Sweet Talk

(Perspectives on Writing Code)

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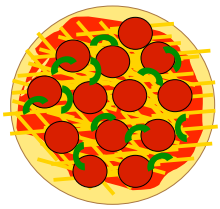
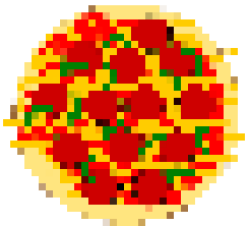
Anyone for … Pizza?



Pizzeria Style

It would be nice if we could write programs like this …



Digital Pizza

This is how we write programs!

This Lecture:

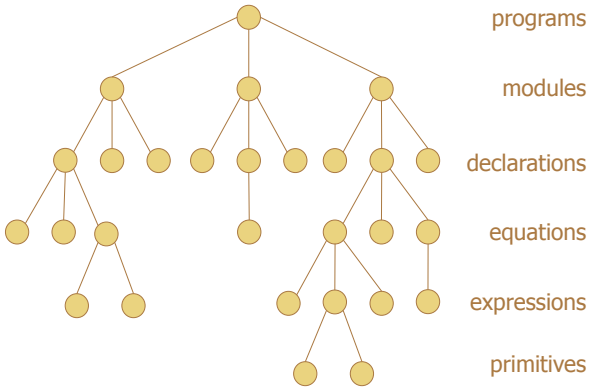
- Background: A long-term, work-in-progress, personal exploration: how do I express myself in the code that I write?
- My goal today: share some thoughts of mine, provoke some thoughts in you
- Themes:
  - Tangling and crosscutting concerns
  - Meta-programming/program generation
  - Literate programming

Tangling

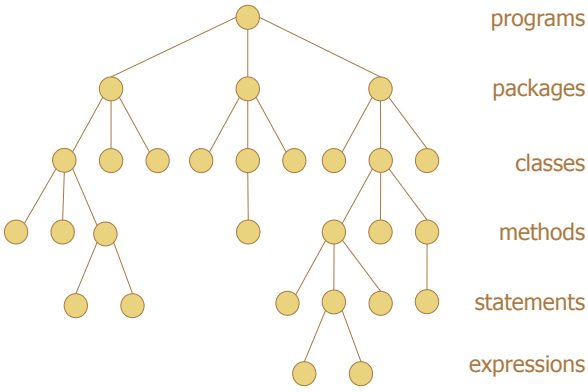
Context:

- This is a talk about programming (no theory)
- Different programming languages teach us:
  - to think in different ways
  - to develop problem solving skills
- But any single language ultimately constrains the way that a programmer thinks …
- The "Tyranny of the Dominant Decomposition" (Ossher & Tarr)

Hierarchical Modularity Mechanisms:



Hierarchical Modularity Mechanisms:



Tangling Considered Inevitable:

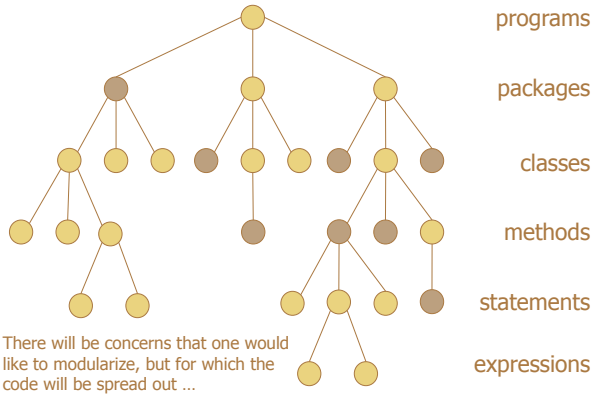
In the implementation of any complex system …

… when programs are written using the hierarchical modularity mechanisms of current programming languages …

… and as they evolve to add new functionality …

… tangling is **inevitable**

Crosscutting Concerns:



There will be concerns that one would like to modularize, but for which the code will be spread out …

Tangling Considered Harmful:

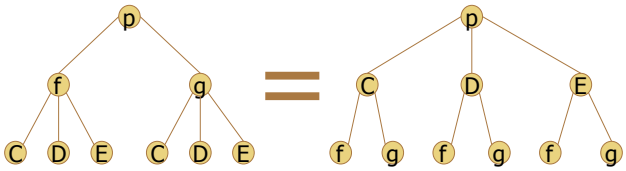
When programmers are forced to weave different aspects of functionality together, the end results are likely to be:

- Harder to write
- Harder to maintain
- Less reliable
- Harder to reuse
- Less portable

What if our tools did this for us instead?

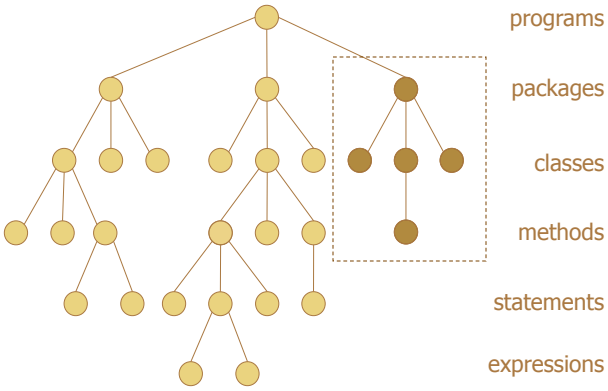
Equalities on Program Trees:

If our programming language admitted structure changing equalities …



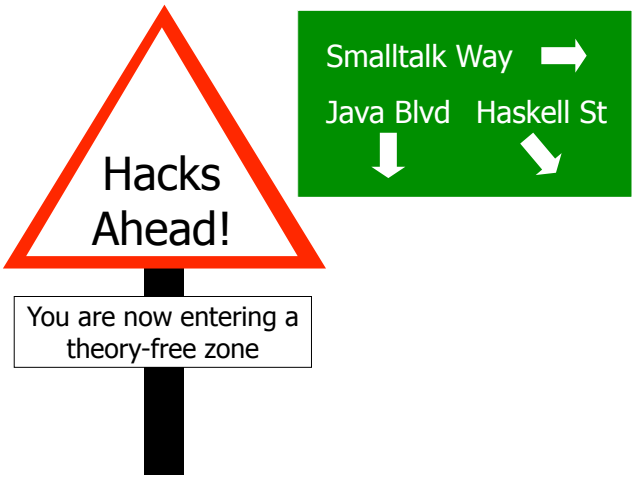
… then perhaps we could factor out new code more easily as a separate structure …

Modularizing Change:



Same Program, Different Views:

- Multiple, equivalent views of a program's source code
- Equivalences described by localized tree transformations
- Potential for additional meta-programming functionality at nodes



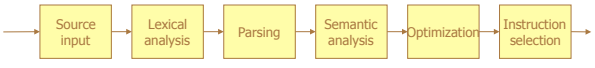
Experiences in Compiler Construction

The mini Java compiler, mjc:

- mjc is a compiler for a subset of Java that produces IA32 assembly code for the 386 and later processors
- mjc was written to accompany my compiler class

The Structure of CS32x:

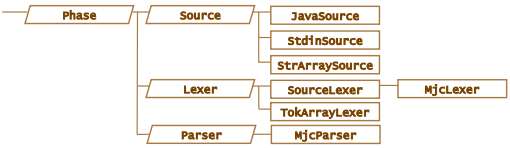
- Compilers are often structured as a pipeline of separate phases …



- It makes sense to structure a compilers class in a similar way …
- But some parts of the code for mjc don't fit this pattern!

Representing Compiler Phases:

- Compiler phases represented by an abstract type Phase:



- Different `Phase`s serve very different purposes, but they all have the potential to generate diagnostics.
- Different `Source`s obtain their input in different ways, but each one can be called on to return a sequence of input lines.
- Some components are specific to Mini Java, others are potentially language independent

Using Inheritance (1):

- In examples like these, we use inheritance to document the existence of multiple implementations of a particular interface …
- Can introduce code for these phases incrementally
- Structure of code corresponds to structure of presentation

Putting the Pieces Together:

```
Source source
  = new JavaSource(handler, descr, reader);

MjcLexer lexer
  = new MjcLexer(handler, source);

MjcParser parser
  = new MjcParser(handler, lexer);

ClassType[] classes
  = parser.getClasses();
```

Source Input

Lexical Analysis

Parsing

Putting the Pieces Together:

```
Source source
  = new JavaSource(handler, descr, reader);

MjcLexer lexer
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MjcParser parser
  = new MjcParser(handler, lexer);

ClassType[] classes
  = parser.getClasses();
```

Error handling

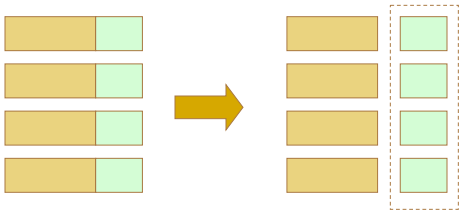
Source Input

Lexical Analysis

Parsing

Factoring out Error Handling:

- It would be nice if I could factor out error handling as a separate aspect:



- I haven't figured out how to do that yet …

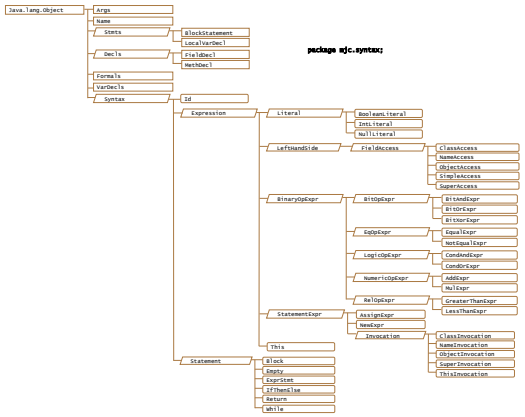
Representing Abstract Syntax:

- The tree structures that are used to representing abstract syntax are described by a collection of classes
- There are more than 60 of these classes, which can seem quite daunting
- Understanding how these classes are organized can make things much easier to follow

Using Inheritance (2):

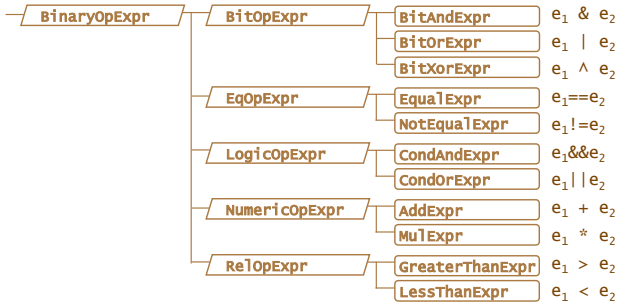
- In examples like these, we use inheritance to encode datatypes …
- Similar to **datatype**/**data** definitions in ML/ Haskell

Abstract Syntax in mjc:



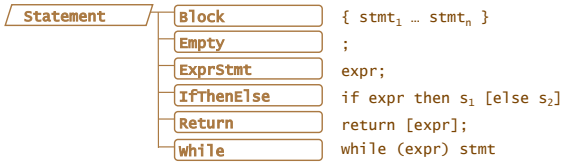
Binary Operator Expressions:

- Expressions with binary operators have two operands:
  `new BinaryOpExpr(pos,expr1,expr2)`



Statements:

- mjc supports only a few kinds of statement, but these are enough to write interesting programs:



An Example:

```
public class While extends Statement {
    private Expression test;
    private Statement  body;

    public While(Position pos,
                 Expression test,
                 Statement body) {
        super(pos);
        this.test = test;
        this.body = body;
    }
    …
}
```

The attributes of a while statement.

Position used in error reports.

Constructs an object that represents a While statement…

static analysis/code generation goes here!

… continued:

```
public class While extends Statement {
    …

    boolean check(Context ctxt, Env env) {…}

    void compile(Assembly a) {…}

    void compileThen(Assembly a, Label l) {…}
}
```

Static analysis & type checking

Standard code generator scheme

Specialized code generator scheme…

… continued

The `While` class encapsulates all of the features of a while statement in one place:

- **Perfect**, if you want to use it as a model for adding a `repeat…until` construct
- **Not at all convenient**, if you want to understand later phases of the compiler (e.g., type checking):
  - Can't see parts corresponding to other constructs
  - Other, irrelevant features obscure your view

Back in CS32x …

- I don't attempt to talk about all the different classes any more … a couple of examples will/have to suffice
- The Java encoding mixes essential details with irritating noise … harder for students to identify and focus on key parts, and greater potential for errors to creep in
- We can't package up "static analysis", "type checking", or "code generation" as modular chunks of code … Instead, we must scatter little bits in each of the abstract syntax classes
- diffs are a useful tool for quick patches, but not a good vehicle for reliable software composition.

Observations:

- There is a lot of boilerplate in declaring classes, attributes, and constructors:
  - uninspiring to code
  - easy to make mistakes
  - painful to change

The Sweet Approach

A List Datatype:


```
public abstract class List {
   abstract public int length();
}
public class Nil extends List {
   public Nil() {}
   public int length() { return 0; }
}
public class Cons extends List {
    private int  head;
    private List tail;
    public Cons(int head, List tail) {
        this.head = head;
        this.tail = tail;
    }
    public int length() {
        return 1 + tail.length();
    }
}
```

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    public Cons(int head, List tail) {
        this.head = head;
        this.tail = tail;
    }
    public int length() {
        return 1 + tail.length();
    }
}
```

A simple enough idiom … but tedious to write …

Lots of boilerplate

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    public Cons(int head, List tail) {
        this.head = head;
        this.tail = tail;
    }
    public int length() {
        return 1 + tail.length();
    }
}
```

Duplication of information!

A List Datatype:

```
public abstract class List {
   abstract public int length();
}
public class Nil extends List {
   public Nil() {}
   public int length() { return 0; }
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public class Cons extends List {
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    public Cons(int head, List tail) {
        this.head = head;
        this.tail = tail;
    }
    public int length() {
        return 1 + tail.length();
    }
}
```

Tangling of datatype definitions with the implementations of operations

First Attempt:

- Capture essential details in a data structure, and use a (Haskell) program to generate all the boilerplate:

```
[Node "List" [] ["public int length()"]
     [Node "Nil" [] [] [],
      Node "Cons" [("int", "head"), ("List", "tail")] [] []]]
```

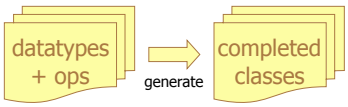
- Nice idea …but:
  - Deeply nested expressions like this are not easy to write (or get right) in Haskell syntax
  - The data structures become increasingly complicated as new features are added …
  - Once you start modifying the generated code, it's hard to change the datatype.

Generating Skeletons is Not Enough!

- We generate code and then modify it, by hand, to add the implementations of any operations.

- These modifications are not captured in the real source code for the program.

- We need a new **s**tatic **we**aving and **e**diting **t**ool:



Introducing Sweet:

```
public abstract class List {
   public case Nil
   public case Cons(private int head,
                    private List tail)
}

public int length()
  case List abstract;
  case Nil  { return 0; }
  case Cons { return 1 + tail.length(); }
```

Down with boilerplate!
Down with repetition!
Down with tangling!

Hmm, this looks familiar!

```
data List
   = Nil
   | Cons { head :: Int, tail:: List }

length                    :: List -> Int
length Nil                 = 0
length (Cons {head,tail}) = 1 + length tail
```

But looks can be deceiving …

Pizza Recipes, not Pizzas:

```
public abstract class List {
   public case Nil
   public case Cons(private int head,
                    private List tail)
}
```

defining "addresses" in the code

```
public int length()
  case List abstract;
  case Nil  { return 0; }
  case Cons { return 1 + tail.length(); }
```

providing content at specific addresses

Poor man's meta-programming: the input to sweet is **not** a program … it's a description of how to construct/extend a program …

Extensibility:

To build a bigger program, add instructions to define new addresses, and new content:

```
public class Append(private List l,
                    private List r) extends List {
    public int length() {
        return l.length() + r.length();
    }
}
```

You can't do that **in** Haskell! or Java or Smalltalk

```
data List
   = Nil
   | Cons { head :: Int, tail:: List }
   | Append { l :: List, r :: List }

length                    :: List -> Int
length Nil                 = 0
length (Cons head tail)    = 1 + length tail
length (Append l r)        = length l + length r
```

Visitors in Java (infrastructure):

```
interface ListVisitor {
  int visitNil(Nil nil);
  int visitCons(Cons cons);
}
class List { … abstract int accept(ListVisitor v); }
class Nil  { …
  int accept(ListVisitor visitor) {
    visitor.visitNil(this);
  }
}
class Cons { …
  int accept(ListVisitor visitor) {
     visitor.visitCons(this);
  }
}
```

A lot of boilerplate

Can't be generated within running Java code

Adding a new Append class would still be a crosscutting concern

Visitors in Java (instantiation):

```
class LengthVisitor implements ListVisitor {
  int visitNil(Nil nil) { return 0; }
  int visitCons(cons cons) {
    return 1 + cons.getTail().accept(this);
  }
}

class SumVisitor implements ListVisitor {
  int visitNil(Nil nil) { return 0; }
  int visitCons(cons cons) {
    return cons.getHead() + cons.getTail().accept(this);
  }
}
```

Requires us to break object encapsulation

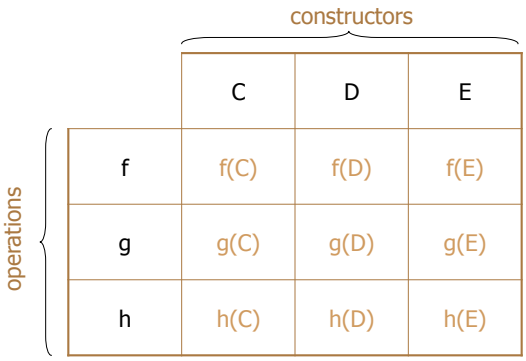
Visitors in Java (… continued):

```
class MemberVisitor implements ListVisitor {
  private int elem;
  MemberVisitor(int elem) {
    this.elem = elem;
  }

  boolean visitNil(Nil nil) { return false; }
  boolean visitCons(cons cons) {
    return cons.getHead()==elem
        || cons.getTail().accept(this);
  }
}
```

Static typing may require us to create a whole family of visitors!

The Program Grid:



Rows …

constructors

operations	C	D	E
f	f(C)	f(D)	f(E)
g	g(C)	g(D)	g(E)
h	h(C)	h(D)	h(E)

"Functional"

… and Columns:

constructors

operations	C	D	E
f	f(C)	f(D)	f(E)
g	g(C)	g(D)	g(E)
h	h(C)	h(D)	h(E)

"Object-oriented"

Same Program, Different Views:

constructors

	C	D	E
f	f(C)	f(D)	f(E)
g	g(C)	g(D)	g(E)
h	h(C)	h(D)	h(E)

Breaking the "Tyranny of the Dominant Decomposition"

Back to mjc:

- In preliminary experiments, I have used sweet to refactor the code for mjc, separating out different aspects for:
  - Abstract syntax
  - Static analysis
  - Typing
  - Code generation
  - Etc…
- And I have also found bugs in mjc resulting from duplication in the original code …
- An ongoing project, yet to be inflicted on my compilers students …

Case Study: Building a Lexical Analyzer

Building a Lexical Analyzer:

- Lexical analysis is a process that breaks an input stream into a series of "tokens" and returns a code to describe each one.
- How do we add a new token to a lexer?
  1. Select a new code to identify the token
  2. Map the token string to the token code
  3. Update code to recognize new token code

Step 1: Define token code

```
public class Alphabet {
  …
  public static final int WHILE = 63;
  public static final int DO    = 64;
  …
}
```

Be sure to pick a distinct code for each token!

But the specific choice doesn't matter …

Step 2: Map string to code

```
public class Alphabet {
  Alphabet() {
    …
    addReserved("while", WHILE);
    addReserved("do",    DO);
    …
  }

  private Hashtable reserved = new Hashtable();
  private void addReserved(String str, int token) {
    reserved.put(str, new Integer(token));
  }
}
```

Step 3: Recognize new code

```
public class Alphabet {
  …
  public String describeToken(int token) {
    switch (token) {
      …
      case  WHILE : return "while keyword";
      case  DO    : return "do keyword";
      …
      default     : return "unknown token";
    }
  }
  …
}
```

default is required in case we forget to cover one or more of the token codes …

Using Sweet Syntax:

```
macro AddReservedSymbol(TOK, lexeme, description) {
  class Alphabet {
    public static final int TOK = @fresh;
    Alphabet()      > { addReserved(lexeme, TOK); }
    @describeTokens > { case TOK : return description; }
  }
}

…
macro AddReservedSymbol(WHILE, "while", "while keyword")
…
```

All three steps combined in one definition …

All three steps invoked in one call …

Sweet Notation:

- @fresh generates a unique integer code for every source code occurrence
- Add code to a particular class:
  - class Foo { … new code goes here … }
- Change code at a particular location:
  - address > { add to end }
  - address ! { replace }
  - address < { add at beginning }
  - Address can be a method or constructor name, or a source position, @Position

Code Positions, @name:

```
public String describeToken(int token, String lexeme) {
  switch (token) {
    case ENDINPUT  : return "end of input";
    case INTLIT    : return "int literal, " + lexeme;
    case STRINGLIT : return "string literal, " + lexeme;
    case POPEN     : return "open parenthesis, \"(\"";
    case PCLOSE    : return "close parenthesis, \")\"";
    …
    case COMMA     : return "comma, \",\"";
    case SEMI      : return "semicolon, \";\"";
    …
    @describeTokens
  }
  return "lexeme, \"" + lexeme + "\"";
}
```

Sweet Macros:

- Define a new macro:
  - macro M(arg1,…,argn) { … code template here … }
  - Arguments arg1, …, argn used in template
- Invoke a macro:
  - macro M(val1, …, valn)
  - Expands to template for macro replacing each arg identifier with the corresponding val value

Identifier Splicing:

Multiple identifiers can be spliced together using a backslash:

```
macro List(X) {
  public class X\s(public X head, public X\s next)
}
macro AddCons(X) {
  class X {
    public X\s cons(X\s next) {
      return new X\s(this, next);
    }
  }
}
```

Setters and Getters:

Sweet provides some limited methods for deriving code automatically:

```
public int setter getter foo;
```

This can almost be captured with macros:

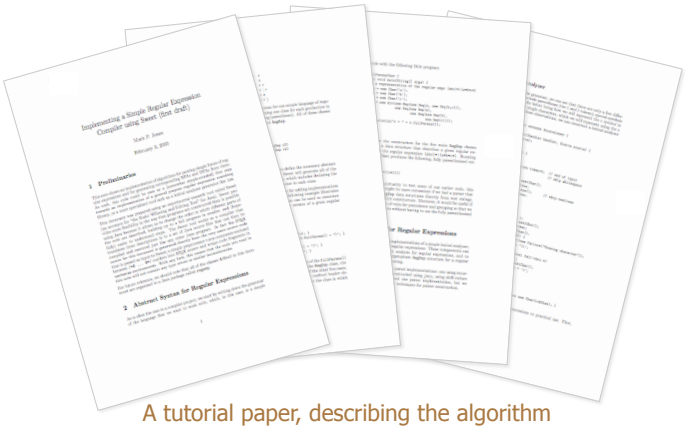
```
macro setter(T,X) { void set\X(T X) { this.X = X; } }
macro getter(T,X) { T get\X() { return this.X; } }
```

(But this is ugly; it duplicates type information, and doesn't camel case the setter/getter names)

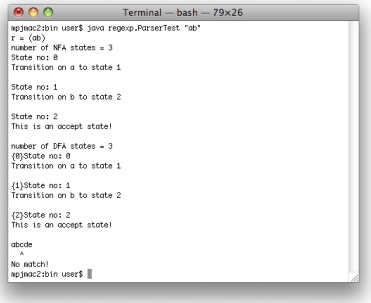
Band-aid for a Bad Language?

- The features that I've described are arguably just a work-around for:
  - missing features in the Java programming language
  - my unwillingness to use "standard" Java idioms
- But it's not clear how to achieve some of these features using current language technology, especially if we care about static typing
- Some may one day become part of new language designs, albeit in a more general and elegant form
- Some will never be more than an ugly hack :-)

Case Study: Regular Expressions



A tutorial paper, describing the algorithm for converting regular expressions into NFAs and NFAs into DFAs



Executable code for the algorithm for converting regular expressions into NFAs and NFAs into DFAs

Abstract Syntax

We can generate all of the classes for representing the syntax of regular expressions from the following lines of sweet code:

```
abstract class RegExp {
  case Epsilon
  case Char(private int c)
  case Seq(private RegExp r1, private RegExp r2)
  case Alt(private RegExp r1, private RegExp r2)
  case Rep(private RegExp r)
}
```

Functions on RegExps:

We can defined functions on RegExp values by a collection of cases:

```
public String fullParens()
  case RegExp  abstract;
  case Epsilon { return "%"; }
  case Char    { return Character.toString((char)c); }
  case Seq     { return "(" + r1.fullParens()
                            + r2.fullParens() + ")"; }
  case Alt     { return "(" + r1.fullParens()
                            + "|" + r2.fullParens()
                            + ")"; }
  case Rep     { return "(" + r.fullParens() + "*)"; }
```

RegExp Visitors:

We could even use sweet to automate the construction of some of the boilerplate for type-specific visitors:

```
macro RegExpVisitor(T) {
 interface RegExpVisitor\T {
   T visitEpsilon\T(Epsilon epsilon);
   …
   T visitRep\T(Rep rep);
}
T accept(RegExpVisitor\T visitor)
 case RegExp abstract;
 case Epsilon { return visitor.visitEpsilon\T(this); }
 …
 case Rep     { return visitor.visitRep\T(this); }
}
```

Incremental Construction:

Define key parts of the representation for DFA/NFA state:

```
class State {
    Transition[] trans  = null;
    boolean      accept = false;
}
```

Add more code later, to suit the narrative:

```
class State {
    /** Output a description of this machine state.
     */
    void display() {
        …
    }
}
```

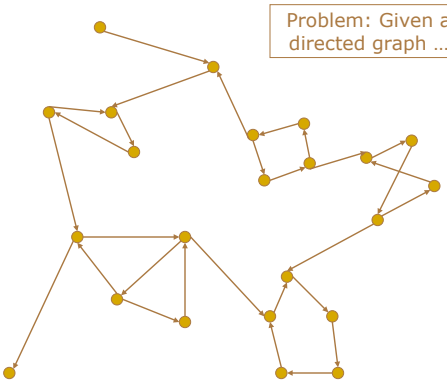
Building NFAs:

```
State toNFA(State s)
  case RegExp abstract;
  case Epsilon { return s; }
  case Seq {
    return r1.toNFA(r2.toNFA(s));
  }
  …
  case Rep {
    State n = new State();
    n.trans = new Transition[] {
      new Transition(r.toNFA(n)), new Transition(s)
    };
    return n;
  }
```

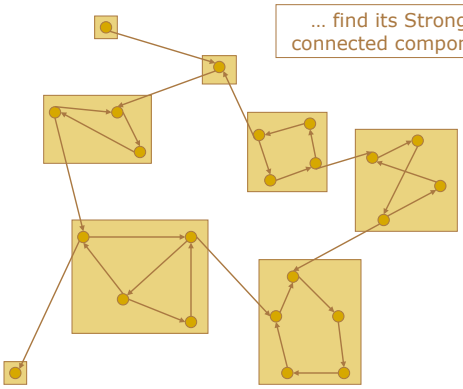
Read the full document at:
http://www.cs.pdx.edu/~mpj/regexp.pdf

Case Study: Dependency Analysis

Dependency Analysis (SCCs):



Dependency Analysis (SCCs):



Dependency Analysis (SCCs):

`class Binding {` | `class Bindings {`

Represent/construct dependency graph

Kosaraju and Sharir's SCC algorithm: $dfs_2(dfs_1(g))$

First depth-first search → ordered list of bindings

Second depth-first search → list of groups

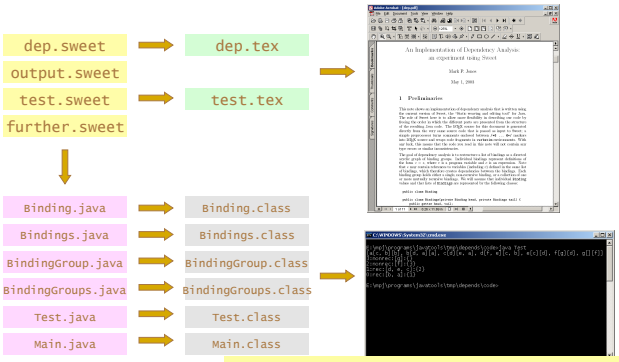
Pointer to binding group

Simple example/test

Further tests

`}` | `}`

Sweet Literate Programming:



Read the full document at:
http://www.cs.pdx.edu/~mpj/dep.pdf

Sweet and Sour

Sweet Problems: (1)

1) Code out of context:

```
/** Check whether this statement is valid and return a boolean
 *  indicating whether execution can continue at the next statement.
 */
public boolean check(Context ctxt, VarEnv env, int slot)
  case Statement abstract;
  case Block {
    return (stmts==null) || stmts.check(ctxt, env, slot);
  }
  case Empty {
    return true; // Always runs on ...
  }
  case ExprStmt {
    try {
        expr.checkExpr(ctxt, env);
    } catch (Diagnostic d) {
        ctxt.report(d);
    }
    return true;
  }
  …
```

where are these variables defined?

An IDE could show context as the user moves from one program point to the next …

Sweet Problems: (2 & 3)

2) Tracing back errors:
How do javac's errors relate back to sensible diagnostics on sweet code?

Does sweet need to provide its own compiler?

How far can static checking go?

3) Incremental computation:
Minor changes in sweet code triggers complete rebuild!

Tyranny Transferred:

- With Sweet, the **language** no longer dictates a "dominant decomposition"
- But there is still a dominant decomposition, courtesy of the program's **initial author**
- When the regime is relaxed … a new tyrant steps in!

Closing Thoughts

Work in Progress:

- There are known flaws in both the design and the implementation of Sweet
- Both design and implementation evolve (very slowly) as I work on case studies
- Sweet is a personal project, not published/ reviewed research, not necessarily novel
- Writing literate code is time consuming, and limits agility

Questions to Ponder:

- How do you want to express yourself as an advanced programmer?
- What are your goals as an author?
- How do current languages and tools help or hinder you?
- How would you write programs if you had the freedom to choose your own decomposition?