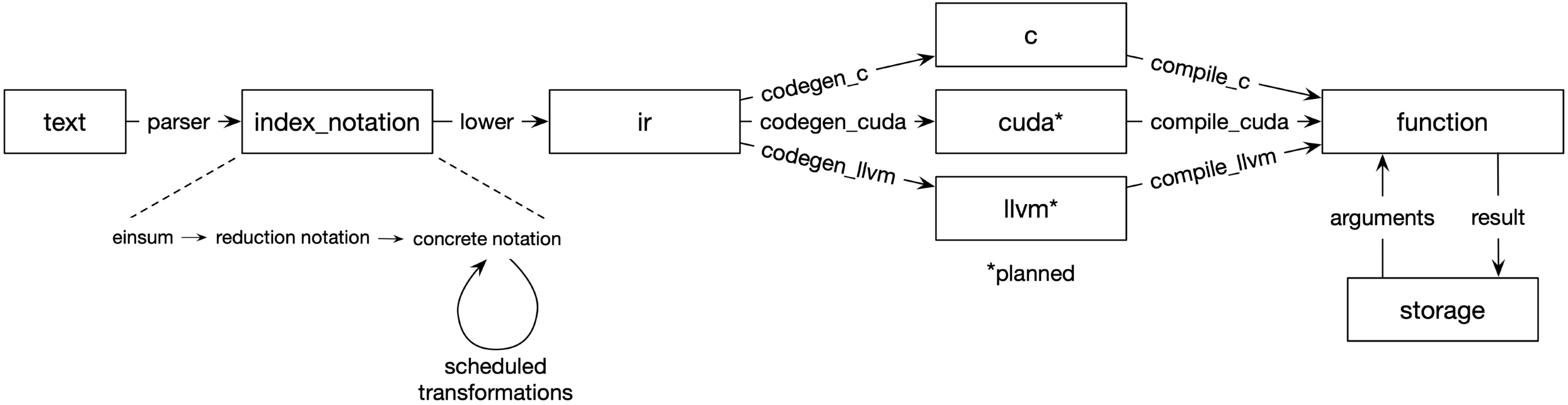
http://d3js.org/

# Sparse Tensor Algebra DSL in C++ (taco)

```
Format dv({dense});
Format csr({dense,compressed});

Tensor<double> a({m},   dv);
Tensor<double> c({n},   dv);
Tensor<double> B({m,n}, csr);

IndexVar i,j,i1,i2;
a(i) = sum(j, B(i,j) * c(j) );

a.split(i, i1, i2, Down, 32);
 .parallelize(i1, CPUThread, NoRaces);

std::cout << a << std::endl;
```

# taco — implementation



# C-like DSL (Pochi) embedded in C++ for online code generation

```
Function* regexfn = codegen(“ab.d*e”);
using Regexs = int(*)(vector<string>*);
auto [regexs, inputs] = newFunction<Regexs>(“regexs”);
auto result = regexs.newVariable<int>();
auto it = regexs.newVariable<vector<string>::iterator>();
regexs.setBody(
  Declare(result, 0),
  For(Declare(it, inputs->begin()),
      it != inputs->end(),
      it++
  ).Do(
    result += StaticCast<int>(
       Call<RegexFn>(regexfn, it->c_str()))
  ),
  Return(result)
);

vector<string> input {“abcde”, “abcdde”,  // good input
                      “abde” , “abcdef”}; // bad input
buildModule();
Regexs match = getFunction<Regexs>(“regexs”);
assert(match(&input) == 2);
```

Pochi loop iterates over a C++ STL iterator

```
using RegexFn = bool(*)(char* /*input*/);
Function* codegen(const char* regex) {
  auto [regexfn, input] = newFunction<RegexFn>();
  if (regex[0] == ‘\0’) {
    regexfn.setBody(
      Return(*input == ‘\0’)
    );
  } else if (regex[1] == ‘*’) {
    regexfn.setBody(
      While(*input == regex[0]).Do(
        input++,
        If (Call<RegexFn>(codegen(regex+2), input)).Then(
          Return(true)
        )
      ),
      Return(false)
    );
  } else if (regex[0] == ‘.’) {
    regexfn.setBody(
      Return(*input != ‘\0’ &&
             Call<RegexFn>(codegen(regex+1), input+1))
    );
  } else {
    regexfn.setBody(
      Return(*input == *regex &&
             Call<RegexFn>(codegen(regex+1), input+1))
    );
  }
  return regexfn;
}
```

Pochi test on runtime regex

# C# language designed for libraries and DSLs

**linq**

```
int count =
   (from character in Characters
   where character.Episodes > 120
   select character).Count();
```

# Embedded DSLs — Advantages and Disadvantages

**Advantages**

+ Familiar host language syntax
+ Can combine DSL code with host language features
+ Can interoperate with other libraries
+ Complete host language toolchain

**Disadvantages**

- Host language syntax can be rigid and verbose
- Hard to debug DSL with host language tools
- Hard to restrict features in DSL
- Still hard to develop

# DSL Construction Features

Type system: algebraic types or classes with inheritance

Polymorphism (multiple interpretation of the same AST)

Higher-order functions and lamdas (insert code)

Flexible syntax (e.g., operator overloading)

# Shallow Embedding

A shallow embedding is when the expressions are interpreted in the semantics of the base language

calc1.py: direct interpretation of arithmetic

# Deep Embedding

A deep embedding first builds an abstract syntax tree (AST). The abstract syntax tree is typically an algebraic data type. The AST is then evaluated with an interpreter.

calc2.py: AST represented as lists of lists

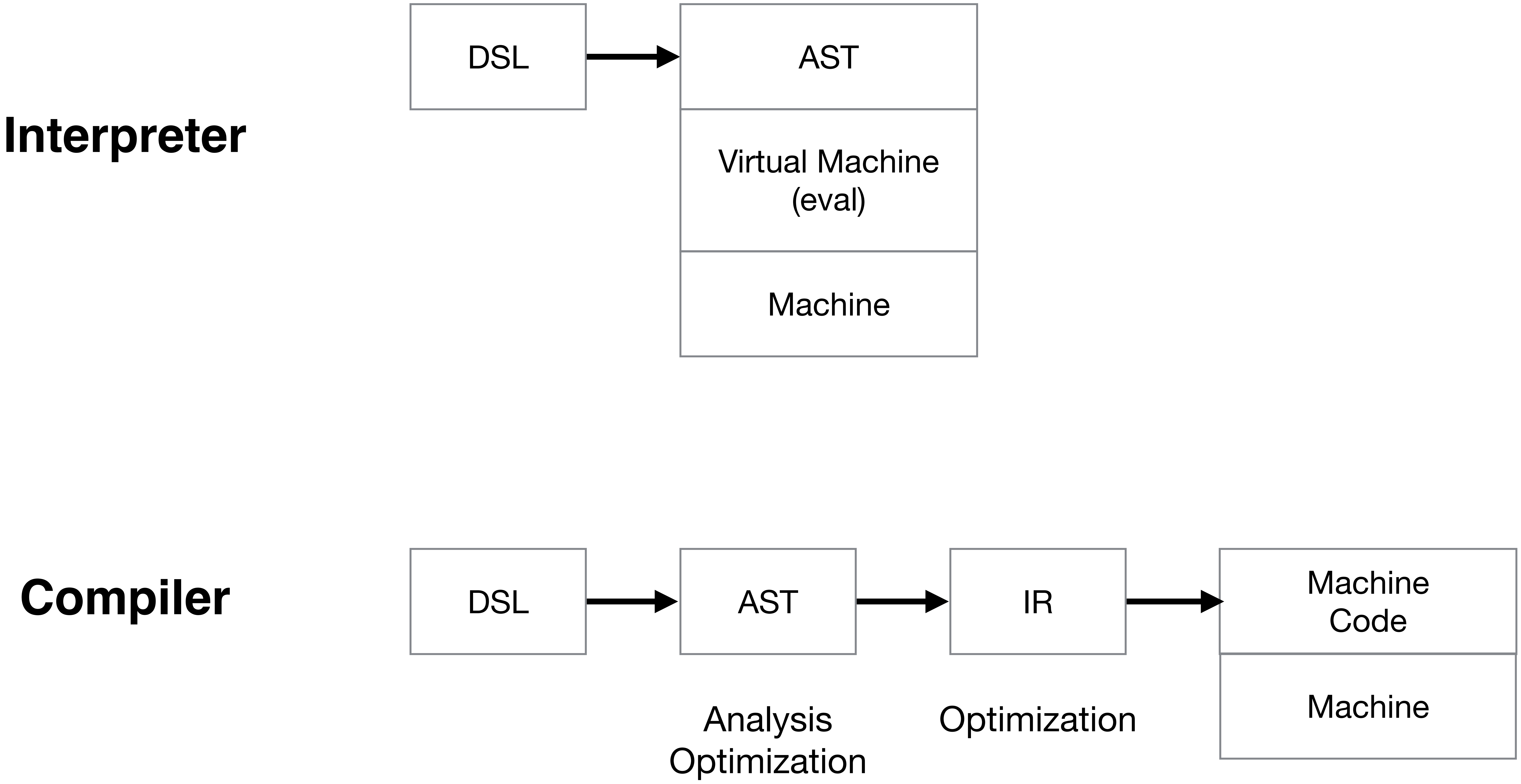
# Operator Overloading

Not all "operations" can be intercepted

- Arithmetic operators
- Iteration operators
- Function definition?
- Type/class definition?
- Equality?
- Assignment?

"Monkey patching" like this can be dangerous

# Interpretation vs. Compilation



# Mini-APL Assignment

- Implement simple array processing language in C++
- We provide recursive descent parser that builds an AST
- Lower the AST to LLVM; use LLVM to generate efficient code!
- The LLVM Kaleidoscope tutorial contains most of what you need to know
- Assignment released today, and due next Thursday (Oct. 7)
- Recitation tomorrow at 5pm with Caleb