GAMMA

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GAMMA: A Strict yet Fair Programming Language

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A Project for Programming Languages and Translators,
taught by Stephen Edwards

1 Introduction

1.1 Why GAMMA? – The Core Concept

We propose to implement an elegant yet secure general purpose object-oriented programming language. Interesting features have been selected from the history of object-oriented programming and will be combined with the familiar ideas and style of modern languages.

GAMMA combines three disparate but equally important tenets:

1. Purely object-oriented

   GAMMA brings to the table a purely object oriented programming language where every type is modeled as an object–including the standard primitives. Integers, Strings, Arrays, and other types may be expressed in the standard fashion but are objects behind the scenes and can be treated as such.

2. Controllable

   GAMMA provides innate security by choosing object level access control as opposed to class level access specifiers. Private members of one object are inaccessible to other objects of the same type. Overloading is not allowed. No subclass can turn your functionality on its head.

3. Versatile

   GAMMA allows programmers to place "refinement methods" inside their code. Alone these methods do nothing, but may be defined by subclasses so as to extend functionality at certain important positions. Anonymous instantiation allows for extension of your classes in a quick easy fashion.

1.2 The Motivation Behind GAMMA

GAMMA is a reaction to the object-oriented languages before it. Obtuse syntax, flaws in security, and awkward implementations plague the average object-oriented language. GAMMA is intended as a step toward ease and comfort as an object-oriented programmer.

The first goal is to make an object-oriented language that is comfortable in its own skin. It should naturally lend itself to constructing API-layers and abstracting general models. It should serve the programmer towards their goal instead of exerting unnecessary effort through verbosity and awkwardness of structure.

The second goal is to make a language that is stable and controllable. The programmer in the lowest abstraction layer has control over how those higher may procede. Unexpected runtime behavior should be reduced through firmness

of semantic structure and debugging should be a straight-forward process due to pure object and method nature of GAMMA.

1.3 GAMMA Feature Set

GAMMA will provide the following features:

- Universal objecthood
- Optional "refinement" functions to extend superclass functionality
- Anonymous class instantiation
- Static typing
- Access specifiers that respect object boundaries, not class boundaries

1.4 ray: The GAMMA Compiler

The compiler will proceed in two steps. First, the compiler will interpret the source containing possible syntactic shorthand into a file consisting only of the most concise and structurally sound GAMMA core. After this the compiler will transform general patterns into (hopefully portable) C code, and compile this to machine code with whatever compiler the user specifies.

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2 Language Tutorial

The structure of the example below should be intimately familiar to any student of Object-Oriented Programming.

```
class IOTest:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := promptInteger("Please enter an integer")
      Float f := promptFloat("Please enter a float")
      p.printString("Sum of integer + float = ")
      p.printFloat(i.toF() + f)
      p.printString("\n")

  private:
    void prompt(String msg):
      system.out.printString(msg)
      system.out.printString(": ")

    Integer promptInteger(String msg):
      prompt(msg)
      return system.in.scanInteger()

    Float promptFloat(String msg):
      prompt(msg)
      return system.in.scanFloat()

  main(System system, String[] args):
    IOTest test := new IOTest()
    test.interact()
```

Example 1: "A simple I/O example"

We start with a definition of our class.

```
class IOTest:
```

We follow by starting a `public` access level, defining an `init` method for our class, and calling the `super` method inside the init method. (Since we have not indicated a superclass for `IOTest`, this `super` method is for `Object`.)

```
    public:
        init():
            super()
```

We also define the `private` access level with three methods: a generic method that prints a prompt message and two prompts for `Integers` and `Floats` respectively. These prompts call the generic message and then read from `system.in`.

```
private:
  void prompt(String msg):
    system.out.printString(msg)
    system.out.printString(": ")

  Integer promptInteger(String msg):
    prompt(msg)
    return system.in.scanInteger()

  Float promptFloat(String msg):
    prompt(msg)
    return system.in.scanFloat()
```

We then write a method under the `public` access level. This calls our `private` level methods, convert our `Integer` to a `Float` and print our operation.

```
  void interact():
    Printer p := system.out
    Integer i := promptInteger("Please enter an integer")
    Float f := promptFloat("Please enter a float")
    p.printString("Sum of integer + float = ")
    p.printFloat(i.toF() + f)
    p.printString("\n")
```

Finally, we define the `main` method for our class. We just make a new object of our class in that method and call our sole public method on it.

```
main(System system, String[] args):
  IOTest test := new IOTest()
  test.interact()
```

3 Language Reference Manual

3.1 Lexical Elements

3.1.1 Whitespace

The new line (line feed), form feed, carriage return, and vertical tab characters will all be treated equivalently as vertical whitespace. Tokens are separated by horizontal (space, tab) and vertical (see previous remark) whitespace of any length (including zero).

3.1.2 Identifiers

Identifiers are used for the identification of variables, methods and types. An identifer is a sequence of alphanumeric characters, uppercase and lowercase, and underscores. A type identifier must start with an uppercase letter; all others must start with a lower case letter. Additionally, the lexeme of a left bracket followed immediately by a right bracket – `[]` – may appear at the end of a type identifier in certain contexts, and that there may be multiple present in this case (denoting arrays, etc). The legal contexts for such will be described later.

3.1.3 Keywords

The following words are reserved keywords. They may not be used as identifiers:

```
   and      class      else      elsif    extends    false
    if       init      main       nand        new      nor
   not         or   private  protected     public refinable
refine refinement    return      super       this       to
  true       void     while        xor
```

3.1.4 Operators

There are a large number of (mostly binary) operators:

```
  =    =/=   <>     <     <=    >       >=
  +     -     *     /     %     ^       :=
 +=    -=    *=    /=    %=    ^=
and   or   not   nand   nor   xor   refinable
```

3.1.5 Literal Classes

A literal class is a value that may be expressed in code without the use of the new keyword. These are the fundamental units of program.

Integer Literals An integer literal is a sequence of digits. It may be prefaced by a unary minus symbol. For example:

- `777`
- `42`
- `2`
- `-999`
- `0001`

Float Literals A float literal is a sequence of digits and exactly one decimal point/period. It must have at least one digit before the decimal point and at least one digit after the decimal point. It may also be prefaced by a unary minus symbol. For example:

- `1.0`
- `-0.567`
- `10000.1`
- `00004.70000`
- `12345.6789`

Boolean Literals A boolean literal is a single keyword, either `true` or `false`.

String Literals A string literal consists of a sequence of characters enclosed in double quotes. Note that a string literal can have the new line escape sequence within it (among others, see below), but cannot have a new line (line feed), form feed, carriage return, or vertical tab within it; nor can it have the end of file. Please note that the sequence may be of length zero. For example:

- `"Yellow matter custard"`
- `""`
- `"Dripping\n   from a dead"`
- `"'s 3y3"`

The following are the escape sequences available within a string literal; a backslash followed by a character outside of those below is an error.

- `\a` - u0007/alert/BEL

- `\b` - u0008/backspace/BB
- `\f` - u000c/form feed/FF
- `\n` - u000a/linefeed/LF
- `\r` - u000d/carriage return/CR
- `\t` - u0009/horizontal tab/HT
- `\v` - u000b/vertical tab/VT
- `\'` - u0027/single quote
- `\"` - u0022/double quote
- `\\` - u005c/backslash
- `\0` - u0000/null character/NUL

3.1.6 Comments

Comments begin with the sequence `/*` and end with `*/`. Comments nest within each other. Comments must be closed before the end of file is reached.

3.1.7 Separators

The following characters delineate various aspects of program organization (such as method arguments, array indexing, blocks, and expressions):

```
[  ]  (  )  ,
```

A notable exception is that `[]` itself is a lexeme related to array types and there can be no space between the two characters in this regard.

3.2 Semantics

3.2.1 Types and Variables

Every *variable* in Gamma is declared with a *type* and an *identifier*. The typing is static and will always be known at compile time for every variable. The variable itself holds a reference to an instance of that type. At compile time, each variable reserves space for one reference to an instance of that type; during run time, each instantiation reserves space for one instance of that type (i.e. *not* a reference but the actual object). To be an instance of a type, an instance must be an instance of the class of the same name as that type or an instance of one of the set of descendants (i.e. a subclass defined via `extends` or within the transitive closure therein) of that class. For the purposes of method and

refinement return types there is a special keyword, `void`, that allows a method or refinement to use the `return` keyword without an expression and thus not produce a value.

Array Types When specifying the type of a variable, the type identifier may be followed by one or more `[]` lexemes. The lexeme implies that the type is an *array type* of the *element type* that precedes it in the identifier. Elements of an array are accessed via an expression resulting in an array followed by a left bracket `[`, an expression producing an offset index of zero or greater, and a right bracket `]`. Elements are of one dimension less and so are themselves either arrays or are individual instances of the overall class/type involved (i.e. `BankAccount`).

3.2.2 Classes, Subclasses, and Their Members

GAMMA is a pure object-oriented language, which means every value is an object – with the exception that `this` is a special reference for the object of the current context; the use of `this` is only useful inside the context of a method, `init`, or refinement and so cannot be used in a `main`. `init` and `main` are defined later.

A class always extends another class; a class inherits all of its superclass's methods and may refine the methods of its superclass. A class must contain a constructor routine named *init* and it must invoke its superclass's constructor via the super keyword – either directly or transitively by referring to other constructors within the class. In the scope of every class, the keyword `this` explicitly refers to the instance itself. Additionally, a class contains three sets of *members* organized in *private*, *protected*, and *public* sections. Members may be either variables or methods. Members in the public section may be accessed (see syntax) by any other object. Members of the protected section may be accessed only by an object of that type or a descendant (i.e. a subtype defined transitively via the `extends` relation). Private members are only accessible by the members defined in that class (and are not accessible to descendants). Note that access is enforced at object boundaries, not class boundaries – two `BankAccount` objects of the same exact type cannot access each other's balance, which is in fact possible in both Java & C++, among others. Likewise if `SavingsAccount` extends `BankAccount`, an object of savings account can access the protected instance members of `SavingsAccount` related to its own data, but *cannot* access those of another object of similar type (`BankAccount` or a type derived from it).

The Object Class The Object class is the superclass of the entire class hierarchy in GAMMA. All objects directly or indirectly inherit from it and share its methods. By default, class declarations without extending explicitly are subclasses of Object.

The Literal Classes There are several *literal classes* that contain uniquely identified members (via their literal representation). These classes come with methods developed for most operators. They are also all subclasses of Object.

Anonymous Classes A class can be anonymously subclassed (such must happen in the context of instantiation) via refinements. They are a subclass of the class they refine, and the objects are a subtype of that type. Note that references are copied at anonymous instantiation, not values.

3.2.3 Methods

A method is a reusable subdivision of code that takes multiple (possibly zero) values as arguments and can either return a value of the type specified for the method, or not return any value in the case that the return type is `void`.

It is a semantic error for two methods of a class to have the same signature – which is the return type, the name, and the type sequence for the arguments. It is also a semantic error for two method signatures to only differ in return type in a given class.

Operators Since all variables are objects, every operator is in truth a method called from one of its operands with the other operands as arguments – with the notable exception of the assignment operators which operate at the language level as they deal not with operations but with the maintenance of references (but even then they use methods as `+=` uses the method for `+` – but the assignment part itself does not use any methods). If an operator is not usable with a certain literal class, then it will not have the method implemented as a member.

3.2.4 Refinements

Methods and constructors of a class can have *refine* statements placed in their bodies. Subclasses must implement *refinements*, special methods that are called in place of their superclass' refine statements, unless the refinements are guarded with a boolean check via the `refinable` operator for their existence – in which case their implementation is optional.

It is a semantic error for two refinements of a method to have the same signature – which is the return type, the method they refine, the refinement name, and the type sequence for the arguments. It is also a semantic error for two method signatures to only differ in return type in a given class.

A refinement cannot be implemented in a class derived by a subclass, it must be provided if at all in the subclass. If it is desired that further subclassing should handle refinement, then these further refinements can be invoked inside the refinements themselves (syntactic sugar will make this easier in future releases). Note that refining within a refinement results in a refinement of the

same method. That is, using `refine extra(someArg) to String` inside the refinement `String toString.extra(someType someArg)` will (possibly, if not guarded) require the next level of subclassing to implement the extra refinement for toString.

3.2.5 Constructors (init)

Constructors are invoked to arrange the state of an object during instantiation and accept the arguments used for such. It is a semantic error for two constructors to have the same signature – that is the same type sequence.

3.2.6 Main

Each class can define at most one `main` method to be executed when that class will 'start the program execution' so to speak. Main methods are not instance methods and cannot refer to instance data. These are the only 'static' methods allowed in the Java sense of the word. It is a semantic error for the main to have a set of arguments other than a system object and a String array.

3.2.7 Expressions and Statements

The fundamental nature of an expression is that it generates a value. A statement can be a call to an expression, thus a method or a variable. Not every statement is an expression, however.

3.3 Syntax

The syntaxic structures presented in this section may have optional elements. If an element is optional, it will be wrapped in the lexemes `<<` and `>>`. This grouping may nest. On rare occasions, a feature of the syntax will allow for truly alternate elements. The elements are presented in the lexemes `{{` and `}}`, each feature is seperated by the lexeme `|`. If an optional element may be repeated without limit, it will finish with the lexeme `....`

3.3.1 Statement Grouping via Bodies

A body of statements is a series of statements at the same level of indentaiton.

```
1    <<stmt1_statement>>
2    <<stmt2_statement>>
3    <<...>>
```

This is pattern is elementry to write.

```
    Mouse mouse = new Mouse()
    mouse.click()
    mouse.click_fast()
    mouse.click("Screen won't respond")
    mouse.defenestrate()
```

Example 2: Statement Grouping of a Typical Interface Simulator

3.3.2 Variables

Variable Assignment Assigning an instance to a variable requires an expression and a variable identifier:

```
var_identifier := val_expr
```

If we wanted to assign instances of Integer for our pythagorean theorem, we'd do it like so:

```
a := 3
b := 4
```

Example 3: Variable Assignment for the Pythagorean Theorem

Variable Declaration Declaring a variable requires a type and a list of identifiers deliminated by commas. Each identifier may be followed by the assignment operator and an expression so as to combine assignment and declaration.

```
var_type var1_identifier << := val1_expr >> << , var2_identifier <<
    := val2_expr >> >> <<...>>
```

If we wanted to declare variables for the pythagorean theorem, we would do it like so:

```
Float a, b, c
```

Example 4: Variable Initialization for the Pythagorean Theorem

Array Declaration Declaring an array is almost the same as declaring a normal variable, simply add square brackets after the type. Note that the dimension need be given.

```
element_type[]...[] array_identifier << := new element_type[](
    dim1_expr,..., dimN_expr) >>
```

If we wanted a set of triangles to operate on, for instance:

```
Triangle[] triangles := new Triangle[](42)
```

Example 5: Array Declaration and Instantiation of Many Triangles

Or perhaps, we want to index them by their short sides and initialize them later:

```
Triangle[][] triangles
```

Example 6: Array Declaration of a 2-Degree Triangle Array

Array Dereferencing To dereference an instance of an array type down to an instance its element type, place the index of the element instance inside the array instance between [and] lexemes after the variable identifier. This syntax can be used to provide a variable for use in assignment or expressions.

```
var_identifier[dim1_index]...[dimN_index]
```

Perhaps we care about the fifth triangle in our array from before for some reason.

```
Triangle my_triangle := triangles[4]
```

Example 7: Array Dereferencing a Triangle

3.3.3 Methods

Method Invocation Invoking a method requires at least an identifier for the method of the current context (i.e. implicit `this` receiver). The instance that the method is invoked upon can be provided as an expression. If it is not provided, the method is invoked upon `this`.

```
<< instance_expr.>>method_identifier(<<arg1_expr>> <<, arg2_expr>>
    <<...>>)
```

Finishing our pythagorean example, we use method invocations and assignment to calculate the length of our third side, c.

```
c := ((a.power(2)).plus(b.power(2))).power(0.5)
```

Example 8: Method Invocation for the Pythagorean Theorem Using Methods

Method Invocation Using Operators Alternatively, certain base methods allow for the use of more familiar binary operators in place of a method invocation.

```
op1_expr operator op2_expr
```

Using operators has advantages in clarity and succinctness even if the end result is the same.

```
c := ( a^2 + b^2 )^0.5
```

Example 9: Method Invocation for the Pythagorean Theorem Using Operators

Operator Precedence In the previous examples, parentheses were used heavily in a context not directly related to method invocation. Parentheses have one additional function: they modify precedence among operators. Every operator has a precidence in relation to its fellow operators. Operators of higher precedence are enacted first. Please consider the following table for determining precidence:

Method Declaration & Definition A method definition begins with the return type – either a type (possibly an n-dimensional array) or void. There is one type and one identifier for each parameter; and they are delimited by commas. Following the parentheses is a colon before the body of the method at an increased level of indentaiton. There can be zero or more statements in the body. Additionally, refinements may be placed throughout the statements.

:=	+=	-=	*=	/=	%=	^=
or	xor	nor				
and	nand					
=	<>	=/=				
>	<	>=	<=			
+	-					
*	/	%				
unary minus						
not	^					
array dereferencing		(	)			
method invocation						

Table 1: Operator Precedence

```
{{return_type | Void}} method_identifier (<<arg1_type
    arg1_identifier>> <<, arg2_type arg2_identifier>> <<...>>):
    method_body
```

Finally, we may define a method to do our pythagorean theorem calculation.

```
Float pythagorean_theorem(Float a, Float b):
    Float c
    c := ( a^2 + b^2 )^0.5
    return c
```

Example 10: Method Definition for the Pythagorean Theorem

3.3.4 Classes

Section Definition Every class always has at least one section that denotes members in a certain access level. A section resembles a body, it has a unified level of indentation throughout a set of variable and method declarations, including `init` methods.

```
    <<{{method1_decl | var1_decl | init1_decl}}>>
    <<{{method2_decl | var2_decl | init2_decl}}>>
    <<...>>
```

Class Declaration & Definition A class definition always starts with the keyword `class` followed by a type (i.e. capitalized) identifier. There can be no

brackets at the end of the identifier, and so this is a case where the type must be purely alphanumeric mixed with underscores. It optionally has the keyword `extends` followed by the identifier of the superclass. What follows is the class body at consistent indentation: an optional `main` method, the three access-level member sections, and refinements. There may be `init` methods in any of the three sections, and there must be (semantically enforced, not syntactically) an `init` method either in the protected or public section (for otherwise there would be no way to generate instances).

While the grammar allows multiple main methods to be defined in a class, any more than one will result in an error during compilation.

```
class class_identifier <<extends superclass_identifier>>:
    <<main_method>>
    <<{{private | protected | public | refinement}} section1>>
    <<{{private | protected | public | refinement}} section1>>
    <<...>>
```

Let's make a basic geometric shape class in anticipation of later examples. We have private members, two access-level sections and an init method. No extends is specified, so it is assumed to inherit from Object.

```
class Geometric_Shape:
    private:
        String name
        Float area
        Float circumfrence
    public:
        init (String name):
            this.name = name
            if (refinable(improve_name)):
              this.name += refine improve_name() to String

            return

        Float get_area():
            Float area
            area := refine custom_area() to Float
```

Example 11: Class Declaration for a Geometric Shape class

Class Instantiation Making a new instance of a class is simple.

```
new class_identifier(<<arg1_expr>> <<,arg2_expr>> <<...>>)
```

For instance:

```
Geometric_Shape = new Geometric_Shape("circle")
```

Example 12: Class Instantiation for a Geometric Shape class

Anonymous Classes An anonymous class definition is used in the instantiation of the class and can only provide refinements, no additional public, protected, or private members. Additionally no init or main can be given.

```
new superclass_identifier(<<arg1_expr>> <<,arg2_expr>> <<...>>):
    <<refinements>>
```

3.3.5 Conditional Structures

If Statements The fundamental unit of an if statement is a keyword, followed by an expression between parentheses to test, and then a body of statements at an increased level of indentaiton. The first keyword is always `if`, each additional condition to be tested in sequence has the keyword `elsif` and a final body of statements may optionally come after the keyword `else`.

```
if (test1_expr): if1_body
<<elsif (test2_expr) if2_body>>
<<elsif(test3_expr) if3_body>>
<<...>>
<<else if4_body>>
```

While Statements A while statement consists of only the `while` keyword, a test expression and a body.

```
while(test_expr): while_body
```

3.3.6 Refinements

The Refine Invocation A refine invocation will eventually evaluate to an expression as long as the appropriate refinement is implemented. It is formed

by using the keyword `refine`, the identifier for the refinement, the keyword `to`, and the type for the desired expression. Note that a method can only invoke its own refinements, not others – but refinements defined *within* a class can be called. This is done in addition to normal invocation. Also note that all overloaded methods of the same name share the same refinements.

```
refine refine_identifier to refine_type
```

The Refinable Test The original programmer cannot garuantee that future extenders will implement the refinement. If it is allowable that the refinement does not happen, then the programmer can use the `refinable` keyword as a callable identifier that evaluates to a Boolean instance. If the programmer contrives a situation where the compiler recognizes that a refinement is guarded but still executes a refine despite the refinement not existing, a runtime error will result.

```
refinable(refinement_identifier)
```

The Refinement Declaration To declare a refinement, declare a method in your subclass' refinement section with the special identifier `supermethod_identifier.refinement_identifier`

3.4 Operators and Literal Types

The following defines the approved behaviour for each combination of operator and literal type. If the literal type is not listed for a certain operator, the operator's behaviour for the literal is undefined. These operators never take operands of different types.

3.4.1 The Operator =

Integer If two Integer instances have the same value, `=` returns `true`. If they do not have the same value, it returns `false`.

Float If two Float instances have an absolute difference of less than or equal to an epsilon of 2^{-24}, `=` returns `true`. If the absolute difference is greater than that epsilon, it returns `false`.

Boolean If two Boolean instances have the same keyword, either `true` or `false`, `=` returns `true`. If their keyword differs, it returns `false`.

3.4.2 The Operators =/= and <>

Integer If two Integer instances have a different value, `=/=` and `<>` return `true`. If they do have the same value, they returns `false`.

Float If two Float instances have an absolute difference of greater than than an epsilon of 2^{-24}, `=` returns `true`. If the absolute difference is less than or equal to that epsilon, it returns `false`.

Boolean If two Boolean instances have different keywords, `=/=` and `<>` return `true`. If their keywords are the same, they return `false`.

3.4.3 The Operator <

Integer and float If the left operand is less than the right operand, `<` returns `true`. If the right operand is less than or equal to the left operand, it returns `false`.

3.4.4 The Operator >

Integer and float If the left operand is greater than the right operand, `>` returns `true`. If the right operand is greater than or equal to the left operand, it returns `false`.

3.4.5 The Operator <=

Integer and float If the left operand is less than or equal to the right operand, `<` returns `true`. If the right operand is less than the left operand, it returns `false`.

3.4.6 The Operator >=

Integer and float If the left operand is greater than or equal to the right operand, `>` returns `true`. If the right operand is greater than the left operand, it returns `false`.

3.4.7 The Operator +

Integer and Float `+` returns the sum of the two operands.

3.4.8 The Operator -

Integer and Float - returns the right operand subtracted from the left operand.

3.4.9 The Operator *

Integer and Float * returns the product of the two operands.

3.4.10 The Operator /

Integer and Float / returns the left operand divided by the right operand.

3.4.11 The Operator %

Integer and Float % returns the modulo of the left operand by the right operand.

3.4.12 The Operator ^

Integer and Float ^ returns the left operand raised to the power of the right operand.

3.4.13 The Operator :=

Integer, Float, and Boolean := assigns the right operand to the left operand and returns the value of the the right operand. This is the sole right precedence operator.

3.4.14 The Operators +=, -=, *=, /= %=, and ^=

Integer, Float, and Boolean This set of operators first applies the operator indicated by the first character of each operator as normal on the operands. It then assigns this value to its left operand.

3.4.15 The Operator and

Boolean and returns the conjunction of the operands.

3.4.16 The Operator or

Boolean or returns the disjunction of the operands.

3.4.17 The Operator `not`

Boolean `not` returns the negation of the operands.

3.4.18 The Operator `nand`

Boolean `nand` returns the negation of the conjunction of the operands.

3.4.19 The Operator `nor`

Boolean `nor` returns the negation of the disjunction of the operands.

3.4.20 The Operator `xor`

Boolean `xor` returns the exclusive disjunction of the operands.

3.4.21 The Operator `refinable`

Boolean `refinable` returns `true` if the refinement is implemented in the current subclass. It returns `false` otherwise.

3.5 Grammar

The following conventions are taken:

- Sequential semicolons (even separated by whitespace) are treated as one.
- the 'digit' class of characters are the numerical digits zero through nine
- the 'upper' class of characters are the upper case roman letters
- the 'lower' class of characters are the lower case roman letters
- the 'ualphanum' class of characters consists of the digit, upper, and lower classes together with the underscore
- a program is a collection of classes; this grammar describes solely classes
- the argument to main is semantically enforced after parsing; its presence here is meant to increase readability

The grammar follows:

• *Classs may extend another class or default to extending Object*
⟨class⟩ ⇒
    class ⟨class id⟩⟨extend⟩ **:** ⟨class section⟩*****
⟨extend⟩ ⇒
    ϵ
  | **extends** ⟨class id⟩

• *Sections – private protected public refinements and main*
⟨class section⟩ ⇒
    ⟨refinement⟩
  | ⟨access group⟩
  | ⟨main⟩

• *Refinements are named method dot refinement*
⟨refinement⟩ ⇒
    refinement ⟨refine⟩*****
⟨refine⟩ ⇒
    ⟨return type⟩⟨var id⟩**.**⟨var id⟩⟨params⟩ **:** ⟨statement⟩*****

• *Access groups contain all the members of a class*
⟨access group⟩ ⇒
    ⟨access type⟩ **:** ⟨member⟩*****
⟨access type⟩ ⇒
    private
  | **protected**
  | **public**
⟨member⟩ ⇒
    ⟨var decl⟩
  | ⟨method⟩
  | ⟨init⟩
⟨method⟩ ⇒
    ⟨return type⟩⟨var id⟩⟨params⟩ **:** ⟨statement⟩*****
⟨init⟩ ⇒
    init ⟨params⟩ **:** ⟨statement⟩*****

• *Main is special – not instance data starts execution*
⟨main⟩ ⇒
    main (System system, String[] ⟨var id⟩ **) :** ⟨statement⟩*****

• *Finally the meat and potatoes*
⟨statement⟩ ⇒
    ⟨var decl⟩
  | ⟨var decl⟩ **:=** ⟨expression⟩
  | ⟨super⟩

| ⟨return⟩
| ⟨conditional⟩
| ⟨loop⟩
| ⟨expression⟩

• *Super invocation is so we can do constructor chaining*
⟨super⟩ ⇒
super ⟨args⟩

• *Methods yield values (or just exit for void/init/main)*
⟨return⟩ ⇒
return
| **return** ⟨expression⟩

• *Basic control structures*
⟨conditional⟩ ⇒
if (⟨expression⟩ **) :** ⟨statement⟩***** ⟨else⟩
⟨else⟩ ⇒
ϵ
| ⟨elseif⟩ **else :** ⟨statement⟩*****
⟨elseif⟩ ⇒
ϵ
| ⟨elseif⟩ **elsif (** ⟨expression⟩ **) :** ⟨statement⟩*****
⟨loop⟩ ⇒
while (⟨expression⟩ **) :** ⟨statement⟩*****

• *Anything that can result in a value*
⟨expression⟩ ⇒
⟨assignment⟩
| ⟨invocation⟩
| ⟨field⟩
| ⟨var id⟩
| ⟨deref⟩
| ⟨arithmetic⟩
| ⟨test⟩
| ⟨instantiate⟩
| ⟨refine expr⟩
| ⟨literal⟩
| **(** ⟨expression⟩ **)**
| **this**

• *Assignment – putting one thing in another*
⟨assignment⟩ ⇒
⟨expression⟩⟨assign op⟩⟨expression⟩

⟨assign op⟩ ⇒
    :=
  | +=
  | **-=**
  | ***=**
  | /=
  | %=
  | ^=

• *Member / data access*
⟨invocation⟩ ⇒
    ⟨expression⟩ **.** ⟨var id⟩⟨args⟩
  | ⟨var id⟩⟨args⟩
⟨field⟩ ⇒
    ⟨expression⟩ **.** ⟨var id⟩
⟨deref⟩ ⇒
    ⟨expression⟩ [⟨expression⟩]

• *Basic arithmetic can and will be done!*
⟨arithmetic⟩ ⇒
    ⟨expression⟩⟨bin op⟩⟨expression⟩
  | ⟨unary op⟩⟨expression⟩
⟨bin op⟩ ⇒
    +
  | **-**
  | ***
  | /
  | %
  | ^
⟨unary op⟩ ⇒
    -

• *Common boolean predicates*
⟨test⟩ ⇒
    ⟨expression⟩⟨bin pred⟩⟨expression⟩
  | ⟨unary pred⟩⟨expression⟩
  | **refinable (** ⟨var id⟩ **)**
⟨bin pred⟩ ⇒
    and
  | **or**
  | **xor**
  | **nand**
  | **nor**
  | <
  | <=

| =
| <>
| =/=
| >=
| >
⟨unary pred⟩ ⇒
not

• *Making something*
⟨instantiate⟩ ⇒
new ⟨type⟩⟨args⟩⟨optional refinements⟩
⟨optional refinements⟩ ⇒
ϵ
| **{** ⟨refine⟩***** **}**

• *Refinement takes a specialization and notes the required return type*
⟨refine expr⟩ ⇒
refine ⟨var id⟩⟨args⟩ **to** ⟨type⟩

• *Literally necessary*
⟨literal⟩ ⇒
⟨int lit⟩
| ⟨bool lit⟩
| ⟨float lit⟩
| ⟨string lit⟩
⟨float lit⟩ ⇒
⟨digit⟩+ **.** ⟨digit⟩+
⟨int lit⟩ ⇒
⟨digits⟩+
⟨bool lit⟩ ⇒
true
| **false**
⟨string lit⟩ ⇒
“⟨string escape seq⟩**”**

• *Params and args are as expected*
⟨params⟩ ⇒
(**)**
| **(** ⟨paramlist⟩ **)**
⟨paramlist⟩ ⇒
⟨var decl⟩
| ⟨paramlist⟩ **,** ⟨var decl⟩
⟨args⟩ ⇒
(**)**
| **(** ⟨arglist⟩ **)**

⟨arglist⟩ ⇒
    ⟨expression⟩
  | ⟨arglist⟩ **,** ⟨expression⟩

• *All the basic stuff we've been saving up until now*
⟨var decl⟩ ⇒
    ⟨type⟩⟨var id⟩
⟨return type⟩ ⇒
    void
  | ⟨type⟩
⟨type⟩ ⇒
    ⟨class id⟩
  | ⟨type⟩[]
⟨class id⟩ ⇒
    ⟨upper⟩⟨ualphanum⟩*****
⟨var id⟩ ⇒
    ⟨lower⟩⟨ualphanum⟩*****

4 Project Plan

4.1 Planning Techniques

The vast majority of all planning happened over a combination of email and google hangouts. The team experimented with a variety of communication methods. We found some success with using Glip late in our process. Zoho docs and google docs were also used without major utility.

The specification of new elements was routinely proposed via an email to all members with an example of the concept and a description of the concepts involved behind it. This proved surprisingly effective at achieving a consensis.

Development was heavily facilited through the use of a shared git repository. Topical google hangouts would be started involving all members. Team members would describe what they were working on with the immediate tasks. Any given team member could only afford to work at the same time as any one other generally, so conflicts over work were rare.

Testing suites were developed concurrently with code. Given the well-traversed nature of object oriented programming, the necessary tests were farely obvious.

4.2 Ocaml Style Guide for the Development of the Ray Compiler

Expert Ocaml technique is not expected for the development of ray, however there are some basic stylistic tendencies that are preferred at all times.

All indentation should be increments of four spaces. Tabs and two space increment indentation are not acceptable.

```
let x = 2
let z =
    let add5 a =
        + a 5 in
    add5 x
```

When constructing a `let...in` statement, the associated in must not be alone on the final line. For a large `let` statement that defines a variable, store the final operational call in a dummy variable and return that dummy. For all but the shortest right-hand sides of `let` statements, the right-hand side should be placed at increased indentation on the next line.

```
let get_x =
    ...
    let n = 2 in
    let x =
```

```
        x_functor1 (x_functor2 y z) n in
    x
```

`match` statements should always include a `|` for the first item. The `|` operators that are used should have aligned indentation, as should `->` operators, functors that follow such operators and comments. Exceedingly long functors should be placed at increased indentaiton on the next line. (These rules also apply to `type` definitions.)

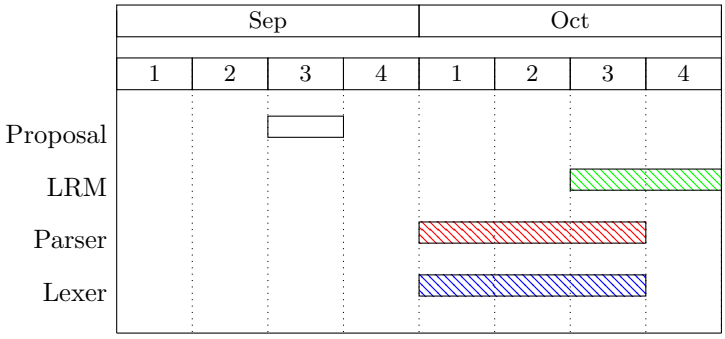
```
let unify_it var =
    match var with
    | X(y)       ->   y                          (* pop out *)
    | Y(y) :: _ ->   to_X y                      (* convert *)
    | Z(y)       ->
        to_X (to_Y (List.hd (List.rest y))   (* mangle *)
```

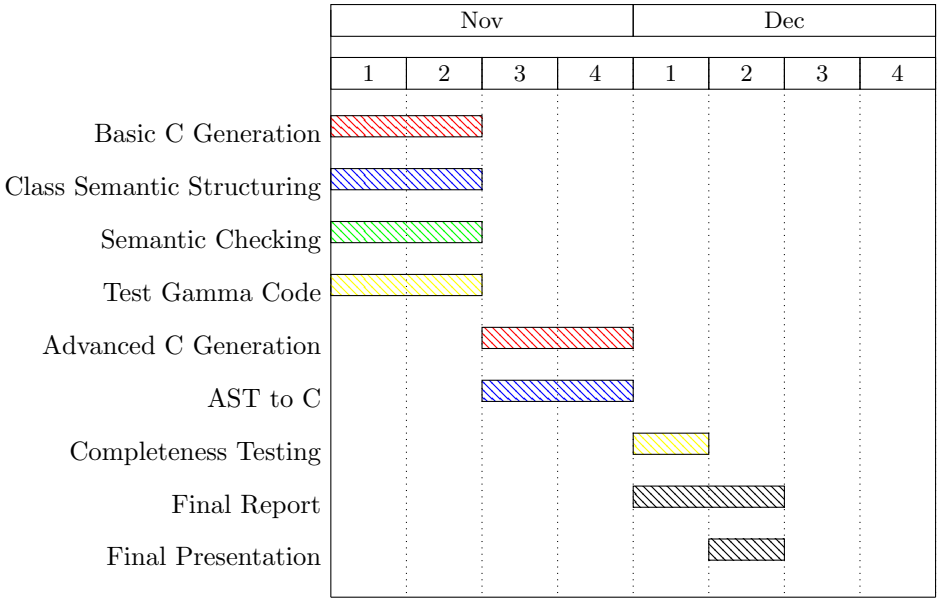
All records should maintain a basic standard of alignement and indentation for readibility. (Field names, colons, and type specs should all be aligned to like.)

```
type person = {
    names  : string list;
    job    : string option;  (* Not everybody has one *)
    family : person list;
    female : bool;
    age    : int;
}
```

4.3 Project Timeline

The following gantt charts show the intended project timeline broken down by weeks of the four months of this semester. The loose units were intended to make our schedules more workable.





4.4 Team Roles

Ben Caimano

- Primary Documentation Officer
- Co-Organizer
- Parser Contributor
- Cast/C Contributor

Weiyuan Li

- Lexer Contributor
- Sast Contributor
- Cast/C Contributor
- Test Suite Contributor

Mathew H. Maycock

- Programming Lead
- Grammar Designer
- Quality Assurance Officer
- Lt. Documentation Officer
- Parser Contributor
- Sast Contributor
- Cast/C Contributor
- Test Suite Contributor

Arthy Sundaram

- Co-Organizer/President
- Parser Contributor
- Sast Contributor
- Cast/C Contributor
- Test Suite Contributor

4.5 Development Environment

4.5.1 Programming Languages

All Gamma code is compiled by the ray compiler to an intermediary file of C (ANSI ISO C90) code which is subsequently compiled to a binary file. Lexographical scanning, semantic parsing and checking, and compilation to C is all done by custom-written code in Ocaml 4.01.

The Ocaml code is compiled using the Ocaml bytecode compiler (ocamlc), the Ocaml parser generator (ocamlyacc), and the Ocaml lexer generator (ocamllex). Incidentally, documentation of the Ocaml code for internal use is done using the Ocaml documentation generator (ocamldoc). The compilation from intermediary C to bytecode is done using the GNU project C and C++ compiler (GCC) 4.7.3.

Scripting of our Ocaml compilation and other useful command-level tasks is done through a combination of the GNU make utility (a Makefile) and the dash command interpreter (shell scripts).

4.5.2 Development Tools

Our development tools were minimalistic. Each team member had a code editor of choice (emacs, vim, etc.). Content management and collaboration was done via git. Our git repository was hosted on BitBucket by Atlassan Inc. The ocaml interpreter shell was used for testing purposes, as was a large suite of testing utilities written in ocaml for the task. Among these created tools were:

- canonical - Takes an input stream of brace-style code and outputs the whitespace-style equivalent
- cannonize - Takes an input stream of whitespace-style code and outputs the brace-style equivalent
- classinfo - Analyzes the defined members (methods and variables) for a given class
- freevars - Lists the variables that remain unbound in the program
- inspect - Stringify a given AST
- prettify - Same as above but with formatting
- streams - Check a whitespace-style source for formatting issues

4.6 Project Log

- September 9th - Team Formed
- September 18th - Proposal drafting begins
- September 19th - A consensis is reached, basic form of the language is hashed out as a Beta-derived object oriented language.
- September 24-25th - Propose written, language essentials described
- October 9-10th - Grammar written
- October 18-20th - Bulk of the lexer/parser is written
- October 24th - Inspector written
- October 26th - Parser officially compiled for first time
- October 29th - Language resource manual finished, language structure semi-rigidly defined
- November 11th - General schedule set, promptly falls apart under the mutual stress of projects and midterms
- November 24th - Class data collection implemented
- November 30th - SAST structure defined
- December 8-10th - Team drama happens
- December 10th - SAST generation code written
- December 12th - CAST and CAST generation begun
- December 14th - C generation development started
- December 15th - Approximate CAST generation written
- December 16th - First ray binary made
- December 19th - Ray compilation of basic code successful
- December 22nd - Ray passes the test suite

5 Test Plan

5.1 Examples Gamma Programs

5.1.1 Hello World

This program simply prints "Hello World". It demonstrates the fundamentals needed to write a Gamma program.

```
class HelloWorld:
  public:
    String greeting
    init():
      super()
      greeting := "Hello World!"

  main(System system, String[] args):
    HelloWorld hw := new HelloWorld()
    system.out.printString(hw.greeting)
    system.out.printString("\n")
```

Example 13: "Hello World in Gamma"

```
/* Starting Build Process...
 * Reading Tokens...
 * Parsing Tokens...
 * Generating Global Data...
 * Using Normal KlassData Builder
 * Building Semantic AST...
 * Deanonymizing Anonymous Classes.
 * Rebinding refinements.
 * Generating C AST...
 * Generating C...
 */


/*
 * Passing over code to find dispatch data.
 */


/*
 * Gamma preamble -- macros and such needed by various things
 */
#include "gamma-preamble.h"



/*
 * Ancestry meta-info to link to later.
 */
char *m_classes[] = {
```

```
30      "t_Boolean", "t_Float", "t_HelloWorld", "t_Integer", "
        t_Object", "t_Printer",
31      "t_Scanner", "t_String", "t_System"
32  };
33
34
35  /*
36   * Enums used to reference into ancestry meta-info strings.
37   */
38  enum m_class_idx {
39      T_BOOLEAN = 0, T_FLOAT, T_HELLOWORLD, T_INTEGER, T_OBJECT,
        T_PRINTER, T_SCANNER,
40      T_STRING, T_SYSTEM
41  };
42
43
44  /*
45   * Header file containing meta information for built in classes.
46   */
47  #include "gamma-builtin-meta.h"
48
49
50
51  /*
52   * Meta structures for each class.
53   */
54  ClassInfo M_HelloWorld;
55
56  void init_class_infos() {
57      init_built_in_infos();
58      class_info_init(&M_HelloWorld, 2, m_classes[T_OBJECT],
        m_classes[T_HELLOWORLD]);
59  }
60
61
62
63  /*
64   * Header file containing structure information for built in
        classes.
65   */
66  #include "gamma-builtin-struct.h"
67
68
69
70  /*
71   * Structures for each of the objects.
72   */
73  struct t_HelloWorld {
74      ClassInfo *meta;
75
76      struct {
77          struct t_System *v_system;
78      } Object;
79
80
81      struct {
82          struct t_String *v_greeting;
```

```
83      } HelloWorld;
84
85  };
86
87
88
89
90  /*
91   * Header file containing information regarding built in
         functions.
92   */
93  #include "gamma-builtin-functions.h"
94
95
96
97  /*
98   * All of the function prototypes we need to do magic.
99   */
100 struct t_HelloWorld *f_00000001_init(struct t_HelloWorld *);
101 void f_00000002_main(struct t_System *, struct t_String **);
102
103
104 /*
105  * All the dispatching functions we need to continue the magic.
106  */
107
108
109 /*
110  * Array allocators also do magic.
111  */
112
113
114 /*
115  * All of the functions we need to run the program.
116  */
117 /* Place-holder for struct t_Boolean *boolean_init(struct
         t_Boolean *this) */
118 /* Place-holder for struct t_Float *float_init(struct t_Float *
         this) */
119 /* Place-holder for struct t_Integer *float_to_i(struct t_Float
         *this) */
120 /* Place-holder for struct t_Integer *integer_init(struct
         t_Integer *this) */
121 /* Place-holder for struct t_Float *integer_to_f(struct
         t_Integer *this) */
122 /* Place-holder for struct t_Object *object_init(struct t_Object
          *this) */
123 /* Place-holder for struct t_Printer *printer_init(struct
         t_Printer *this, struct t_Boolean *v_stdout) */
124 /* Place-holder for void printer_print_float(struct t_Printer *
         this, struct t_Float *v_arg) */
125 /* Place-holder for void printer_print_integer(struct t_Printer
         *this, struct t_Integer *v_arg) */
126 /* Place-holder for void printer_print_string(struct t_Printer *
         this, struct t_String *v_arg) */
127 /* Place-holder for struct t_Scanner *scanner_init(struct
         t_Scanner *this) */
```

```
128 /* Place-holder for struct t_Float *scanner_scan_float(struct
        t_Scanner *this) */
129 /* Place-holder for struct t_Integer *scanner_scan_integer(
        struct t_Scanner *this) */
130 /* Place-holder for struct t_String *scanner_scan_string(struct
        t_Scanner *this) */
131 /* Place-holder for struct t_String *string_init(struct t_String
         *this) */
132 /* Place-holder for void system_exit(struct t_System *this,
        struct t_Integer *v_code) */
133 /* Place-holder for struct t_System *system_init(struct t_System
         *this) */
134
135 struct t_HelloWorld *f_00000001_init(struct t_HelloWorld *this)
136 {
137     object_init((struct t_Object *)(this));
138     ( (this->HelloWorld).v_greeting = ((struct t_String *)(
        LIT_STRING("Hello World!"))) );
139     return ( this );
140 }
141
142
143 void f_00000002_main(struct t_System *v_system, struct t_String
        **v_args)
144 {
145     struct t_HelloWorld *v_hw = ((struct t_HelloWorld *)(
        f_00000001_init(MAKENEW(HelloWorld))));
146     ( printer_print_string(((struct t_Printer *)((v_system)->
        System.v_out)), (v_hw)->HelloWorld.v_greeting) );
147     ( printer_print_string(((struct t_Printer *)((v_system)->
        System.v_out)), LIT_STRING("\n")) );
148 }
149
150
151
152 /*
153  * Dispatch looks like this.
154  */
155
156
157 /*
158  * Array allocators.
159  */
160
161
162 /*
163  * The main.
164  */
165 #define CASES "HelloWorld"
166
167 int main(int argc, char **argv) {
168     INIT_MAIN(CASES)
169     if (!strncmp(gmain, "HelloWorld", 11)) { f_00000002_main(&
        global_system, str_args); return 0; }
170     FAIL_MAIN(CASES)
171     return 1;
172 }
```

Example 14: "Hello World in Compiled C"

5.1.2 I/O

This program prompts the user for an integer and a float. It converts the integer to a float and adds the two together. It then prints the equation and result. (You might recognize this from the tutorial.)

```
class IOTest:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := promptInteger("Please enter an integer")
      Float f := promptFloat("Please enter a float")
      p.printString("Sum of integer + float = ")
      p.printFloat(i.toF() + f)
      p.printString("\n")

  private:
    void prompt(String msg):
      system.out.printString(msg)
      system.out.printString(": ")

    Integer promptInteger(String msg):
      prompt(msg)
      return system.in.scanInteger()

    Float promptFloat(String msg):
      prompt(msg)
      return system.in.scanFloat()

  main(System system, String[] args):
    IOTest test := new IOTest()
    test.interact()
```

Example 15: "I/O in Gamma"

```
/* Starting Build Process...
 * Reading Tokens...
 * Parsing Tokens...
 * Generating Global Data...
 * Using Normal KlassData Builder
 * Building Semantic AST...
 * Deanonymizing Anonymous Classes.
 * Rebinding refinements.
 * Generating C AST...
 * Generating C...
```

```
 */


/*
 * Passing over code to find dispatch data.
 */


/*
 * Gamma preamble -- macros and such needed by various things
 */
#include "gamma-preamble.h"



/*
 * Ancestry meta-info to link to later.
 */
char *m_classes[] = {
    "t_Boolean", "t_Float", "t_IOTest", "t_Integer", "t_Object",
     "t_Printer", "t_Scanner",
    "t_String", "t_System"
};


/*
 * Enums used to reference into ancestry meta-info strings.
 */
enum m_class_idx {
    T_BOOLEAN = 0, T_FLOAT, T_IOTEST, T_INTEGER, T_OBJECT,
    T_PRINTER, T_SCANNER,
    T_STRING, T_SYSTEM
};


/*
 * Header file containing meta information for built in classes.
 */
#include "gamma-builtin-meta.h"



/*
 * Meta structures for each class.
 */
ClassInfo M_IOTest;

void init_class_infos() {
    init_built_in_infos();
    class_info_init(&M_IOTest, 2, m_classes[T_OBJECT], m_classes
    [T_IOTEST]);
}


/*
```

```
 * Header file containing structure information for built in
    classes.
 */
#include "gamma-builtin-struct.h"



/*
 * Structures for each of the objects.
 */
struct t_IOTest {
    ClassInfo *meta;

    struct {
        struct t_System *v_system;
    } Object;


    struct { BYTE empty_vars; } IOTest;
};




/*
 * Header file containing information regarding built in
    functions.
 */
#include "gamma-builtin-functions.h"



/*
 * All of the function prototypes we need to do magic.
 */
struct t_IOTest *f_00000001_init(struct t_IOTest *);
void f_00000002_interact(struct t_IOTest *);
void f_00000003_prompt(struct t_IOTest *, struct t_String *);
struct t_Integer *f_00000004_promptInteger(struct t_IOTest *,
    struct t_String *);
struct t_Float *f_00000005_promptFloat(struct t_IOTest *, struct
     t_String *);
void f_00000006_main(struct t_System *, struct t_String **);


/*
 * All the dispatching functions we need to continue the magic.
 */


/*
 * Array allocators also do magic.
 */


/*
 * All of the functions we need to run the program.
```

```
117  */
118 /* Place-holder for struct t_Boolean *boolean_init(struct
        t_Boolean *this) */
119 /* Place-holder for struct t_Float *float_init(struct t_Float *
        this) */
120 /* Place-holder for struct t_Integer *float_to_i(struct t_Float
        *this) */
121 /* Place-holder for struct t_Integer *integer_init(struct
        t_Integer *this) */
122 /* Place-holder for struct t_Float *integer_to_f(struct
        t_Integer *this) */
123 /* Place-holder for struct t_Object *object_init(struct t_Object
         *this) */
124 /* Place-holder for struct t_Printer *printer_init(struct
        t_Printer *this, struct t_Boolean *v_stdout) */
125 /* Place-holder for void printer_print_float(struct t_Printer *
        this, struct t_Float *v_arg) */
126 /* Place-holder for void printer_print_integer(struct t_Printer
        *this, struct t_Integer *v_arg) */
127 /* Place-holder for void printer_print_string(struct t_Printer *
        this, struct t_String *v_arg) */
128 /* Place-holder for struct t_Scanner *scanner_init(struct
        t_Scanner *this) */
129 /* Place-holder for struct t_Float *scanner_scan_float(struct
        t_Scanner *this) */
130 /* Place-holder for struct t_Integer *scanner_scan_integer(
        struct t_Scanner *this) */
131 /* Place-holder for struct t_String *scanner_scan_string(struct
        t_Scanner *this) */
132 /* Place-holder for struct t_String *string_init(struct t_String
         *this) */
133 /* Place-holder for void system_exit(struct t_System *this,
        struct t_Integer *v_code) */
134 /* Place-holder for struct t_System *system_init(struct t_System
         *this) */
135
136 struct t_IOTest *f_00000001_init(struct t_IOTest *this)
137 {
138     object_init((struct t_Object *)(this));
139     return ( this );
140 }
141
142
143 void f_00000002_interact(struct t_IOTest *this)
144 {
145     struct t_Printer *v_p = ((struct t_Printer *)(((this->Object
        ).v_system)->System.v_out));
146     struct t_Integer *v_i = ((struct t_Integer *)(
        f_00000004_promptInteger(((struct t_IOTest *)(this)),
        LIT_STRING("Please enter an integer"))));
147     struct t_Float *v_f = ((struct t_Float *)(
        f_00000005_promptFloat(((struct t_IOTest *)(this)),
        LIT_STRING("Please enter a float"))));
148     ( printer_print_string(((struct t_Printer *)(v_p)),
        LIT_STRING("Sum of integer + float = ")) );
149     ( printer_print_float(((struct t_Printer *)(v_p)),
        ADD_FLOAT_FLOAT( integer_to_f(((struct t_Integer *)(v_i))) ,
```

```
      v_f )) );
150       ( printer_print_string(((struct t_Printer *)(v_p)),
          LIT_STRING("\n")) );
151   }
152
153
154   void f_00000003_prompt(struct t_IOTest *this, struct t_String *
          v_msg)
155   {
156       ( printer_print_string(((struct t_Printer *)(((this->Object)
          .v_system)->System.v_out)), v_msg) );
157       ( printer_print_string(((struct t_Printer *)(((this->Object)
          .v_system)->System.v_out)), LIT_STRING(": ")) );
158   }
159
160
161   struct t_Integer *f_00000004_promptInteger(struct t_IOTest *this
          , struct t_String *v_msg)
162   {
163       ( f_00000003_prompt(((struct t_IOTest *)(this)), v_msg) );
164       return ( scanner_scan_integer(((struct t_Scanner *)(((this->
          Object).v_system)->System.v_in))) );
165   }
166
167
168   struct t_Float *f_00000005_promptFloat(struct t_IOTest *this,
          struct t_String *v_msg)
169   {
170       ( f_00000003_prompt(((struct t_IOTest *)(this)), v_msg) );
171       return ( scanner_scan_float(((struct t_Scanner *)(((this->
          Object).v_system)->System.v_in))) );
172   }
173
174
175   void f_00000006_main(struct t_System *v_system, struct t_String
          **v_args)
176   {
177       struct t_IOTest *v_test = ((struct t_IOTest *)(
          f_00000001_init(MAKE_NEW(IOTest))));
178       ( f_00000002_interact(((struct t_IOTest *)(v_test))) );
179   }
180
181
182
183   /*
184    * Dispatch looks like this.
185    */
186
187
188   /*
189    * Array allocators.
190    */
191
192
193   /*
194    * The main.
195    */
```

```c
#define CASES "IOTest"

int main(int argc, char **argv) {
    INIT_MAIN(CASES)
    if (!strncmp(gmain, "IOTest", 7)) { f_00000006_main(&
    global_system, str_args); return 0; }
    FAIL_MAIN(CASES)
    return 1;
}
```

Example 16: "I/O in Compiled C"

5.1.3 Argument Reading

This program prints out each argument passed to the program.

```
class Test:
  public:
    init():
      super()

  main(System sys, String[] args):
    Integer i := 0
    Printer p := sys.out

    while (i < sys.argc):
      p.printString("arg[")
      p.printInteger(i)
      p.printString("] = ")
      p.printString(args[i])
      p.printString("\n")
      i += 1
```

Example 17: "Argument Reading in Gamma"

```
/* Starting Build Process...
 * Reading Tokens...
 * Parsing Tokens...
 * Generating Global Data...
 * Using Normal KlassData Builder
 * Building Semantic AST...
 * Deanonymizing Anonymous Classes.
 * Rebinding refinements.
 * Generating C AST...
 * Generating C...
 */


/*
 * Passing over code to find dispatch data.
 */

```

```
18
19  /*
20   * Gamma preamble -- macros and such needed by various things
21   */
22  #include "gamma-preamble.h"
23
24
25
26  /*
27   * Ancestry meta-info to link to later.
28   */
29  char *m_classes[] = {
30      "t_Boolean", "t_Float", "t_Integer", "t_Object", "t_Printer"
        , "t_Scanner",
31      "t_String", "t_System", "t_Test"
32  };
33
34
35  /*
36   * Enums used to reference into ancestry meta-info strings.
37   */
38  enum m_class_idx {
39      T_BOOLEAN = 0, T_FLOAT, T_INTEGER, T_OBJECT, T_PRINTER,
        T_SCANNER, T_STRING,
40      T_SYSTEM, T_TEST
41  };
42
43
44  /*
45   * Header file containing meta information for built in classes.
46   */
47  #include "gamma-builtin-meta.h"
48
49
50
51  /*
52   * Meta structures for each class.
53   */
54  ClassInfo M_Test;
55
56  void init_class_infos() {
57      init_built_in_infos();
58      class_info_init(&M_Test, 2, m_classes[T_OBJECT], m_classes[
        T_TEST]);
59  }
60
61
62
63  /*
64   * Header file containing structure information for built in
        classes.
65   */
66  #include "gamma-builtin-struct.h"
67
68
69
70  /*
```

```
 * Structures for each of the objects.
 */
struct t_Test {
    ClassInfo *meta;

    struct {
        struct t_System *v_system;
    } Object;


    struct { BYTE empty_vars; } Test;
};




/*
 * Header file containing information regarding built in
    functions.
 */
#include "gamma-builtin-functions.h"



/*
 * All of the function prototypes we need to do magic.
 */
struct t_Test *f_00000001_init(struct t_Test *);
void f_00000002_main(struct t_System *, struct t_String **);


/*
 * All the dispatching functions we need to continue the magic.
 */


/*
 * Array allocators also do magic.
 */


/*
 * All of the functions we need to run the program.
 */
/* Place-holder for struct t_Boolean *boolean_init(struct
    t_Boolean *this) */
/* Place-holder for struct t_Float *float_init(struct t_Float *
    this) */
/* Place-holder for struct t_Integer *float_to_i(struct t_Float
    *this) */
/* Place-holder for struct t_Integer *integer_init(struct
    t_Integer *this) */
/* Place-holder for struct t_Float *integer_to_f(struct
    t_Integer *this) */
/* Place-holder for struct t_Object *object_init(struct t_Object
     *this) */
```

```
120 /* Place-holder for struct t_Printer *printer_init(struct
        t_Printer *this, struct t_Boolean *v_stdout) */
121 /* Place-holder for void printer_print_float(struct t_Printer *
        this, struct t_Float *v_arg) */
122 /* Place-holder for void printer_print_integer(struct t_Printer
        *this, struct t_Integer *v_arg) */
123 /* Place-holder for void printer_print_string(struct t_Printer *
        this, struct t_String *v_arg) */
124 /* Place-holder for struct t_Scanner *scanner_init(struct
        t_Scanner *this) */
125 /* Place-holder for struct t_Float *scanner_scan_float(struct
        t_Scanner *this) */
126 /* Place-holder for struct t_Integer *scanner_scan_integer(
        struct t_Scanner *this) */
127 /* Place-holder for struct t_String *scanner_scan_string(struct
        t_Scanner *this) */
128 /* Place-holder for struct t_String *string_init(struct t_String
         *this) */
129 /* Place-holder for void system_exit(struct t_System *this,
        struct t_Integer *v_code) */
130 /* Place-holder for struct t_System *system_init(struct t_System
         *this) */
131
132 struct t_Test *f_00000001_init(struct t_Test *this)
133 {
134     object_init((struct t_Object *)(this));
135     return ( this );
136 }
137
138
139 void f_00000002_main(struct t_System *v_sys, struct t_String **
        v_args)
140 {
141     struct t_Integer *v_i = ((struct t_Integer *)(LIT_INT(0)));
142     struct t_Printer *v_p = ((struct t_Printer *)((v_sys)->
        System.v_out));
143     while ( BOOL_OF( NTEST_LESS_INT_INT( v_i , (v_sys)->System.
        v_argc ) ) ) {
144         ( printer_print_string(((struct t_Printer *)(v_p)),
        LIT_STRING("arg[")) );
145         ( printer_print_integer(((struct t_Printer *)(v_p)), v_i
        ) );
146         ( printer_print_string(((struct t_Printer *)(v_p)),
        LIT_STRING("] = ")) );
147         ( printer_print_string(((struct t_Printer *)(v_p)), ((
        struct t_String **)(v_args))[INTEGER_OF((v_i))]) );
148         ( printer_print_string(((struct t_Printer *)(v_p)),
        LIT_STRING("\n")) );
149         ( v_i = ((struct t_Integer *)(ADD_INT_INT( v_i , LIT_INT
        (1) ))) );
150     }
151 }
152
153
154
155 /*
156  * Dispatch looks like this.
```

```
157  */
158
159
160 /*
161  * Array allocators.
162  */
163
164
165 /*
166  * The main.
167  */
168 #define CASES "Test"
169
170 int main(int argc, char **argv) {
171     INIT_MAIN(CASES)
172     if (!strncmp(gmain, "Test", 5)) { f_00000002_main(&
        global_system, str_args); return 0; }
173     FAIL_MAIN(CASES)
174     return 1;
175 }
```

Example 18: "Argument Reading in Compiled C"

5.2 Test Suites

All tests suites involved Gamma source code that was compiled through ray and GCC to check for desired functionality. This was done as a communal effort towards the end of the project.

5.2.1 Desired Failure Testing

This suite of tests made sure that bad code did not compile.

```
class Parent:
  public:
    init():
      super()

class Child extends Parent:
  public:
    init():
      super()

class Test:
  public:
    init():
      super()

  main(System system, String[] args):
    Child child := new Parent()
```

Test Source 1: "Superclass Typed to Subclass"

While a subclass can be stored in a variable typed to its parent, the reverse should not be possible.

```
class BadDecl:
  public:
    init():
      super()
      Integer a := 3.4
```

Test Source 2: "Improper Variable Declaration/Assignment"

A Float should never be allowed to be stored in an Integer variable.

```
class Test:
  public:
    Float a
    Float b
    Integer c

    init():
      super()
```

```
9         a := 1.5
10        b := 2.2
11        c := 3
12
13      Float overview():
14        Float success := a+b+c
15        return success
16
17    main(System system, String[] args):
18      Test ab := new Test()
19      Printer p := system.out
20      p.printString("Sum of integer = ")
21      p.printFloat(ab.overview())
22      p.printString("\n")
```

Test Source 3: "Binary Operations Between Incompatible Types"

A Float should not be allowed to be added to an Integer.

```
1  class BadReturn:
2    public:
3      init():
4        super()
5
6      Integer badReturn():
7        return "Hey There"
```

Test Source 4: "Return Variable of the Wrong Type"

It is not allowed for a function to return a variable of a different type than its declared return type.

```
1  class BadReturn:
2    public:
3      init():
4        super()
5
6      Integer badReturn():
7        return
```

Test Source 5: "Empty Return Statement"

A return statement should return something.

```
1  class BadReturn:
2    public:
3      init():
4        super()
5
6      void badReturn():
7        return "Hey There"
```

Test Source 6: "Return Statement in a Void Method"

A method with a return type of void should have no return statement.

```
class BadAssign:
  public:
    init():
      super()
      Integer a
      a := 3.4
```

Test Source 7: "Improper Literal Assignment"

A literal object cannot be assigned to a variable of the wrong type.

```
class BadStatic:
  public:
    Integer getZero():
      return 0
    init():
      super()
  main(System system, String[] args):
    getZero()  /* This is supposed to fail. DON'T CHANGE */
```

Test Source 8: "Static Method Calls"

A method must be called on an object.

```
class Parent:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 0

    Integer overview():
      Integer success := refine toExtra(a,b) to Integer
      return success

class Child extends Parent:
  refinement:
    Integer overview.toExtra(Integer a, Integer b):
      Integer success :=  a + b
      Printer p := new Printer(true)
      p.printInteger(a)
      p.printInteger(b)
```

```
24        p.printInteger(c)
25        return success
26    public:
27      Integer a1
28      Integer b1
29      Integer c1
30
31      init():
32        super()
33        a1 := 1
34        b1 := 2
35        c1 := 0
36
37  class Test:
38    public:
39      init():
40        super()
41
42    main(System system, String[] args):
43      Parent ab := new Parent
44      Printer p := system.out
45      p.printString("Sum of integer = ")
46      p.printInteger(ab.overview())
47      p.printString("\n")
```

Test Source 9: "Unimplemented Refinement"

A method that has a refinement must be called from a subclass of the original class that implements the refinement.

```
1   class Parent:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 0
12
13      Integer overview():
14        Integer success := -1
15        if (refinable(toExtra)) {
16            success := refine toExtra(a,b) to Integer;
17        }
18        return success
19
20  class Child extends Parent:
21    refinement:
22      Integer overview.toExtra(Integer a, Integer b):
23        Integer success :=  a + b
24        Printer p := new Printer(true)
25        p.printInteger(a)
```

```
26        p.printInteger(b)
27        p.printInteger(c)
28        return success
29    public:
30      Integer a1
31      Integer b1
32      Integer c1
33
34      init():
35        super()
36        a1 := 1
37        b1 := 2
38        c1 := 0
39
40  class Test:
41    public:
42      init():
43        super()
44
45    main(System system, String[] args):
46      Parent ab := new Parent()
47      Printer p := system.out
48      p.printString("Sum of integer = ")
49      p.printInteger(ab.overview())
50      p.printString("\n")
```

Test Source 10: "unimplemented Refinement with Refinable"

This case uses refinable to avoid paths with unimplemented refinements. It should function.

5.2.2 Statement Testing

This suite of test case makes sure that basic statements do compile.

```
1
2   class WhileLoopTest:
3     public:
4       init():
5         super()
6         Integer a := 0
7         while((a>=0) and (a<10)):
8           system.out.printInteger(a)
9           system.out.printString("\n")
10          a := a + 1
11
12    main(System system, String[] args):
13      new WhileLoopTest()
```

Test Source 11: "Conditioned While Statements"

This test makes sure while loops function.

```
1
2  class WhileLoopTest:
3    public:
4      init():
5        super()
6        Integer a := 0
7        while(true):
8          system.out.printInteger(a)
9          system.out.printString("\n")
10         a := a + 1
11
12   main(System system, String[] args):
13     new WhileLoopTest()
```

Test Source 12: "Infinite While Statement"

This test makes sure that while loops can continue within the bounds of memory.

```
1  class IfTest:
2    private:
3      void line():
4        system.out.printString("\n")
5
6      void out(String msg):
7        system.out.printString(msg)
8        line()
9
10     void yes():
11       out("This should print.")
12     void no():
13       out("This should not print.")
14
15   public:
16     init():
17       super()
18
19       out("Simple (1/2)")
20       if (true)  { yes(); }
21       if (false) { no();  }
22       line()
23
24       out("Basic (2/2)")
25       if (true)  { yes(); } else { no();  }
26       if (false) { no();  } else { yes(); }
27       line()
28
29       out("Multiple (3/3)")
30       if (true)  { yes(); } elsif (false) { no();  } else { no
     (); }
31       if (false) { no();  } elsif (true)  { yes(); } else { no
     (); }
32       if (false) { no();  } elsif (false) { no();  } else { yes
     (); }
33       line()
```

```
34
35        out("Non-exhaustive (2/3)")
36        if (true)  { yes(); } elsif (false) { no();  }
37        if (false) { no();  } elsif (true)  { yes(); }
38        if (false) { no();  } elsif (false) { no();  }
39
40    main(System system, String[] args):
41      IfTest theif := new IfTest()
```

Test Source 13: "If Statements"

This test makes sure if statements function.

5.2.3 Expression Testing

This suite of test case makes sure that basic expressions do compile.

```
1   class Test:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 3
12
13      Integer overview():
14        Integer success := a+b
15        return success
16
17    main(System system, String[] args):
18      Test ab := new Test()
19      Printer p := system.out
20      p.printString("Sum of integer = ")
21      p.printInteger(ab.overview())
22      p.printString("\n")
```

Test Source 14: "Add Integers"

```
1   class Test:
2     public:
3       Float a
4       Float b
5       Integer c
6
7       init():
8         super()
9         a := 1.5
10        b := 2.2
```

```
11        c := 0
12
13      Float overview():
14        Float success := a+b
15        return success
16
17    main(System system, String[] args):
18      Test ab := new Test()
19      Printer p := system.out
20      p.printString("Sum of integer = ")
21      p.printFloat(ab.overview())
22      p.printString("\n")
```

Test Source 15: "Add Floats"

These tests add numeric literal objects together.

```
1   class Test:
2     public:
3       Integer a
4       Float   b
5
6       init():
7         super()
8
9       Integer add():
10        a := 10 * 2 * 9
11        b := 6.0 * 0.5 * (-2.0)
12        return 0
13
14    main(System sys, String[] args):
```

Test Source 16: "Multiplication"

```
1   class Test:
2     public:
3       Integer a
4       Float   b
5
6       init():
7         super()
8
9       Integer add():
10        a := (10 / 5) / -2
11        b := (10.0 / 5.0) / -2.0
12        return 0
13
14    main(System sys, String[] args):
15      Test t := new Test()
16      Printer p := sys.out
17
18      t.add()
19      p.printString("A is ")
20      p.printInteger(t.a)
```

```
21      p.printString(", B is ")
22      p.printFloat(t.b)
23      p.printString("\n")
```

Test Source 17: "Divition"

These tests form products/quotions of Floats/Integers.

```
1   class Test:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 3
12
13      Integer overview():
14        Integer success := a%b
15        return success
16
17    main(System system, String[] args):
18      Test ab := new Test()
19      Printer p := system.out
20      p.printString(" 1 % 2 = ")
21      p.printInteger(ab.overview())
22      p.printString("\n")
```

Test Source 18: "Modulus"

This test forms the modulus of Integers.

```
1   class Test:
2     public:
3       init():
4         super()
5
6       void interact():
7         Printer p := system.out
8         Integer i := 5
9         Float f := 1.5
10        p.printString("Sum of integer + float = ")
11        p.printFloat(i.toF() + f)
12        p.printString("\n")
13
14    main(System system, String[] args):
15      Test test := new Test()
16      test.interact()
```

Test Source 19: "Literal Casting and Addition"

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("integer - float = ")
      p.printFloat(i.toF() - f)
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Test Source 20: "Literal Casting and Subtraction"

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("integer * float = ")
      p.printFloat(i.toF() * f)
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Test Source 21: "Literal Casting and Multiplication"

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("float/Integer = ")
      p.printFloat(f/i.toF())
      p.printString("\n")

  main(System system, String[] args):
```

```
15      Test test := new Test()
16      test.interact()
```

Test Source 22: "Literal Casting and Divition"

```
1   class Test:
2     public:
3       init():
4         super()
5
6       void interact():
7         Printer p := system.out
8         Integer i := 5
9         Float f := 1.5
10        p.printString("integer ^ float = ")
11        p.printFloat(i.toF() ^ f)
12        p.printString("\n")
13
14    main(System system, String[] args):
15      Test test := new Test()
16      test.interact()
```

Test Source 23: "Literal Casting and Exponentiation"

These tests check that numerical literal objects can be cast to allow mathematic operations.

```
1   class Parent:
2     public:
3       init():
4         super()
5
6   class Child extends Parent:
7     public:
8       init():
9         super()
10
11  class Test:
12    public:
13      init():
14        super()
15
16    main(System system, String[] args):
17      Parent child := new Child()
```

Test Source 24: "Superclass Typing"

This test assigns a subclass to a variable typed to its parent.

```
1   class Test:
2     private:
3       void line():
```

```
4         system.out.printString("\n")
5
6       void out(String msg):
7         system.out.printString(msg)
8         line()
9
10    public:
11      init():
12        super()
13        Integer a:=2
14        Integer b:=3
15        Integer c
16
17        /* less and less and equal*/
18        if (a<2)  { system.out.printString("1. a=2 a<2 shouldnot
        print\n"); }
19        elsif (a<=2)  { system.out.printString("1. a=2 a<=2
        success\n"); }
20        else { system.out.printString("1. should never hit here\n"
        ); }
21
22
23        /* greater and greater than equal */
24        if (b>3)  { system.out.printString("2. b=3 b>3 shouldnot
        print\n"); }
25        else  { system.out.printString("2. b=3 b>=3 success\n"); }
26
27        /*Equal and not equal*/
28        if (a <> b)  { system.out.printString("3. a!=b success \n"
        ); }
29        a:=b
30        if (a=b)  { system.out.printString("4. a=b success\n"); }
31
32        /*And or */
33        if(a=3 and b=3) {  system.out.printString("5. a=3 and b=3
        success\n"); }
34
35        b:=5
36        if(b=3 or a=3) {  system.out.printString("6. b=3 or a=3
        success\n"); }
37
38        /*nand and nor and not*/
39        b:=4
40        a:=4
41        if(b=3 nor a=3) {  system.out.printString("7. b=10 nor a
        =10 success\n"); }
42        if(not(b=4 nand a=4)) {  system.out.printString("8. not(b
        =4 nand a=4) success\n"); }
43        b:=3
44        if(b=4 nand a=4) {  system.out.printString("9. b=4 nand a
        =4 success\n"); }
45        if(b=3 xor a=3) {  system.out.printString("10. b=3 xor a=3
         success\n"); }
46        c:=10
47        if((a<>b or b=c) and c=10)  {  system.out.printString("11.
         (a<>b or b=c) and c=10 success\n"); }
48        line()
```

```
49
50    main(System system, String[] args):
51      Test theif := new Test()
```

Test Source 25: "Boolean Comparison"

This test performs boolean comparisons between numeric literal objects.

```
1
2   class Person:
3     protected:
4       String name
5
6     public:
7       init(String name):
8         super()
9         this.name := name
10
11      void introduce():
12        Printer p := system.out
13        p.printString("Hello, my name is ")
14        p.printString(name)
15        p.printString(", and I am from ")
16        p.printString(refine origin() to String)
17        p.printString(". I am ")
18        p.printInteger(refine age() to Integer)
19        p.printString(" years old. My occupation is ")
20        p.printString(refine work() to String)
21        p.printString(". It was nice meeting you.\n")
22
23  class Test:
24    protected:
25      init():
26        super()
27
28    main(System sys, String[] args):
29      (new Person("Matthew") {
30        String introduce.origin() { return "New Jersey"; }
31        Integer introduce.age() { return 33; }
32        String introduce.work() { return "Student"; }
33      }).introduce()
34
35      (new Person("Arthy") {
36        String introduce.origin() { return "India"; }
37        Integer introduce.age() { return 57; }
38        String introduce.work() { return "Student"; }
39      }).introduce()
40
41      (new Person("Weiyuan") {
42        String introduce.origin() { return "China"; }
43        Integer introduce.age() { return 24; }
44        String introduce.work() { return "Student"; }
45      }).introduce()
46
47      (new Person("Ben") {
48        String introduce.origin() { return "New York"; }
```

```
49        Integer introduce.age() { return 24; }
50        String introduce.work() { return "Student"; }
51      }).introduce()
```

Test Source 26: "Anonymous objects"

This tests forms anonymous objects.

```
class Test:
  private:
    void print(Integer i):
      Printer p := system.out
      p.printString("a[")
      p.printInteger(i)
      p.printString("] = ")
      p.printInteger(a[i])
      p.printString("\n")

  public:
    Integer[] a
    init():
      super()
      a := new Integer[](4)
      a[0] := 3
      a[1] := 2
      a[2] := 1
      a[3] := 0

    void print():
      Integer i := 0
      while (i < 4):
        print(i)
        i += 1

  main(System system, String[] args):
    Test f
    f := new Test()
    f.print()
```

Test Source 27: "Arrays"

This test forms an array.

```
class Parent:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 0
```

```
12
13      Integer overview():
14        Integer success := refine toExtra(a,b) to Integer
15        return success
16
17  class Child extends Parent:
18    refinement:
19      Integer overview.toExtra(Integer a, Integer b):
20        Integer success :=  a + b
21        Printer p := new Printer(true)
22        p.printInteger(a)
23        p.printInteger(b)
24        p.printInteger(c)
25        return success
26    public:
27      Integer a1
28      Integer b1
29      Integer c1
30
31      init():
32        super()
33        a1 := 1
34        b1 := 2
35        c1 := 0
36
37  class Test:
38    public:
39      init():
40        super()
41
42    main(System system, String[] args):
43      Parent ab := new Child()
44      Printer p := system.out
45      p.printString("Sum of integer = ")
46      p.printInteger(ab.overview())
47      p.printString("\n")
```

Test Source 28: "Refinement"

This test checks that basic refinement works.

```
1   class Parent:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 0
12
13      Integer overview():
14        Integer success := -1
15        if (refinable(toExtra)) {
```

```
16            success := refine toExtra(a,b) to Integer;
17        }
18        return success
19
20  class Child extends Parent:
21    refinement:
22      Integer overview.toExtra(Integer a, Integer b):
23        Integer success :=  a + b
24        Printer p := new Printer(true)
25        p.printInteger(a)
26        p.printInteger(b)
27        p.printInteger(c)
28        return success
29    public:
30      Integer a1
31      Integer b1
32      Integer c1
33
34      init():
35        super()
36        a1 := 1
37        b1 := 2
38        c1 := 0
39
40  class Test:
41    public:
42      init():
43        super()
44
45    main(System system, String[] args):
46      Parent ab := new Child()
47      Printer p := system.out
48      p.printString("Sum of integer = ")
49      p.printInteger(ab.overview())
50      p.printString("\n")
```

Test Source 29: "Refinable"

This test checks that the refinable keyword works.

```
1   class Parent:
2     protected:
3       Integer a
4       Integer b
5       String name
6
7     public:
8       init(String name):
9         super()
10
11        this.name := name
12        a := 1
13        b := 2
14
15      void print():
16        Printer p := system.out
```

```
17        p.printString(name)
18        p.printString(":  A is ")
19        p.printInteger(a)
20        p.printString(", B is ")
21        p.printInteger(b)
22        p.printString("\n")
23
24      void update():
25        if (refinable(setA)):
26          a := refine setA() to Integer
27        if (refinable(setB)):
28          b := refine setB() to Integer
29
30  class Son extends Parent:
31    public:
32      init(String name):
33        super(name)
34
35    refinement:
36      Integer update.setA():
37        return -1
38      Integer update.setB():
39        return -2
40
41  class Daughter extends Parent:
42    public:
43      init(String name):
44        super(name)
45
46    refinement:
47      Integer update.setA():
48        return 10
49      Integer update.setB():
50        return -5
51
52
53  class Test:
54    protected:
55      init():
56        super()
57
58    main(System sys, String[] args):
59      Parent pop := new Parent("Father")
60      Son son := new Son("Son")
61      Daughter daughter := new Daughter("Daughter")
62
63      pop.print()
64      son.print()
65      daughter.print()
66      sys.out.printString("-------------\n")
67      pop.update()
68      son.update()
69      daughter.update()
70
71      pop.print()
72      son.print()
73      daughter.print()
```

Test Source 30: "Refinements"

This test makes multiple trivial refinements.

5.2.4 Structure Testing

```
class MainTest:
  public:
    init():
      super()
  main(System system, String[] args):
    Integer a
    a := 0
    a += 1
```

Test Source 31: "Main Method"

This test forms a main method

```
class Math:
  private:
    Float xyz
  public:
    init():
      super()
    Integer add(Integer a, Integer b):
      return 6
    Integer sub(Integer a, Integer c):
      return 4
  main(System sys, String[] args):

class NonMath:
  private:
    String shakespeare
  public:
    init():
      super()
    String recite():
      return "hey"
  main(System sys, String[] hey):
```

Test Source 32: "Empty Bodies"

This test presents minimalistic bodies for a variety of methods.

```
class FuncTest:
  public:
      Integer a

```

```
5       init():
6           super()
7           a := 1
8
9     private:
10          Integer incre_a(Integer b):
11              a := a + b
12              return a
13
14          Integer incre_a_twice(Integer b):
15              incre_a(b)
16              incre_a(b)
17              return a
18
19    main(System system, String[] args):
20          FuncTest test := new FuncTest()
```

Test Source 33: "Functions"

This test probes function scope.

5.2.5 A Complex Test

```
1   class IOTest:
2     public:
3       Integer a
4       Integer b
5       Integer c
6       init():
7         super()
8         a := 1
9         b := 2
10        c := 0
11      void overview():
12        Printer p := new Printer(true)
13        p.printInteger(a)
14        p.printInteger(b)
15        p.printInteger(c)
16      Integer incre_ab():
17        Scanner s := new Scanner()
18        Integer delta
19        delta := s.scanInteger()
20        a := a + delta
21        b := b + delta
22        return c
23      Integer arith():
24        c := -(a + b)
25        return c
26
27  class Main:
28    public:
29      init():
30        super()
31    main(String[] args):
```

```
32      IOTest ab := new IOTest()
33      ab.overview()
34      ab.incre_ab()
35      ab.overview()
36      ab.arith()
37      ab.overview()
```

Test Source 34: "Complex Scanning"

This test does a series of more advanced tasks in Gamma.

6 Lessons Learnt

Arthy

First of all, I should thank my wonderful team mates and I enjoyed every bit working with them. Be it clearly silly questions on the language or design or OCAML anything and everything they were always there! And without them it would have certainly not been possible to have pulled this project i must confess well yea at the last moment. Thanks guys!

Thanks to Professor Edwards for making this course so much fun - you never feel the pressure of taking a theoretical course as this - as he puts it - "...in how many other theoretical courses have you had a lecture that ends with a tatooed hand.."

As any team projects we had our own idiosyncracies that left us with missing deadlines and extending demo deadline and what not - so we were not that one off team which miraculously fit well - we were just like any other team but a team that learnt lessons quickly applied them - left ego outside the door - and worked for the fun of the project! If the team has such a spirit that's all that is required.

Advice 1. Do have a team lead 2. Do have one person who is good in OCAML if possible or at least has had experiences with modern programming languages. 3. Have one who is good in programming language theory 4. Ensure you have team meetings - if people do not turn up or go missing - do open up talk to them 5. Ensure everyone is comfortable with the project and is at the same pace as yours early on 6. Discuss the design and make a combined decision - different people think differently that definitely will help. 7. This is definitely a fun course and do not spoil it by procastrination - with OCAML you just have few lines to code why not start early and get it done early (Smiley) 8. I may want to say do not be ambitious - but in retrospect - I learnt a lot - and may be wish some more - so try something cool - after all that's what is grad school for!

Good luck

Ben

This class has been amazing in terms of a practical experience in writting low-level programing and forming a platform for others to write at a higher more abstract-level. I came into this expecting a lot of what the others say they have learned, the most important learning for me is how vital it is to understand your team as much as possible. We are four people with a very diverse set of talents and styles. Applied properly, we probably could have done just about anything with our collective talents. (Spoiler, we did not apply our group talents effectively as would have been hoped.)

My advice to future teams is to get to know each other as computer scientists and people first. If you have the time, do a small (day-long) project together like a mini hackathon. Figure out if your styles differ and write a style guide on which you can all agree. Realistically look at who will have time when. This is not the only thing on anyone's plate, you might have to front-load one member and back-load another. Establish clear leadership and a division of tasks. We just pushed people at the task at hand and were delaying by half-days for a given component to be ready. Write in parallel, it's easier to make your code match up than write linearly and mix schedules and styles. (If you could see the amount of formatting and style correction commits on our repository...)

Good luck. This course is worth it but a real challenge.

Matthew

I had a beginning of an idea of how OOP stuff worked underneath the hood, but this really opened my eyes up to how much work was going on.

It also taught me a lot about making design decisions, and how it's never a good idea to say "this time we'll just use strings and marker values cause we need it done sooner than later" – if Algebraic Data Types are available, use them. Even if it means you have to go back and adjust old code because of previous ideas fall out of line with new ones.

I learned how annoying the idea of a NULL value in a typed system can be when we don't give casting as an option (something we should have thought about before), and how smart python is by having methods accept and name the implicit parameter themselves. Good job, GvR.

Advice

- Start early and procrastinate less
- Have a team leader and communicate better
- Enjoy it

Weiyuan

First I would like to say that this is a very cool, educational and fun project.

One thing I learned from this project is that I take modern programming languages for granted. I enjoyed many comfortable features and syntactic sugar but never realized there is so much craziness under the hood. We had a long list of ambitious goals at the beginning. Many of them had to be given up as the project went on. From parsing to code generation, I faced a lot of design decisions that I did not even know existed. I gained a much better understanding of how programming languages work and why they are designed the way they

are. Also, now I have a completely refreshed view when I see posts titled "Java vs. C++" on the Internet.

Another thing I learned is that proper task division, time management and effective communication are extremely important for a team project. Doing things in parallel and communicating smoothly can save you a lot of trouble.

Finally, I learned my first functional programming language OCaml and I do like it, though I still feel it's weird sometimes.

7 Appendix

```
class IOTest:
  public:
    Integer a
    Integer b
    Integer c
    init():
      super()
      a := 1
      b := 2
      c := 0
    void overview():
      Printer p := new Printer(true)
      p.printInteger(a)
      p.printInteger(b)
      p.printInteger(c)
    Integer incre_ab():
      Scanner s := new Scanner()
      Integer delta
      delta := s.scanInteger()
      a := a + delta
      b := b + delta
      return c
    Integer arith():
      c := -(a + b)
      return c

class Main:
  public:
    init():
      super()
  main(String[] args):
    IOTest ab := new IOTest()
    ab.overview()
    ab.incre_ab()
    ab.overview()
    ab.arith()
    ab.overview()
```

Source 1: `compiler-tests/mix.gamma`

```
class IOTest:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := promptInteger("Please enter an integer")
      Float f := promptFloat("Please enter a float")
      p.printString("Sum of integer + float = ")
      p.printFloat(i.toF() + f)
```

```
      p.printString("\n")

  private:
    void prompt(String msg):
      system.out.printString(msg)
      system.out.printString(": ")

    Integer promptInteger(String msg):
      prompt(msg)
      return system.in.scanInteger()

    Float promptFloat(String msg):
      prompt(msg)
      return system.in.scanFloat()

  main(System system, String[] args):
    IOTest test := new IOTest()
    test.interact()
```

Source 2: `compiler-tests/programs/io.gamma`

```
class HelloWorld:
  public:
    String greeting
    init():
      super()
      greeting := "Hello World!"

  main(System system, String[] args):
    HelloWorld hw := new HelloWorld()
    system.out.printString(hw.greeting)
    system.out.printString("\n")
```

Source 3: `compiler-tests/programs/helloworld.gamma`

```
class Test:
  public:
    init():
      super()

  main(System sys, String[] args):
    Integer i := 0
    Printer p := sys.out

    while (i < sys.argc):
      p.printString("arg[")
      p.printInteger(i)
      p.printString("] = ")
      p.printString(args[i])
      p.printString("\n")
      i += 1
```

Source 4: `compiler-tests/programs/args.gamma`

```
class Parent:
  public:
    init():
      super()

class Child extends Parent:
  public:
    init():
      super()

class Test:
  public:
    init():
      super()

  main(System system, String[] args):
    Child child := new Parent()
```

Source 5: `compiler-tests/bad/super-assign.gamma`

```
class BadDecl:
  public:
    init():
      super()
      Integer a := 3.4
```

Source 6: `compiler-tests/bad/decl.gamma`

```
class Test:
  public:
    Float a
    Float b
    Integer c

    init():
      super()
      a := 1.5
      b := 2.2
      c := 3

    Float overview():
      Float success := a+b+c
      return success

  main(System system, String[] args):
    Test ab := new Test()
    Printer p := system.out
```

```
20      p.printString("Sum of integer = ")
21      p.printFloat(ab.overview())
22      p.printString("\n")
```

Source 7: `compiler-tests/bad/addMix.gamma`

```
1   class BadReturn:
2     public:
3       init():
4         super()
5
6       Integer badReturn():
7         return "Hey There"
```

Source 8: `compiler-tests/bad/return1.gamma`

```
1   class BadAssign:
2     public:
3       init():
4         super()
5         Integer a
6         a := 3.4
```

Source 9: `compiler-tests/bad/assign.gamma`

```
1   class BadStatic:
2     public:
3       Integer getZero():
4         return 0
5       init():
6         super()
7     main(System system, String[] args):
8       getZero()  /* This is supposed to fail. DON'T CHANGE */
```

Source 10: `compiler-tests/bad/static.gamma`

```
1   class Parent:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 0
12
13      Integer overview():
```

```
14        Integer success := refine toExtra(a,b) to Integer
15        return success
16
17  class Child extends Parent:
18    refinement:
19      Integer overview.toExtra(Integer a, Integer b):
20        Integer success :=  a + b
21        Printer p := new Printer(true)
22        p.printInteger(a)
23        p.printInteger(b)
24        p.printInteger(c)
25        return success
26    public:
27      Integer a1
28      Integer b1
29      Integer c1
30
31      init():
32        super()
33        a1 := 1
34        b1 := 2
35        c1 := 0
36
37  class Test:
38    public:
39      init():
40        super()
41
42    main(System system, String[] args):
43      Parent ab := new Parent
44      Printer p := system.out
45      p.printString("Sum of integer = ")
46      p.printInteger(ab.overview())
47      p.printString("\n")
```

Source 11: `compiler-tests/bad/refine_refinable.gamma`

```
1   class BadReturn:
2     public:
3       init():
4         super()
5
6       Integer badReturn():
7         return
```

Source 12: `compiler-tests/bad/return2.gamma`

```
1   class BadReturn:
2     public:
3       init():
4         super()
5
6       void badReturn():
```

```
7       return "Hey There"
```

Source 13: `compiler-tests/bad/return3.gamma`

```
1   class Parent:
2     public:
3       Integer a
4       Integer b
5       Integer c
6
7       init():
8         super()
9         a := 1
10        b := 2
11        c := 0
12
13      Integer overview():
14        Integer success := -1
15        if (refinable(toExtra)) {
16            success := refine toExtra(a,b) to Integer;
17        }
18        return success
19
20  class Child extends Parent:
21    refinement:
22      Integer overview.toExtra(Integer a, Integer b):
23        Integer success :=  a + b
24        Printer p := new Printer(true)
25        p.printInteger(a)
26        p.printInteger(b)
27        p.printInteger(c)
28        return success
29    public:
30      Integer a1
31      Integer b1
32      Integer c1
33
34      init():
35        super()
36        a1 := 1
37        b1 := 2
38        c1 := 0
39
40  class Test:
41    public:
42      init():
43        super()
44
45    main(System system, String[] args):
46      Parent ab := new Parent()
47      Printer p := system.out
48      p.printString("Sum of integer = ")
49      p.printInteger(ab.overview())
50      p.printString("\n")
```

Source 14: `compiler-tests/bad/refinable.gamma`

```
1
2  class WhileLoopTest:
3    public:
4      init():
5        super()
6        Integer a := 0
7        while((a>=0) and (a<10)):
8          system.out.printInteger(a)
9          system.out.printString("\n")
10         a := a + 1
11
12   main(System system, String[] args):
13     new WhileLoopTest()
```

Source 15: `compiler-tests/stmts/while_condn.gamma`

```
1
2  class WhileLoopTest:
3    public:
4      init():
5        super()
6        Integer a := 0
7        while(true):
8          system.out.printInteger(a)
9          system.out.printString("\n")
10         a := a + 1
11
12   main(System system, String[] args):
13     new WhileLoopTest()
```

Source 16: `compiler-tests/stmts/while.gamma`

```
1  class IfTest:
2    private:
3      void line():
4        system.out.printString("\n")
5
6      void out(String msg):
7        system.out.printString(msg)
8        line()
9
10     void yes():
11       out("This should print.")
12     void no():
13       out("This should not print.")
14
15   public:
```

```
    init():
      super()

      out("Simple (1/2)")
      if (true)  { yes(); }
      if (false) { no();  }
      line()

      out("Basic (2/2)")
      if (true)  { yes(); } else { no();  }
      if (false) { no();  } else { yes(); }
      line()

      out("Multiple (3/3)")
      if (true)  { yes(); } elsif (false) { no();  } else { no
    (); }
      if (false) { no();  } elsif (true)  { yes(); } else { no
    (); }
      if (false) { no();  } elsif (false) { no();  } else { yes
    (); }
      line()

      out("Non-exhaustive (2/3)")
      if (true)  { yes(); } elsif (false) { no();  }
      if (false) { no();  } elsif (true)  { yes(); }
      if (false) { no();  } elsif (false) { no();  }

  main(System system, String[] args):
    IfTest theif := new IfTest()
```

Source 17: `compiler-tests/stmts/if.gamma`

```
class Test:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 3

    Integer overview():
      Integer success := a+b
      return success

  main(System system, String[] args):
    Test ab := new Test()
    Printer p := system.out
    p.printString("Sum of integer = ")
    p.printInteger(ab.overview())
    p.printString("\n")
```

Source 18: `compiler-tests/exprs/addInt.gamma`

```
class Test:
  public:
    Integer a
    Float   b

    init():
      super()

    Integer add():
      a := 10 * 2 * 9
      b := 6.0 * 0.5 * (-2.0)
      return 0

  main(System sys, String[] args):
```

Source 19: `compiler-tests/exprs/prod.gamma`

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("integer - float = ")
      p.printFloat(i.toF() - f)
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Source 20: `compiler-tests/exprs/subMix.gamma`

```
class Parent:
  public:
    init():
      super()

class Child extends Parent:
  public:
    init():
      super()

class Test:
```

```
  public:
    init():
      super()

  main(System system, String[] args):
    Parent child := new Child()
```

Source 21: `compiler-tests/exprs/super-assign.gamma`

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("float/Integer = ")
      p.printFloat(f/i.toF())
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Source 22: `compiler-tests/exprs/divMix.gamma`

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("Sum of integer + float = ")
      p.printFloat(i.toF() + f)
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Source 23: `compiler-tests/exprs/addMix.gamma`

```
class Test:
  private:
    void line():
      system.out.printString("\n")
```

```
5
6       void out(String msg):
7         system.out.printString(msg)
8         line()
9
10    public:
11      init():
12        super()
13        Integer a:=2
14        Integer b:=3
15        Integer c
16
17        /* less and less and equal*/
18        if (a<2)  { system.out.printString("1. a=2 a<2 shouldnot
        print\n"); }
19        elsif (a<=2)  { system.out.printString("1. a=2 a<=2
        success\n"); }
20        else { system.out.printString("1. should never hit here\n"
        ); }
21
22
23        /* greater and greater than equal */
24        if (b>3)  { system.out.printString("2. b=3 b>3 shouldnot
        print\n"); }
25        else  { system.out.printString("2. b=3 b>=3 success\n"); }
26
27        /*Equal and not equal*/
28        if (a <> b)  { system.out.printString("3. a!=b success \n"
        ); }
29        a:=b
30        if (a=b)  { system.out.printString("4. a=b success\n"); }
31
32        /*And or */
33        if(a=3 and b=3) {  system.out.printString("5. a=3 and b=3
        success\n"); }
34
35        b:=5
36        if(b=3 or a=3) {  system.out.printString("6. b=3 or a=3
        success\n"); }
37
38        /*nand and nor and not*/
39        b:=4
40        a:=4
41        if(b=3 nor a=3) {  system.out.printString("7. b=10 nor a
        =10 success\n"); }
42        if(not(b=4 nand a=4)) {  system.out.printString("8. not(b
        =4 nand a=4) success\n"); }
43        b:=3
44        if(b=4 nand a=4) {  system.out.printString("9. b=4 nand a
        =4 success\n"); }
45        if(b=3 xor a=3) {  system.out.printString("10. b=3 xor a=3
         success\n"); }
46        c:=10
47        if((a<>b or b=c) and c=10)  {  system.out.printString("11.
         (a<>b or b=c) and c=10 success\n"); }
48        line()
49
```

```
  main(System system, String[] args):
    Test theif := new Test()
```

Source 24: `compiler-tests/exprs/ifeq.gamma`

```
class Test:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 3

    Integer overview():
      Integer success := a%b
      return success

  main(System system, String[] args):
    Test ab := new Test()
    Printer p := system.out
    p.printString(" 1 % 2 = ")
    p.printInteger(ab.overview())
    p.printString("\n")
```

Source 25: `compiler-tests/exprs/mod.gamma`

```

class Person:
  protected:
    String name

  public:
    init(String name):
      super()
      this.name := name

    void introduce():
      Printer p := system.out
      p.printString("Hello, my name is ")
      p.printString(name)
      p.printString(", and I am from ")
      p.printString(refine origin() to String)
      p.printString(". I am ")
      p.printInteger(refine age() to Integer)
      p.printString(" years old. My occupation is ")
      p.printString(refine work() to String)
      p.printString(". It was nice meeting you.\n")

class Test:
```

```
  protected:
    init():
      super()

  main(System sys, String[] args):
    (new Person("Matthew") {
      String introduce.origin() { return "New Jersey"; }
      Integer introduce.age() { return 33; }
      String introduce.work() { return "Student"; }
    }).introduce()

    (new Person("Arthy") {
      String introduce.origin() { return "India"; }
      Integer introduce.age() { return 57; }
      String introduce.work() { return "Student"; }
    }).introduce()

    (new Person("Weiyuan") {
      String introduce.origin() { return "China"; }
      Integer introduce.age() { return 24; }
      String introduce.work() { return "Student"; }
    }).introduce()

    (new Person("Ben") {
      String introduce.origin() { return "New York"; }
      Integer introduce.age() { return 24; }
      String introduce.work() { return "Student"; }
    }).introduce()
```

Source 26: `compiler-tests/exprs/anonymous.gamma`

```
class Test:
  public:
    init():
      super()

    void interact():
      Printer p := system.out
      Integer i := 5
      Float f := 1.5
      p.printString("integer ^ float = ")
      p.printFloat(i.toF() ^ f)
      p.printString("\n")

  main(System system, String[] args):
    Test test := new Test()
    test.interact()
```

Source 27: `compiler-tests/exprs/powMix.gamma`

```
class Test:
  public:
    init():
```

```
    super()

  void interact():
    Printer p := system.out
    Integer i := 5
    Float f := 1.5
    p.printString("integer * float = ")
    p.printFloat(i.toF() * f)
    p.printString("\n")

main(System system, String[] args):
  Test test := new Test()
  test.interact()
```

Source 28: `compiler-tests/exprs/prodMix.gamma`

```
class Parent:
  protected:
    Integer a
    Integer b
    String name

  public:
    init(String name):
      super()

      this.name := name
      a := 1
      b := 2

    void print():
      Printer p := system.out
      p.printString(name)
      p.printString(": A is ")
      p.printInteger(a)
      p.printString(", B is ")
      p.printInteger(b)
      p.printString("\n")

    void update():
      if (refinable(setA)):
        a := refine setA() to Integer
      if (refinable(setB)):
        b := refine setB() to Integer

class Son extends Parent:
  public:
    init(String name):
      super(name)

  refinement:
    Integer update.setA():
      return -1
    Integer update.setB():
      return -2
```

```
40
41  class Daughter extends Parent:
42    public:
43      init(String name):
44        super(name)
45
46    refinement:
47      Integer update.setA():
48        return 10
49      Integer update.setB():
50        return -5
51
52
53  class Test:
54    protected:
55      init():
56        super()
57
58    main(System sys, String[] args):
59      Parent pop := new Parent("Father")
60      Son son := new Son("Son")
61      Daughter daughter := new Daughter("Daughter")
62
63      pop.print()
64      son.print()
65      daughter.print()
66      sys.out.printString("-------------\n")
67      pop.update()
68      son.update()
69      daughter.update()
70
71      pop.print()
72      son.print()
73      daughter.print()
```

Source 29: `compiler-tests/exprs/simple-refine.gamma`

```
1   class Test:
2     private:
3       void print(Integer i):
4         Printer p := system.out
5         p.printString("a[")
6         p.printInteger(i)
7         p.printString("] = ")
8         p.printInteger(a[i])
9         p.printString("\n")
10
11    public:
12      Integer[] a
13      init():
14        super()
15        a := new Integer[](4)
16        a[0] := 3
17        a[1] := 2
18        a[2] := 1
```

```
      a[3] := 0

    void print():
      Integer i := 0
      while (i < 4):
        print(i)
        i += 1

  main(System system, String[] args):
    Test f
    f := new Test()
    f.print()
```

Source 30: `compiler-tests/exprs/newarr.gamma`

```
class Test:
  public:
    Float a
    Float b
    Integer c

    init():
      super()
      a := 1.5
      b := 2.2
      c := 0

    Float overview():
      Float success := a+b
      return success

  main(System system, String[] args):
    Test ab := new Test()
    Printer p := system.out
    p.printString("Sum of integer = ")
    p.printFloat(ab.overview())
    p.printString("\n")
```

Source 31: `compiler-tests/exprs/addFloat.gamma`

```
class Test:
  public:
    Integer a
    Float   b

    init():
      super()

    Integer add():
      a := (10 / 5) / -2
      b := (10.0 / 5.0) / -2.0
      return 0

```

```
  main(System sys, String[] args):
    Test t := new Test()
    Printer p := sys.out

    t.add()
    p.printString("A is ")
    p.printInteger(t.a)
    p.printString(", B is ")
    p.printFloat(t.b)
    p.printString("\n")
```

Source 32: `compiler-tests/exprs/div.gamma`

```
class Parent:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 0

    Integer overview():
      Integer success := refine toExtra(a,b) to Integer
      return success

class Child extends Parent:
  refinement:
    Integer overview.toExtra(Integer a, Integer b):
      Integer success :=  a + b
      Printer p := new Printer(true)
      p.printInteger(a)
      p.printInteger(b)
      p.printInteger(c)
      return success
  public:
    Integer a1
    Integer b1
    Integer c1

    init():
      super()
      a1 := 1
      b1 := 2
      c1 := 0

class Test:
  public:
    init():
      super()

  main(System system, String[] args):
```

```
    Parent ab := new Child()
    Printer p := system.out
    p.printString("Sum of integer = ")
    p.printInteger(ab.overview())
    p.printString("\n")
```

Source 33: `compiler-tests/exprs/refine_refinable.gamma`

```
class Parent:
  public:
    Integer a
    Integer b
    Integer c

    init():
      super()
      a := 1
      b := 2
      c := 0

    Integer overview():
      Integer success := -1
      if (refinable(toExtra)) {
          success := refine toExtra(a,b) to Integer;
      }
      return success

class Child extends Parent:
  refinement:
    Integer overview.toExtra(Integer a, Integer b):
      Integer success :=  a + b
      Printer p := new Printer(true)
      p.printInteger(a)
      p.printInteger(b)
      p.printInteger(c)
      return success
  public:
    Integer a1
    Integer b1
    Integer c1

    init():
      super()
      a1 := 1
      b1 := 2
      c1 := 0

class Test:
  public:
    init():
      super()

  main(System system, String[] args):
    Parent ab := new Child()
    Printer p := system.out
```

```
48      p.printString("Sum of integer = ")
49      p.printInteger(ab.overview())
50      p.printString("\n")
```

Source 34: `compiler-tests/exprs/refinable.gamma`

```
1   class MainTest:
2     public:
3       init():
4         super()
5     main(System system, String[] args):
6       Integer a
7       a := 0
8       a += 1
```

Source 35: `compiler-tests/structure/main.gamma`

```
1   class Math:
2     private:
3       Float xyz
4     public:
5       init():
6         super()
7       Integer add(Integer a, Integer b):
8         return 6
9       Integer sub(Integer a, Integer c):
10        return 4
11    main(System sys, String[] args):
12
13  class NonMath:
14    private:
15      String shakespeare
16    public:
17      init():
18        super()
19      String recite():
20        return "hey"
21    main(System sys, String[] hey):
```

Source 36: `compiler-tests/structure/no-bodies.gamma`

```
1   class FuncTest:
2     public:
3         Integer a
4
5         init():
6             super()
7             a := 1
8
9     private:
10        Integer incre_a(Integer b):
```

```
            a := a + b
            return a

        Integer incre_a_twice(Integer b):
            incre_a(b)
            incre_a(b)
            return a

    main(System system, String[] args):
        FuncTest test := new FuncTest()
```

Source 37: `compiler-tests/structure/func.gamma`

```
open Ast
open Klass

(** Functions to be used with testing in the interpreter (or
    test scripts we write later) *)

let get_example_path dir example = String.concat Filename.
    dir_sep ["test"; "tests"; "Brace"; dir; example]

let get_example_scan dir example =
    let input = open_in (get_example_path dir example) in
    let tokens = Inspector.from_channel input in
    let _ = close_in input in
    tokens

let get_example_parse dir example =
    let tokens = get_example_scan dir example in
    Parser.cdecls (WhiteSpace.lextoks tokens) (Lexing.
    from_string "")

let get_example_longest_body dir example =
    let klasses = get_example_parse dir example in
    let methods aklass = List.flatten (List.map snd (Klass.
    klass_to_functions aklass)) in
    let all_methods = List.flatten (List.map methods klasses) in
    let with_counts = List.map (function func -> (Util.
    get_statement_count func.body, func)) all_methods in
    let maximum = List.fold_left max 0 (List.map fst with_counts
    ) in
    List.map snd (List.filter (function (c, _) -> c == maximum)
    with_counts)
```

Source 38: `Debug.ml`

```
open Printf
open Util

let output_string whatever =
    print_string whatever;
    print_newline()
```

```
7
8  let load_file filename =
9      if Sys.file_exists filename
10         then open_in filename
11         else raise(Failure("Could not find file " ^ filename ^ "
       ."))
12
13 let with_file f file =
14     let input = load_file file in
15     let result = f input in
16     close_in input;
17     result
18
19 let get_data ast =
20     let (which, builder) = if (Array.length Sys.argv <= 2)
21         then ("Normal", KlassData.build_class_data)
22         else ("Experimental", KlassData.build_class_data_test)
       in
23     output_string (Format.sprintf " * Using %s KlassData Builder
       " which);
24     match builder ast with
25         | Left(data) -> data
26         | Right(issue) -> Printf.fprintf stderr "%s\n" (
       KlassData.errstr issue); exit 1
27
28 let do_deanon klass_data sast = match Unanonymous.deanonymize
       klass_data sast with
29     | Left(result) -> result
30     | Right(issue) -> Printf.fprintf stderr "Error Deanonymizing
       :\n%s\n" (KlassData.errstr issue); exit 1
31
32 let source_cast _ =
33     output_string " * Reading Tokens...";
34     let tokens = with_file Inspector.from_channel Sys.argv.(1)
       in
35     output_string " * Parsing Tokens...";
36     let ast = Parser.cdecls (WhiteSpace.lextoks tokens) (Lexing.
       from_string "") in
37     output_string " * Generating Global Data...";
38     let klass_data = get_data ast in
39     output_string " * Building Semantic AST...";
40     let sast = BuildSast.ast_to_sast klass_data in
41     output_string " * Deanonymizing Anonymous Classes.";
42     let (klass_data, sast) = do_deanon klass_data sast in
43     output_string " * Rebinding refinements.";
44     let sast = BuildSast.update_refinements klass_data sast in
45     output_string " * Generating C AST...";
46     GenCast.sast_to_cast klass_data sast
47
48 let main _ =
49     Printexc.record_backtrace true;
50     output_string "/* Starting Build Process...";
51     try
52         let source = source_cast () in
53         output_string " * Generating C...";
54         output_string " */";
55         GenC.cast_to_c source stdout;
```

```
        print_newline ();
        exit 0
    with excn ->
        let backtrace = Printexc.get_backtrace () in
        let reraise = ref false in
        let out = match excn with
            | Failure(reason) -> Format.sprintf "Failed: %s\n" reason
            | Invalid_argument(msg) -> Format.sprintf "Argument issue somewhere: %s\n" msg
            | Parsing.Parse_error -> "Parsing error."
            | _ -> reraise := true; "Unknown Exception" in
        Printf.fprintf stderr "%s\n%s\n" out backtrace;
        if !reraise then raise(excn) else exit 1

let _ = main ()
```

Source 39: `ray.ml`

```
module StringMap = Map.Make (String);;

type class_def = { klass : string; parent : string option};;

let d1 = { klass = "myname"; parent = "Object" };;
let d3 = { klass = "myname2"; parent = "Object1" };;
let d4 = { klass = "myname3"; parent = "Object2" };;
let d2 = { klass = "myname1"; parent = "Object" };;

(*let myfunc cnameMap cdef =
    if StringMap.mem cdef.parent cnameMap then
        let cur = StringMap.find cdef.parent cnameMap in
        StringMap.add cdef.parent (cdef.klass::cur) cnameMap
    else
            StringMap.add cdef.parent [cdef.klass] cnameMap;;

*)
let rec print_list = function
[] -> ()
| e::l -> print_string e ; print_string " " ; print_list l;;

let rec spitmap fst scnd = print_string fst; print_list scnd;;

let cnameMap =

let myfunc cnameMap cdef =
    if StringMap.mem cdef.parent cnameMap then
        let cur = StringMap.find cdef.parent cnameMap in
        StringMap.add cdef.parent (cdef.klass::cur) cnameMap
    else
            StringMap.add cdef.parent [cdef.klass] cnameMap

in
   List.fold_left
    myfunc
   StringMap.empty [d1;d2;d3;d4];;
```

```
37 StringMap.iter spitmap cnameMap;;
38
39 print_newline
```

Source 40: `unittest/bkup.ml`

```
1  module StringMap = Map.Make (String);;
2
3
4
5  type var_def = string * string;;
6  type func_def = {
7    returns : string option;
8    host    : string option;
9    name    : string;
10   static  : bool;
11   formals : var_def list;
12   (*body    : stmt list;*)
13 };;
14 type member_def = VarMem of var_def | MethodMem of func_def |
       InitMem of func_def;;
15
16 (* Things that can go in a class *)
17 type class_sections_def = {
18   privates : member_def list;
19   protects : member_def list;
20   publics  : member_def list;
21 (*  refines  : func_def list;
22   mains    : func_def list;*)
23 };;
24
25 type class_def = { klass : string; parent : string option;
       sections : class_sections_def; };;
26
27 let sdef1 = {
28  privates = [VarMem("int","a"); VarMem("int","b");];
29  protects = [VarMem("int","c"); VarMem("int","d");];
30  publics  = [VarMem("int","e"); VarMem("int","f");];
31 };;
32
33 let sdef2 = {
34  privates = [ VarMem("int","g"); VarMem("int","h");];
35  protects = [ VarMem("int","j"); VarMem("int","i");];
36  publics = [ VarMem("int","k"); VarMem("int","l");];
37 };;
38
39 let sdef3 = {
40  privates = [ VarMem("int","m"); VarMem("int","n");];
41  protects = [ VarMem("int","p"); VarMem("int","o");];
42  publics = [ VarMem("int","q"); VarMem("int","r");];
43 };;
44
45 let sdef4 = {
46  privates = [VarMem("int","x"); VarMem("int","s");];
47  protects = [VarMem("int","w"); VarMem("int","t");];
```

```
 publics = [VarMem("int","v"); VarMem("int","u");];
};;
let d1 = { klass = "myname"; parent = Some("Object"); sections =
     sdef1 };;
let d3 = { klass = "myname2"; parent = Some("myname1");
    sections = sdef3; };;
let d4 = { klass = "myname3"; parent = Some("myname2");
    sections = sdef4; };;
let d2 = { klass = "myname1"; parent = Some("myname"); sections
    = sdef2; };;
(*
let myfunc cnameMap cdef =
    if StringMap.mem cdef.parent cnameMap then
        let cur = StringMap.find cdef.parent cnameMap in
        StringMap.add cdef.parent (cdef.klass::cur) cnameMap
    else
            StringMap.add cdef.parent [cdef.klass] cnameMap;;

*)
let rec print_list = function
[] -> print_string "No more subclasses\n";
| e::l -> print_string e ; print_string "," ; print_list l;;

let rec spitmap fst scnd = print_string fst; print_string "->";
    print_list scnd;;

let cnameMap =

let myfunc cnameMap cdef =

    let cnameMap = StringMap.add cdef.klass [] cnameMap
    in
    let myparent =
        match cdef.parent with
        None -> "Object"
        | Some str -> str
    in
    if StringMap.mem myparent cnameMap then
        let cur = StringMap.find myparent cnameMap in
        StringMap.add myparent (cdef.klass::cur) cnameMap
    else
            StringMap.add myparent [cdef.klass] cnameMap;


in
   List.fold_left myfunc StringMap.empty [d1;d2;d3;d4];;
StringMap.iter spitmap cnameMap;;

let s2bmap =

    let subtobase s2bmap cdef =
        if StringMap.mem cdef.klass s2bmap then
                (*how to raise exception*)
            s2bmap
        else
            StringMap.add cdef.klass cdef.parent s2bmap

```

```
100     in
101     List.fold_left
102         subtobase
103        StringMap.empty [d1;d2;d3;d4];;
104
105 let rec spitmap fst snd = print_string fst; print_string "->";
106         match snd with
107           Some str ->  print_string str;print_string "\n"
108         | None -> print_string "Object's parent is none\n";
109 in
110 StringMap.iter spitmap s2bmap;;
111
112 print_newline;;
113
114
115 print_string "getclassdef test\n\n";;
116 let rec getclassdef cname clist =
117     match clist with
118     [] -> None
119     | hd::tl -> if hd.klass = cname then Some(hd) else
    getclassdef cname tl;;
120
121 let print_cdef c = match c with None -> "No classdef" | Some c1
    -> c1.klass;;
122 let print_pdef p = match p with None -> "No classdef" | Some p1
    ->
123             (match p1.parent with None -> "No parent" | Some x
    -> x);;
124
125 let def1 = getclassdef "myname" [d1;d2;d3;d4];;
126 print_string (print_cdef def1);;
127 print_string "\n";;
128 print_string(print_pdef def1);;
129
130 print_string "\n\ngetmethoddef test\n";;
131
132
133
134 let rec getmemdef mname mlist =
135     match mlist with
136     [] -> None
137     | hd::tl -> match hd with
138             VarMem(typeid, varname) -> if varname = mname then
    Some(typeid) else getmemdef mname tl
139             | _ -> None
140 ;;
141
142 (*Given a class definition and variable name, the lookupfield
143 looksup for the field in the privates, publics and protects list
    .
144 If found returns a (classname, accessspecifier, typeid,
    variablename) tuple
145 If not found returns a None*)
146 let lookupfield cdef vname =
147     let pmem = getmemdef vname cdef.sections.privates
148     in
149     match pmem with
```

```
150     Some def -> Some(cdef.klass, "private", vname, def)
151      | None     ->
152         let pubmem = getmemdef vname cdef.sections.publics
153         in
154         match pubmem with
155             Some def -> Some(cdef.klass, "public", vname, def)
156              | None     ->
157                 let promem = getmemdef vname cdef.sections.
    protects
158                 in
159                 match promem with
160                     Some def -> Some(cdef.klass, "protect",
    vname, def)
161                   |     None  -> None
162 ;;
163
164 (*getfield takes classname and variablename;
165   looks for the class with the classname;
166   If classname found, looksup the variable in the class;
167   Else returns None
168 *)
169 let fstoffour (x,_,_,_) = x;;
170 let sndoffour (_,x,_,_) = x;;
171 let throffour (_,_,x,_) = x;;
172 let lstoffour (_,_,_,x) = x;;
173
174 let rec getfield cname vname cdeflist =
175     let classdef = getclassdef cname cdeflist
176     in
177     match classdef with
178               None ->
179         if cname = "Object" then
180             None
181         else
182             let basename = match(StringMap.find cname s2bmap)
    with Some b -> b | None -> "Object"
183             in
184             getfield basename vname cdeflist
185     |    Some (cdef) -> lookupfield cdef vname;;
186
187 let field = getfield "myname3" "a" [d1;d2;d3;d4]
188 in
189 match field with
190 None -> print_string "field not found\n";
191 | Some tup -> print_string (fstoffour(tup));;
```

Source 41: `unittest/sast.ml`

```
1 %{
2 open Ast
3
4 (** Parser that reads from the scanner and produces an AST. *)
5
6 (** Set a single function to belong to a certain section *)
7 let set_func_section_to sect f = { f with section = sect }
```

```
8  (** Set a list of functions to belong to a certain section *)
9  let set_func_section sect = List.map (set_func_section_to sect)
10
11 (** Set a single member to belong to a certain subset of class
       memory.
12     This is necessary as a complicated function because init and
        main
13     can live in one of the several access levels. *)
14 let set_mem_section_to sect = function
15   | VarMem(v) -> VarMem(v)
16   | InitMem(func) -> InitMem({ func with section = sect })
17   | MethodMem(func) -> MethodMem({ func with section = sect })
18
19 (** Set a list of members to belong to a certain subset of class
        memory *)
20 let set_mem_section sect = List.map (set_mem_section_to sect)
21
22
23 (** Set the klass of a func_def *)
24 let set_func_klass aklass func = { func with inklass = aklass }
25
26 (** Set the klass of a function member *)
27 let set_member_klass aklass = function
28   | InitMem(func) -> InitMem(set_func_klass aklass func)
29   | MethodMem(func) -> MethodMem(set_func_klass aklass func)
30   | v -> v
31
32 (** Set the klass of all sections *)
33 let set_func_class aklass sections =
34   let set_mems = List.map (set_member_klass aklass) in
35   let set_funcs = List.map (set_func_klass aklass) in
36   { privates = set_mems  sections.privates;
37     publics  = set_mems  sections.publics;
38     protects = set_mems  sections.protects;
39     refines  = set_funcs sections.refines;
40     mains    = set_funcs sections.mains }
41 %}
42
43 %token <int> SPACE
44 %token COLON NEWLINE
45 %token LPAREN RPAREN LBRACKET RBRACKET COMMA LBRACE RBRACE
46 %token PLUS MINUS TIMES DIVIDE MOD POWER
47 %token PLUSA MINUSA TIMESA DIVIDEA MODA POWERA
48 %token EQ NEQ GT LT GEQ LEQ AND OR NAND NOR XOR NOT
49 %token IF ELSE ELSIF WHILE
50 %token ASSIGN RETURN CLASS EXTEND SUPER INIT PRIVATE PROTECTED
       PUBLIC
51 %token NULL VOID THIS
52 %token NEW MAIN ARRAY
53 %token REFINABLE REFINE REFINES TO
54 %token SEMI COMMA DOT EOF
55
56 %token <string> TYPE
57 %token <int> ILIT
58 %token <float> FLIT
59 %token <bool> BLIT
60 %token <string> SLIT
```

```
%token <string> ID

/* Want to work on associtivity when I'm a bit fresher */
%right ASSIGN PLUSA MINUSA TIMESA DIVIDEA MODA POWERA
%left OR NOR XOR
%left AND NAND
%left EQ NEQ
%left LT GT LEQ GEQ
%left PLUS MINUS
%left TIMES DIVIDE MOD
%nonassoc UMINUS
%left NOT POWER
%left LPAREN RPAREN LBRACKET RBRACKET
%left DOT

%start cdecls
%type <Ast.program> cdecls

%%

/* Classe and subclassing */
cdecls:
  | cdecl { [$1] }
  | cdecls cdecl { $2 :: $1 }
cdecl:
  | CLASS TYPE extend_opt class_section_list
    { { klass      = $2;
        parent     = $3;
        sections   = set_func_class $2 $4  } }
extend_opt:
  | /* default */  { Some("Object") }
  | EXTEND TYPE    { Some($2) }

/* Class sections */
class_section_list:
  | LBRACE class_sections RBRACE  { $2 }
class_sections:
  | /* Base Case */
    { { privates = [];
        protects = [];
        publics  = [];
        refines  = [];
        mains    = [] } }
  | class_sections private_list  { { $1 with privates = (
    set_mem_section Privates $2)  @  $1.privates } }
  | class_sections protect_list  { { $1 with protects = (
    set_mem_section Protects $2)  @  $1.protects } }
  | class_sections public_list   { { $1 with publics  = (
    set_mem_section Publics $2)   @  $1.publics  } }
  | class_sections refine_list   { { $1 with refines  = (
    set_func_section Refines $2)  @  $1.refines  } }
  | class_sections main_method   { { $1 with mains    = (
    set_func_section_to Mains $2) :: $1.mains    } }

/* Refinements */
refine_list:
  | REFINES LBRACE refinements RBRACE { $3 }
```

```
113 refinements:
114   | /* Can be empty */       { [] }
115   | refinements refinement   { $2 :: $1 }
116 refinement:
117   | vartype ID DOT invocable  { { $4 with returns = Some($1);
      host = Some($2) } }
118   | VOID ID DOT invocable     { { $4 with host = Some($2) } }
119
120 /* Private, protected, public members */
121 private_list:
122   | PRIVATE member_list     { $2 }
123 protect_list:
124   | PROTECTED member_list   { $2 }
125 public_list:
126   | PUBLIC member_list      { $2 }
127
128 /* Members of such access groups */
129 member_list:
130   | LBRACE members RBRACE   { $2 }
131 members:
132   | { [] }
133   | members member   { $2 :: $1 }
134 member:
135   | vdecl semi   { VarMem($1)    }
136   | mdecl        { MethodMem($1) }
137   | init         { InitMem($1)   }
138
139 /* Methods */
140 mdecl:
141   | vartype invocable   { { $2 with returns = Some($1) } }
142   | VOID invocable      { $2 }
143
144 /* Constructors */
145 init:
146   | INIT callable   { { $2 with name = "init" } }
147
148 /* Each class has an optional main */
149 main_method:
150   | MAIN callable   { { $2 with name = "main"; static = true } }
151
152 /* Anything that is callable has these forms */
153 invocable:
154   | ID callable   { { $2 with name = $1 } }
155 callable:
156   | formals stmt_block
157     { { returns = None;
158         host    = None;
159         name    = "";
160         static  = false;
161         formals = $1;
162         body    = $2;
163         section = Privates;
164         inklass = "";
165         uid     = UID.uid_counter ();
166         builtin = false } }
167
168 /* Statements */
```

```
169 stmt_block:
170   | LBRACE stmt_list RBRACE  { List.rev $2 }
171 stmt_list:
172   | /* nada */      { [] }
173   | stmt_list stmt  { $2 :: $1 }
174 stmt:
175   | vdecl semi              { Decl($1, None) }
176   | vdecl ASSIGN expr semi  { Decl($1, Some($3)) }
177   | SUPER actuals semi      { Super($2) }
178   | RETURN expr semi        { Return(Some($2)) }
179   | RETURN semi;            { Return(None) }
180   | conditional             { $1 }
181   | loop                    { $1 }
182   | expr semi               { Expr($1) }
183
184 /* Control Flow */
185 conditional:
186   | IF pred stmt_block else_list  { If((Some($2), $3) :: $4) }
187 else_list:
188   | /* nada */                          { [] }
189   | ELSE stmt_block                     { [(None, $2)] }
190   | ELSIF pred stmt_block else_list     { (Some($2), $3) :: $4 }
191 loop:
192   | WHILE pred stmt_block  { While($2, $3) }
193 pred:
194   | LPAREN expr RPAREN  { $2 }
195
196
197 /* Expressions */
198 expr:
199   | assignment          { $1 }
200   | invocation          { $1 }
201   | field               { $1 }
202   | value               { $1 }
203   | arithmetic          { $1 }
204   | test                { $1 }
205   | instantiate         { $1 }
206   | refineexpr          { $1 }
207   | literal             { $1 }
208   | LPAREN expr RPAREN  { $2 }
209   | THIS                { This }
210   | NULL                { Null }
211
212 assignment:
213   | expr ASSIGN expr   { Assign($1, $3) }
214   | expr PLUSA expr    { Assign($1, Binop($1, Arithmetic(Add),
      $3)) }
215   | expr MINUSA expr   { Assign($1, Binop($1, Arithmetic(Sub),
      $3)) }
216   | expr TIMESA expr   { Assign($1, Binop($1, Arithmetic(Prod),
      $3)) }
217   | expr DIVIDEA expr  { Assign($1, Binop($1, Arithmetic(Div),
      $3)) }
218   | expr MODA expr     { Assign($1, Binop($1, Arithmetic(Mod),
      $3)) }
219   | expr POWERA expr   { Assign($1, Binop($1, Arithmetic(Pow),
      $3)) }
```

```
220
221 invocation:
222   | expr DOT ID actuals { Invoc($1, $3, $4) }
223   | ID actuals { Invoc(This, $1, $2) }
224
225 field:
226   | expr DOT ID  { Field($1, $3) }
227
228 value:
229   | ID    { Id($1) }
230   | expr LBRACKET expr RBRACKET  { Deref($1, $3) }
231
232 arithmetic:
233   | expr PLUS expr           { Binop($1, Arithmetic(Add), $3) }
234   | expr MINUS expr          { Binop($1, Arithmetic(Sub), $3) }
235   | expr TIMES expr          { Binop($1, Arithmetic(Prod), $3) }
236   | expr DIVIDE expr         { Binop($1, Arithmetic(Div), $3) }
237   | expr MOD expr            { Binop($1, Arithmetic(Mod), $3) }
238   | expr POWER expr          { Binop($1, Arithmetic(Pow), $3) }
239   | MINUS expr %prec UMINUS  { Unop(Arithmetic(Neg), $2) }
240
241 test:
242   | expr AND expr   { Binop($1, CombTest(And), $3) }
243   | expr OR expr    { Binop($1, CombTest(Or), $3) }
244   | expr XOR expr   { Binop($1, CombTest(Xor), $3) }
245   | expr NAND expr  { Binop($1, CombTest(Nand), $3) }
246   | expr NOR expr   { Binop($1, CombTest(Nor), $3) }
247   | expr LT expr    { Binop($1, NumTest(Less), $3) }
248   | expr LEQ expr   { Binop($1, NumTest(Leq), $3) }
249   | expr EQ expr    { Binop($1, NumTest(Eq), $3) }
250   | expr NEQ expr   { Binop($1, NumTest(Neq), $3) }
251   | expr GEQ expr   { Binop($1, NumTest(Geq), $3) }
252   | expr GT expr    { Binop($1, NumTest(Grtr), $3) }
253   | NOT expr        { Unop(CombTest(Not), $2) }
254   | REFINABLE LPAREN ID RPAREN { Refinable($3) }
255
256 instantiate:
257   | NEW vartype actuals  { NewObj($2, $3) }
258   | NEW vartype actuals LBRACE refinements RBRACE  { Anonymous(
      $2, $3, List.map (set_func_klass $2) $5) }
259
260 refineexpr:
261   | REFINE ID actuals TO vartype  { Refine($2, $3, Some($5)) }
262   | REFINE ID actuals TO VOID     { Refine($2, $3, None) }
263
264 literal:
265   | lit  { Literal($1) }
266
267 /* Literally necessary */
268 lit:
269   | SLIT { String($1) }
270   | ILIT { Int($1) }
271   | FLIT { Float($1) }
272   | BLIT { Bool($1) }
273
274 /* Parameter lists */
275 formals:
```

```
276     | LPAREN formals_opt RPAREN  { $2 }
277   formals_opt:
278     | { [] }
279     | formals_list  { List.rev $1 }
280   formals_list:
281     | vdecl  { [$1] }
282     | formals_list COMMA vdecl  { $3 :: $1 }
283
284   /* Arguments */
285   actuals:
286     | LPAREN actuals_opt RPAREN { $2 }
287   actuals_opt:
288     | { [] }
289     | actuals_list { List.rev $1 }
290   actuals_list:
291     | expr { [$1] }
292     | actuals_list COMMA expr { $3 :: $1}
293
294   /* Variable declaration */
295   vdecl:
296     | vartype ID { ($1, $2) }
297   vartype:
298     | TYPE          { $1 }
299     | vartype ARRAY { $1 ^ "[]" }
300
301   /* Eat multiple semis */
302   semi:
303     | SEMI  {}
304     | semi SEMI  {}
```

Source 42: `parser.mly`

```
1   open Ast
2   open Util
3   open StringModules
4   open GlobalData
5
6   (** Approximates a class *)
7   (**
8       From a class get the parent
9       @param aklass is a class_def to get the parent of
10      @return The name of the parent object
11    *)
12  let klass_to_parent aklass = match aklass with
13      | { klass = "Object" } -> raise(Invalid_argument("Cannot get
          parent of the root"))
14      | { parent = None; _ } -> "Object"
15      | { parent = Some(aklass); _ } -> aklass
16
17  (**
18      Utility function -- place variables in left, methods (
        including init) in right
19      @param mem A member_def value (VarMem, MethodMem, InitMem)
20      @return Places the values held by VarMem in Left, values
        held by MethodMem or InitMem in Right
```

```
21    *)
22  let member_split mem = match mem with
23      | VarMem(v) -> Left(v)
24      | MethodMem(m) -> Right(m)
25      | InitMem(i) -> Right(i)
26
27  (**
28      Stringify a section to be printed
29      @param section A class_section value (Privates, Protects,
        Publics, Refines, or Mains)
30      @return The stringification of the section for printing
31    *)
32  let section_string section = match section with
33      | Privates -> "private"
34      | Protects -> "protected"
35      | Publics -> "public"
36      | Refines -> "refinement"
37      | Mains -> "main"
38
39  (**
40      Return the variables of the class
41      @param aklass The class to explore
42      @return A list of ordered pairs representing different
        sections,
43      the first item of each pair is the type of the section, the
        second
44      is a list of the variables defs (type, name). Note that this
         only
45      returns pairs for Publics, Protects, and Privates as the
        others
46      cannot have variables
47    *)
48  let klass_to_variables aklass =
49      let vars members = fst (either_split (List.map member_split
        members)) in
50      let s = aklass.sections in
51      [(Publics, vars s.publics); (Protects, vars s.protects); (
        Privates, vars s.privates)]
52
53  (**
54      Return the methods of the class
55      @param aklass The class to explore
56      @return A list of ordered pairs representing different
        sections,
57      the first item of each pair is the type of the section, the
        second
58      is a list of the methods. Note that this only returns the
        methods
59      in Publics, Protects, or Privates as the other sections don'
        t have
60      'normal' methods in them
61    *)
62  let klass_to_methods aklass =
63      let funcs members = snd (either_split (List.map member_split
         members)) in
64      let s = aklass.sections in
65      [(Publics, funcs s.publics); (Protects, funcs s.protects); (
```

```
    Privates, funcs s.privates)]

(**
    Get anything that is invocable, not just instance methods
    @param aklass The class to explore
    @return The combined list of refinements, mains, and methods
  *)
let klass_to_functions aklass =
    let s = aklass.sections in
    (Refines, s.refines) :: (Mains, s.mains) :: klass_to_methods
     aklass

(**
    Return whether two function definitions have conflicting
    signatures
    @param func1 A func_def
    @param func2 A func_def
    @return Whether the functions have the same name and the
    same parameter type sequence
  *)
let conflicting_signatures func1 func2 =
    let same_type (t1, _) (t2, _) = (t1 = t2) in
    let same_name = (func1.name = func2.name) in
    let same_params = try List.for_all2 same_type func1.formals
    func2.formals with
        | Invalid_argument(_) -> false in
    same_name && same_params

(**
    Return a string that describes a function
    @param func A func_def
    @return A string showing the simple signature ([host.]name
    and arg types)
  *)
let signature_string func =
    let name = match func.host with
        | None -> func.name
        | Some(h) -> Format.sprintf "%s.%s" h func.name in
    Format.sprintf "%s(%s)" name (String.concat ", " (List.map
    fst func.formals))

(**
    Return a string representing the full signature of the
    function
    @param func A func_def
    @return A string showing the signature (section, [host.]name
    , arg types)
  *)
let full_signature_string func =
    let ret = match func.returns with
        | None -> "Void"
        | Some(t) -> t in
    Format.sprintf "%s %s %s" (section_string func.section) ret
    (signature_string func)

(**
    Given a class_data record, a class name, and a variable name
```

```
    , lookup the section and type
    info for that variable.
    @param data A class_data record
    @param klass_name The name of a class (string)
    @param var_name The name of a variable (string)
    @return Either None if the variable is not declared in the
    class or Some((section, type))
    where the variable is declared in section and has the given
    type.
  *)
let class_var_lookup data klass_name var_name =
    match map_lookup klass_name data.variables with
        | Some(var_map) -> map_lookup var_name var_map
        | _ -> None

(**
    Given a class_data record, a class_name, and a variable name
    , lookup the class in the hierarchy
    that provides access to that variable from within that class
     (i.e. private in that class or
    public / protected in an ancestor).
    @param data A class_data record.
    @param klass_name The name of a class (string)
    @param var_name The name of a variable (string).
    @return (class (string), type (string), class_section)
    option (None if not found).
  *)
let class_field_lookup data klass_name var_name =
    let var_lookup klass = class_var_lookup data klass var_name
    in
    let rec lookup klass sections = match var_lookup klass,
    klass with
        | Some((sect, vtype)), _ when List.mem sect sections ->
    Some((klass, vtype, sect))
        | _, "Object" -> None
        | _, _ -> lookup (StringMap.find klass data.parents) [
    Publics; Protects] in
    lookup klass_name [Publics; Protects; Privates]

(**
    Given a class_data record, a class name, a var_name, and
    whether the receiver of the field lookup
    is this, return the lookup of the field in the ancestry of
    the object. Note that this restricts
    things that should be kept protected (thus this thusly
    passed)
    @param data A class_data record
    @param klass_name The name of a class (string)
    @param var_name The name of a variable (string)
    @return Either the left of a triple (class found, type,
    section) or a Right of a boolean, which
    is true if the item was found but inaccessible and false
    otherwise.
  *)
let class_field_far_lookup data klass_name var_name this =
    match class_field_lookup data klass_name var_name with
        | Some((klass, vtyp, section)) when this || section =
```

```
    Publics -> Left((klass, vtyp, section))
155         | Some(_) -> Right(true)
156         | None -> Right(false)
157
158 (**
159     Given a class_data record, a class name, and a method name,
        lookup all the methods in the
160     given class with that name.
161     @param data A class_data record
162     @param klass_name The name of a class (string)
163     @param func_name The name of a method (string)
164     @return A list of methods in the class with that name or the
         empty list if no such method exists.
165   *)
166 let class_method_lookup data klass_name func_name =
167     match map_lookup klass_name data.methods with
168         | Some(method_map) -> map_lookup_list func_name
        method_map
169         | _ -> []
170
171 (**
172     Given a class_data record, a class name, a method name, and
        whether the current context is
173     'this' (i.e. if we want private / protected / etc), then
        return all methods in the ancestry
174     of that class with that name (in the appropriate sections).
175     @param data A class_data record value
176     @param klass_name The name of a class.
177     @param method_name The name of a method to look up
178     @param this search mode -- true means public/protected/
        private and then public/protected,
179     false is always public
180     @return A list of methods with the given name.
181   *)
182 let class_ancestor_method_lookup data klass_name method_name
        this =
183     let (startsects, recsects) = if this then ([Publics;
        Protects; Privates], [Publics; Protects]) else ([Publics], [
        Publics]) in
184     let rec find_methods found aklass sects =
185         let accessible f = List.mem f.section sects in
186         let funcs = List.filter accessible (class_method_lookup
        data aklass method_name) in
187         let found = funcs @ found in
188         if aklass = "Object" then found
189         else if method_name = "init" then found
190         else find_methods found (StringMap.find aklass data.
        parents) recsects in
191     find_methods [] klass_name startsects
192
193 (**
194     Given a class_data record, class name, method name, and
        refinement name, return the list of
195     refinements in that class for that method with that name.
196     @param data A class_data record value
197     @param klass_name A class name
198     @param method_name A method name
```

```
199         @param refinement_name A refinement name
200         @return A list of func_def values that match the given
            requirements. Note that this returns the
201         functions defined IN class name, not the ones that could be
            used INSIDE class name (via a refine
202         invocation). i.e. functions that may be invoked by the
            parent.
203       *)
204     let refine_lookup data klass_name method_name refinement_name =
205         match map_lookup klass_name data.refines with
206             | Some(map) -> map_lookup_list (method_name ^ "." ^
            refinement_name) map
207             | _ -> []
208
209     (**
210         Given a class_data record, a class name, a method name, and
            a refinement name, return the list
211         of refinements across all subclasses for the method with
            that name.
212         @param data A class_data record value
213         @param klass_name A class name
214         @param method_name A method name
215         @param refinement_name A refinement name
216         @return A list of func_def values that meet the criteria and
             may be invoked by this given method.
217         i.e. these are all functions residing in SUBCLASSES of the
            named class.
218       *)
219     let refinable_lookup data klass_name method_name refinement_name
            =
220         let refines = match map_lookup klass_name data.refinable
            with
221             | Some(map) -> map_lookup_list method_name map
222             | None -> [] in
223         List.filter (fun f -> f.name = refinement_name) refines
224
225     (**
226         Given a class_data record and two classes, returns the
            distance between them. If one is a proper
227         subtype of the other then Some(n) is returned where n is non
            -zero when the two classes are different
228         and comparable (one is a subtype of the other), zero when
            they are the same, and None when they are
229         incomparable (one is not a subtype of the other)
230         @param data A class_data record
231         @param klass1 A class to check the relation of to klass2
232         @param klass2 A class to check the relation of to klass1
233         @return An int option, None when the two classes are
            incomparable, Some(positive) when klass2 is an
234         ancestor of klass1, Some(negative) when klass1 is an
            ancestor of klass2.
235       *)
236     let get_distance data klass1 klass2 =
237         (* We let these pop exceptions because that means bad
            programming on the compiler
238          * writers part, not on the GAMMA programmer's part (when
            klass1, klass2 aren't found)
```

```
239         *)
240     let klass1_map = StringMap.find klass1 data.distance in
241     let klass2_map = StringMap.find klass2 data.distance in
242     match map_lookup klass2 klass1_map, map_lookup klass1
        klass2_map with
243         | None, None -> None
244         | None, Some(n) -> Some(-n)
245         | res, _ ->  res
246
247 (**
248     Check if a type exists in the class data -- convenience
        function
249     @param data A class_data record
250     @param atype The name of a class (string)
251     @return True if the atype is a known type, false otherwise.
252   *)
253 let is_type data atype =
254     let lookup = try String.sub atype 0 (String.index atype '[')
         with
255         | Not_found -> atype in
256     StringSet.mem lookup data.known
257
258 (**
259     Check if a class is a subclass of another given a class_data
         record
260     @param data A class_data record
261     @param subtype A class name (string)
262     @param supertype A class name (string)
263     @return Whether subtype has supertype as an ancestor given
        data.
264     Note that this is true when the two are equal (trivial
        ancestor).
265   *)
266 let is_subtype data subtype supertype =
267     let basetype s = try let n = String.index s '[' in String.
        sub s 0 n with Not_found -> s in
268     match get_distance data (basetype subtype) (basetype
        supertype) with
269         | Some(n) when n >= 0 -> true
270         | _ -> false
271
272 (**
273     Check if a class is a proper subclass of another given a
        class_data record
274     @param data A class_data record
275     @param subtype A class name (string)
276     @param supertype A class name (string)
277     @return Whether subtype has supertype as an ancestor given
        data.
278     Note that this IS NOT true when the two are equal (trivial
        ancestor).
279   *)
280 let is_proper_subtype data subtype supertype =
281     match get_distance data subtype supertype with
282         | Some(n) when n > 0 -> true
283         | _ -> false
284
```

```
285 (**
286     Return whether a list of actuals and a list of formals are
        compatible.
287     For this to be true, each actual must be a (not-necessarily-
        proper) subtype
288     of the formal at the same position. This requires that both
        be the same
289     in quantity, obviously.
290     @param data A class_data record (has type information)
291     @param actuals A list of the types (and just the types) of
        the actual arguments
292     @param formals A list of the types (and just the types) of
        the formal arguments
293     @return Whether the actual arguments are compatible with the
         formal arguments.
294   *)
295 let compatible_formals data actuals formals =
296     let compatible formal actual = is_subtype data actual formal
         in
297     try List.for_all2 compatible formals actuals with
298         | Invalid_argument(_) -> false
299
300 (**
301     Return whether a given func_def is compatible with a list of
         actual arguments.
302     This means making sure that it has the right number of
        formal arguments and that
303     each actual agument is a subtype of the corresponding formal
         argument.
304     @param data A class_data record (has type information)
305     @param actuals A list of the types (and just the types) of
        the actual arguments
306     @param func A func_def from which to get formals
307     @return Whether the given func_def is compatible with the
        actual arguments.
308   *)
309 let compatible_function data actuals func =
310     compatible_formals data actuals (List.map fst func.formals)
311
312 (**
313     Return whether a function's return type is compatible with a
         desired return type.
314     Note that if the desired return type is None then the
        function is compatible.
315     Otherwise if it is not None and the function's is, then it
        is not compatible.
316     Lastly, if the desired type is a supertype of the function's
         return type then the
317     function is compatible.
318     @param data A class_data record value
319     @param ret_type The desired return type
320     @param func A func_def to test.
321     @return True if compatible, false if not.
322   *)
323 let compatible_return data ret_type func =
324     match ret_type, func.returns with
325         | None, _ -> true
```

```
326             | _, None -> false
327             | Some(desired), Some(given) -> is_subtype data given
        desired
328
329     (**
330         Return whether a function's signature is completely
        compatible with a return type
331         and a set of actuals
332         @param data A class_data record value
333         @param ret_type The return type (string option)
334         @param actuals The list of actual types
335         @param func A func_def value
336         @return True if compatible, false if not.
337       *)
338     let compatible_signature data ret_type actuals func =
339         compatible_return data ret_type func && compatible_function
        data actuals func
340
341     (**
342         Filter a list of functions based on their section.
343         @param funcs a list of functions
344         @param sects a list of class_section values
345         @return a list of functions in the given sections
346         *)
347     let in_section sects funcs =
348         List.filter (fun f -> List.mem f.section sects) funcs
349
350     (**
351         Given a class_data record, a list of actual arguments, and a
         list of methods,
352         find the best matches for the actuals. Note that if there
        are multiple best
353         matches (i.e. ties) then a non-empty non-singleton list is
        returned.
354         Raises an error if somehow our list of compatible methods
        becomes incompatible
355         [i.e. there is a logic error in the compiler].
356         @param data A class_data record
357         @param actuals The list of types (and only types) for the
        actual arguments
358         @param funcs The list of candidate functions
359         @return The list of all best matching functions (should be
        at most one, we hope).
360       *)
361     let best_matching_signature data actuals funcs =
362         let funcs = List.filter (compatible_function data actuals)
        funcs in
363         let distance_of actual formal = match get_distance data
        actual formal with
364             | Some(n) when n >= 0 -> n
365             | _ -> raise(Invalid_argument("Compatible methods
        somehow incompatible: " ^ actual ^ " vs. " ^ formal ^ ".
        Compiler error.")) in
366         let to_distance func = List.map2 distance_of actuals (List.
        map fst func.formals) in
367         let with_distances = List.map (fun func -> (func,
        to_distance func)) funcs in
```

```
368     let lex_compare (_, lex1) (_, lex2) = lexical_compare lex1
        lex2 in
369     List.map fst (find_all_min lex_compare with_distances)
370
371 (**
372     Given a class_data record, method name, and list of actuals,
         and a list of sections to consider,
373     get the best matching  method. Note that if there is more
        than one then an exception is raised
374     as this should have been reported during collision detection
         [compiler error].
375     @param data A class_data record
376     @param method_name The name to lookup candidates for
377     @param actuals The list of types (and only types) for the
        actual arguments
378     @param sections The sections to filter on (only look in
        these sections)
379     @return Either None if no function is found, Some(f) if one
        function is found, or an error is raised.
380   *)
381 let best_method data klass_name method_name actuals sections =
382     let methods = class_method_lookup data klass_name
        method_name in
383     let methods = in_section sections methods in
384     match best_matching_signature data actuals methods with
385         | [] -> None
386         | [func] -> Some(func)
387         | _ -> raise(Invalid_argument("Multiple methods named "
        ^ method_name ^ " of the same signature in " ^ klass_name ^
        "; Compiler error."))
388
389 let best_inherited_method data klass_name method_name actuals
        this =
390     let methods = class_ancestor_method_lookup data klass_name
        method_name this in
391     match best_matching_signature data actuals methods with
392         | [] -> None
393         | [func] -> Some(func)
394         | _ -> raise(Invalid_argument("Multiple methods named "
        ^ method_name ^ " of the same signature inherited in " ^
        klass_name ^ "; Compiler error."))
395
396 (**
397     Given the name of a refinement to apply, the list of actual
        types,
398     find the compatible refinements via the data / klass_name /
        method_name.
399     Partition the refinements by their inklass value and then
        return a list
400     of the best matches from each partition.
401     @param data A class_data record value
402     @param klass_name A class name
403     @param method_name A method name
404     @param refine_name A refinement name
405     @param actuals The types of the actual arguments
406     @return A list of functions to switch on based on the
        actuals.
```

```
407     *)
408   let refine_on data klass_name method_name refine_name actuals
          ret_type =
409       (* These are all the refinements available from subclasses
          *)
410       let refines = refinable_lookup data klass_name method_name
          refine_name in
411
412       (* Compatible functions *)
413       let compat = List.filter (compatible_signature data ret_type
           actuals) refines in
414
415       (* Organize by inklass *)
416       let to_class map f = add_map_list f.inklass f map in
417       let by_class = List.fold_left to_class StringMap.empty
          compat in
418
419       (* Now make a map of only the best *)
420       let best funcs = match best_matching_signature data actuals
          funcs with
421           | [func] -> func
422           | _ -> raise(Failure("Compiler error finding a unique
          best refinement.")) in
423       let to_best klass funcs map = StringMap.add klass (best
          funcs) map in
424       let best_map = StringMap.fold to_best by_class StringMap.
          empty in
425
426       (* Now just return the bindings from the best *)
427       List.map snd (StringMap.bindings best_map)
428
429   (**
430       Get the names of the classes in level order (i.e. from root
          down).
431       @param data A class_data record
432       @return The list of known classes, from the root down.
433     *)
434   let get_class_names data =
435       let kids aklass = map_lookup_list aklass data.children in
436       let rec append found = function
437           | [] -> List.rev found
438           | items -> let next = List.flatten (List.map kids items)
           in
439                   append (items@found) next in
440       append [] ["Object"]
441
442
443   (**
444       Get leaf classes
445       @param data A class_data record
446       @return A list of leaf classes
447     *)
448   let get_leaves data =
449       let is_leaf f = match map_lookup_list f data.children with
450           | [] -> true
451           | _ -> false in
452       let leaves = StringSet.filter is_leaf data.known in
```

```
453     StringSet.elements leaves
```

Source 43: `Klass.ml`

```
1   all: compile _tools _ray _doc
2
3   compile:
4       #Generate the lexer and parser
5       ocamllex scanner.mll
6       ocamlyacc parser.mly
7
8       ocamlc -c -g Ast.mli
9       ocamlc -c -g UID.ml
10
11      ocamlc -c -g parser.mli
12      ocamlc -c -g scanner.ml
13      ocamlc -c -g parser.ml
14
15      ocamlc -c -g WhiteSpace.ml
16      ocamlc -c -g Inspector.mli
17      ocamlc -c -g Inspector.ml
18      ocamlc -c -g Pretty.ml
19
20      ocamlc -c -g Util.ml
21      ocamlc -c -g StringModules.ml
22      ocamlc -c -g GlobalData.mli
23      ocamlc -c -g Klass.mli
24      ocamlc -c -g KlassData.mli
25      ocamlc -c -g BuiltIns.mli
26      ocamlc -c -g BuiltIns.ml
27      ocamlc -c -g Klass.ml
28      ocamlc -c -g KlassData.ml
29      ocamlc -c -g Variables.ml
30      ocamlc -c -g Sast.mli
31      ocamlc -c -g BuildSast.mli
32      ocamlc -c -g BuildSast.ml
33      ocamlc -c -g Unanonymous.mli
34      ocamlc -c -g Unanonymous.ml
35      ocamlc -c -g Cast.mli
36      ocamlc -c -g GenCast.ml
37      ocamlc -c -g GenC.ml
38      ocamlc -c -g Debug.ml
39
40      ocamlc -c -g classinfo.ml
41      ocamlc -c -g inspect.ml
42      ocamlc -c -g prettify.ml
43      ocamlc -c -g streams.ml
44      ocamlc -c -g canonical.ml
45      ocamlc -c -g freevars.ml
46      ocamlc -c -g ray.ml
47
48  _tools:
49      #Make the tools
50      ocamlc -g -o tools/prettify UID.cmo scanner.cmo parser.cmo
        Inspector.cmo Pretty.cmo WhiteSpace.cmo prettify.cmo
```

```
51      ocamlc -g -o tools/inspect UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo inspect.cmo
52      ocamlc -g -o tools/streams UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo streams.cmo
53      ocamlc -g -o tools/canonical UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo canonical.cmo
54      ocamlc -g -o tools/freevars UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo Util.cmo StringModules.cmo str.
        cma BuiltIns.cmo Klass.cmo KlassData.cmo Debug.cmo Variables
        .cmo freevars.cmo
55      ocamlc -g -o tools/classinfo UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo Util.cmo StringModules.cmo str.
        cma BuiltIns.cmo Klass.cmo KlassData.cmo classinfo.cmo
56
57  _ray:
58      #Make ray
59      mkdir -p bin
60      ocamlc -g -o bin/ray UID.cmo scanner.cmo parser.cmo
        Inspector.cmo WhiteSpace.cmo Util.cmo StringModules.cmo str.
        cma BuiltIns.cmo Klass.cmo KlassData.cmo Debug.cmo Variables
        .cmo BuildSast.cmo Unanonymous.cmo GenCast.cmo GenC.cmo ray.
        cmo
61
62  nodoc: compile _tools _ray
63
64  docsources = Ast.mli BuildSast.ml BuildSast.mli BuiltIns.ml
        BuiltIns.mli Cast.mli Debug.ml GenCast.ml GenC.ml GlobalData
        .mli Inspector.ml Inspector.mli Klass.ml Klass.mli KlassData
        .ml KlassData.mli Pretty.ml Sast.mli StringModules.ml UID.ml
         Unanonymous.ml Unanonymous.mli Util.ml Variables.ml
        WhiteSpace.ml parser.ml parser.mli scanner.ml
65  docgen = ./doc/.docgen
66
67  _doc:
68      #Generate the documentation
69      mkdir -p doc
70      ocamldoc -hide-warnings -dump $(docgen) -keep-code $(
        docsources)
71      ocamldoc -hide-warnings -load $(docgen) -d doc -t "The Ray
        Compiler" -html -colorize-code -all-params
72      ocamldoc -hide-warnings -load $(docgen) -dot -o "./doc/ray-
        modules.dot"
73      ocamldoc -hide-warnings -load $(docgen) -dot -dot-types -o "
        ./doc/ray-types.dot"
74
75  bleach:
76      rm *.cmi *.cmo parser.ml parser.mli scanner.ml
77      rm -r ./doc
78
79  clean:
80      rm *.cmi *.cmo parser.ml parser.mli scanner.ml
81
82  cleantools:
83      rm tools/{prettify,inspect,streams,canonical,freevars,
        classinfo}
```

```

```

Source 44: `Makefile`

```

val ast_to_sast_klass : GlobalData.class_data -> Ast.class_def
    -> Sast.class_def
val ast_to_sast : GlobalData.class_data -> Sast.class_def list
val update_refinements : GlobalData.class_data -> Sast.class_def
     list -> Sast.class_def list
```

Source 45: `BuildSast.mli`

```
/* N queens iterative solution */

class ChessBoard:
  public:
    init(Integer size):
      super()
      n := size
      solution_count := 0
      arrangement := new Integer[](n)
      Integer i := 0
      while(i < n):
        arrangement[i] := -1
        i += 1

    Boolean test_column(Integer row):
      Integer i := 0
      while(i < row):
        if(arrangement[i] = arrangement[row]):
          return false
        i += 1
      return true

    Boolean test_diag(Integer row):
      Integer i := 0
      while(i < row):
        if(((arrangement[row] - arrangement[i]) = row - i) or ((
    arrangement[row] - arrangement[i]) = i - row)):
          return false
        i += 1
      return true

    Boolean test(Integer row):
      if(test_column(row) and test_diag(row)):
        return true
      else:
        return false

    Integer print_board():
      system.out.printString("\nSolution # ")
      system.out.printInteger(solution_count)
```

```
      system.out.printString("\n")
      Integer r := 0
      while(r < n):
        Integer c := 0
        while(c < n):
          if(arrangement[r] = c):
            system.out.printString("Q ")
          else:
            system.out.printString("* ")
          c += 1
        system.out.printString("\n")
        r += 1
      return 0

    Integer get_solutions():
      arrangement[0] := -1
      Integer row := 0
      while(row >= 0):
        arrangement[row] += 1
        while(arrangement[row] < n and not test(row)):
          arrangement[row] += 1
        if(arrangement[row] < n):
          if(row = n - 1):
            solution_count += 1
            print_board()
          else:
            row += 1
            arrangement[row] := -1
        else:
          row -= 1
      return 0

  private:
    Integer n
    Integer solution_count
    Integer[] arrangement

  main(System system, String[] args):
    system.out.printString("Chess board size: ")
    Integer size := system.in.scanInteger()
    ChessBoard nqueens := new ChessBoard(size)
    nqueens.get_solutions()
```

Source 46: `demo/nqueens.gamma`

```
class HelloWorld:
  public:
    String greeting
    init():
      super()
      greeting := "Hello World!"

  main(System system, String[] args):
    HelloWorld hw := new HelloWorld()
    system.out.printString(hw.greeting)
```

```
    system.out.printString("\n")
```

Source 47: `demo/helloworld.gamma`

```
class Bank:
  public:
    init():
      super()
      id_counter := 0
      accounts := new Account[](100)

      /* Anonymous instantiation can 'get around' protected
    constructors */
      Account president := (new Account(id_counter, "Bank
    President") {
        Float apply_interest.rate() { return 0.10; }
      })
      accounts[id_counter] := president
      id_counter += 1

    Integer open_checking(String client_name):
      Account new_account := new Checking(id_counter,
    client_name)
      accounts[id_counter] := new_account
      id_counter += 1
      return id_counter-1

    Integer open_savings(String client_name):
      Account new_account := new Savings(id_counter, client_name
    )
      accounts[id_counter] := new_account
      id_counter += 1
      return id_counter-1

    Integer apply_interest(Integer id):
      if(id > id_counter or id < 0):
        return 1
      accounts[id].apply_interest()
      return 0

    Float get_balance(Integer id):
      if(id > id_counter):
        system.out.printString("Invalid account number.\n")
        return -1.0
      return accounts[id].get_balance()

    Integer deposit(Integer id, Float amount):
      if(id > id_counter):
        system.out.printString("Invalid account number.\n")
        return 1

      accounts[id].deposit(amount)
      return 0

    Integer withdraw(Integer id, Float amount):
```

```
48          if(id > id_counter):
49            system.out.printString("Invalid account number.\n")
50            return 1
51          if(amount > accounts[id].get_balance()):
52            return 1
53
54          accounts[id].withdraw(amount)
55          return 0
56
57        Integer transfer(Integer from_id, Integer to_id, Float
          amount):
58          if(from_id > id_counter):
59            system.out.printString("Invalid account number.\n")
60            return 1
61          if(accounts[from_id].get_balance() < amount):
62            system.out.printString("Insufficient funds.\n")
63            return 1
64          accounts[from_id].withdraw(amount)
65          accounts[to_id].deposit(amount)
66          return 0
67
68        Float get_balance(Integer id, Float amount):
69          if(id > id_counter):
70            return -1.0
71          return accounts[id].get_balance()
72
73
74      protected:
75        Integer id_counter
76        Account[] accounts
77
78    /* Subclasses can come before classes if you like */
79    class Checking extends Account:
80      public:
81        init(Integer id, String name):
82          super(id, name)
83
84      refinement:
85        Float apply_interest.rate():
86          return 0.005
87
88    class Savings extends Account:
89      public:
90        init(Integer id, String name):
91          super(id, name)
92
93      refinement:
94        Float apply_interest.rate():
95          return 0.02
96
97    class Account:
98      protected:
99        void apply_interest(Boolean check):
100         if (not (refinable(rate))):
101           system.out.printString("Account must have some interest
          rate.\n")
102           system.exit(1)
```

```
103
104       init(Integer new_id, String name):
105         super()
106         apply_interest(false)
107
108         id := new_id
109         client := name
110         balance := 0.0
111         transactions := new Float[](100)
112         trans_len := 0
113
114     public:
115       Integer get_id():
116         return id
117
118       String get_client_name():
119         return client
120
121       Float get_balance():
122         return balance
123
124       void apply_interest():
125         balance *= (1.0 + (refine rate() to Float))
126
127       Integer deposit(Float amount):
128         if(amount < 0.0):
129           return 1
130         balance += amount
131         transactions[trans_len] := amount
132         trans_len += 1
133         return 0
134
135       Integer withdraw(Float amount):
136         if(amount < 0.0):
137           system.out.printString("Invalid number entered.\n")
138           return 1
139         if(balance < amount):
140           system.out.printString("Insufficient funds.\n")
141           return 1
142         balance -= amount
143         return 0
144
145     private:
146       Integer id
147       String client
148       Float balance
149       Float[] transactions
150       Integer trans_len
151
152
153   class Main:
154     public:
155       init():
156         super()
157
158     main(System system, String[] args):
159       Bank citibank := new Bank()
```

```
160       Integer menu_lvl := 0
161       Integer menu_num := 0
162       Integer selection := new Integer()
163       Integer account_id := -1
164
165       while(true):
166         if(menu_lvl = 0):
167           system.out.printString("Please Select:\n1.Open New
          Account\n2.Manage Existing Account\n3.I'm the President!\n->
          ")
168           selection := system.in.scanInteger()
169           account_id := -1
170           menu_lvl := 1
171
172         if(menu_lvl = 1):
173           if(selection = 1):
174             system.out.printString("Your Name Please:")
175             String name := new String()
176             name := system.in.scanString()
177             Integer checking_id := citibank.open_checking(name)
178             Integer savings_id := citibank.open_savings(name)
179
180             system.out.printString("\nDear ")
181             system.out.printString(name)
182             system.out.printString("\n")
183             system.out.printString("Your new checking account
          number: ")
184             system.out.printInteger(checking_id)
185             system.out.printString("\n")
186             system.out.printString("Your new savings account
          number: ")
187             system.out.printInteger(savings_id)
188             system.out.printString("\n")
189             selection := 0
190             menu_lvl := 0
191           else:
192             if(selection = 2):
193               if(account_id < 0):
194                 system.out.printString("Your Account Number Please
          : ")
195                 account_id := system.in.scanInteger()
196
197               citibank.apply_interest(account_id)
198               system.out.printString("Please Select:\n1.Check
          Balance\n2.Deposit\n3.Withdraw\n4.Transfer\n5.Exit\n-> ")
199               menu_lvl := 2
200               selection := system.in.scanInteger()
201               if(selection = 5):
202                 selection := 0
203                 menu_lvl := 0
204             else:
205               if(selection = 3):
206                 selection := 2
207                 account_id := 0
208                 menu_lvl := 1
209
210         if(menu_lvl = 2):
```

```
211             if(selection = 1):
212               system.out.printString("Your current balance: ")
213               system.out.printFloat(citibank.get_balance(account_id
    ))
214               system.out.printString("\n")
215               menu_lvl := 1
216               selection := 2
217             else:
218               if(selection = 2):
219                 system.out.printString("Please enter the amount you
     want to deposit: ")
220                 Float amount := system.in.scanFloat()
221                 citibank.deposit(account_id, amount)
222                 menu_lvl := 1
223                 selection := 2
224               else:
225                 if(selection = 3):
226                   system.out.printString("Pleaser enter the amount
    you want to withdraw: ")
227                   Float amount := system.in.scanFloat()
228                   citibank.withdraw(account_id, amount)
229                   menu_lvl := 1
230                   selection := 2
231                 else:
232                   if(selection = 4):
233                     system.out.printString("Please enter the
    account number you want to transfer to: ")
234                     Integer to_account := system.in.scanInteger()
235                     system.out.printString("Please enter the amount
     you want to transfer: ")
236                     Float amount := system.in.scanFloat()
237                     citibank.transfer(account_id, to_account,
    amount)
238                     menu_lvl := 1
239                     selection := 2
```

Source 48: `demo/bank.gamma`

```
1   open Parser
2
3   (** Convert a whitespace file into a brace file. *)
4
5   (**
6       Gracefully tell the programmer that they done goofed
7       @param msg The descriptive error message to convey to the
        programmer
8     *)
9   let wsfail msg = raise(Failure(msg))
10
11  (**
12      Only allow spacing that is at the start of a line
13      @param program A program as a list of tokens
14      @return a list of tokens where the only white space is
        indentation, newlines,
15      and colons (which count as a newline as it must be followed
```

```
    by them)
  *)
let indenting_space program =
    let rec space_indenting rtokens = function
        | NEWLINE::SPACE(n)::rest -> space_indenting (SPACE(n)::
    NEWLINE::rtokens) rest
        | COLON::SPACE(n)::rest -> space_indenting (SPACE(n)::
    COLON::rtokens) rest
        | SPACE(n)::rest -> space_indenting rtokens rest
        | token::rest -> space_indenting (token::rtokens) rest
        | [] -> List.rev rtokens in
    match (space_indenting [] (NEWLINE::program)) with
        | NEWLINE::rest -> rest
        | _ -> wsfail "Indenting should have left a NEWLINE at
    the start of program; did not."

(**
    Between LBRACE and RBRACE we ignore spaces and newlines;
    colons are errors in this context.
    It's not necessary that this be done after the above, but it
     is recommended.
    @param program A program in the form of a list of tokens
    @return A slightly slimmer program
  *)
let despace_brace program =
    let rec brace_despace depth tokens rtokens last =
        if depth > 0 then
            match tokens with
                | SPACE(_)::rest -> brace_despace depth rest
    rtokens last
                | NEWLINE::rest -> brace_despace depth rest
    rtokens last
                | COLON::_ -> wsfail "Colon inside brace scoping
    ."
                | LBRACE::rest -> brace_despace (depth+1) rest (
    LBRACE::rtokens) last
                | RBRACE::rest -> let rtokens = if depth = 1
                    then SPACE(last)::NEWLINE::RBRACE::rtokens
                    else RBRACE::rtokens in
                    brace_despace (depth-1) rest rtokens last
                | token::rest -> brace_despace depth rest (token
    ::rtokens) last
                | [] -> List.rev rtokens
        else
            match tokens with
                | SPACE(n)::rest -> brace_despace depth rest (
    SPACE(n)::rtokens) n
                | LBRACE::rest -> brace_despace (depth+1) rest (
    LBRACE::rtokens) last
                | token::rest -> brace_despace depth rest (token
    ::rtokens) last
                | [] -> List.rev rtokens in
    brace_despace 0 program [] 0

(**
    Remove empty indentation -- SPACE followed by COLON or
    NEWLINE
```

```
58      @param program A program as a list of tokens
59      @return A program without superfluous indentation
60    *)
61  let trim_lines program =
62      let rec lines_trim tokens rtokens =
63          match tokens with
64              | [] -> List.rev rtokens
65              | SPACE(_)::NEWLINE::rest -> lines_trim rest (
      NEWLINE::rtokens)
66              | SPACE(_)::COLON::rest -> lines_trim rest (COLON::
      rtokens)
67              | token::rest -> lines_trim rest (token::rtokens) in
68      lines_trim program []
69
70  (**
71      Remove consecutive newlines
72      @param program A program as a list of tokens
73      @return A program without consecutive newlines
74    *)
75  let squeeze_lines program =
76      let rec lines_squeeze tokens rtokens =
77          match tokens with
78              | [] -> List.rev rtokens
79              | NEWLINE::NEWLINE::rest -> lines_squeeze (NEWLINE::
      rest) rtokens
80              | COLON::NEWLINE::rest -> lines_squeeze (COLON::rest
      ) rtokens (* scanner handled this though *)
81              | token::rest -> lines_squeeze rest (token::rtokens)
       in
82      lines_squeeze program []
83
84  (**
85      Remove the initial space from a line but semantically note
        it
86      @return an ordered pair of the number of spaces at the
        beginning
87      of the line and the tokens in the line
88  *)
89  let spacing = function
90      | SPACE(n)::rest -> (n, rest)
91      | list           -> (0, list)
92
93  (**
94      Remove spaces, newlines, and colons but semantically note
        their presence.
95      @param program A full program (transformed by the above
        pipeline)
96      @return a list of triples, one for each line. Each triple's
        first item is
97      the number of spaces at the beginning of the line; the
        second item is the
98      tokens in the line; the third is whether the line ended in a
         colon.
99    *)
100 let tokens_to_lines program =
101     let rec lines_from_tokens rline rlines = function
102         | NEWLINE::rest ->
```

```
103             (match rline with
104                 | [] -> lines_from_tokens [] rlines rest
105                 | _ -> let (spacer, line) = spacing (List.rev
    rline) in
106                                 lines_from_tokens [] ((spacer,
    line, false)::rlines) rest)
107         | COLON::rest ->
108             (match rline with
109                 | [] -> lines_from_tokens [] rlines rest
110                 | _ -> let (spacer, line) = spacing (List.rev
    rline) in
111                                 lines_from_tokens [] ((spacer,
    line, true)::rlines) rest)
112         | [] ->
113             (match rline with
114                 | [] -> List.rev rlines
115                 | _ -> let (spacer, line) = spacing (List.rev
    rline) in
116                                 lines_from_tokens [] ((spacer,
    line, false)::rlines) [])
117         | token::rest -> lines_from_tokens (token::rline) rlines
     rest in
118     lines_from_tokens [] [] program
119
120 (**
121     Merge line continuatons given output from tokens_to_lines.
122     Line n+1 continues n if n does not end in a colon and n+1 is
     more
123     indented than n (or if line n is a continuation and they are
     both
124     equally indented).
125     @param program_lines The individual lines of the program
126     @return The lines of the program with whitespace collapsed
127   *)
128 let merge_lines program_lines =
129     let rec lines_merge rlines = function
130         | ((n1, _, _) as line1)::((n2, _, _) as line2)::rest
    when n1 >= n2 -> lines_merge (line1::rlines) (line2::rest)
131         | (n, line1, false)::(_, line2, colon)::rest ->
    lines_merge rlines ((n, line1@line2, colon)::rest)
132         | ((_, _, true) as line)::rest -> lines_merge (line::
    rlines) rest
133         | line::[] -> lines_merge (line::rlines) []
134         | [] -> List.rev rlines in
135     lines_merge [] program_lines
136
137 (**
138     Check if a given line needs a semicolon at the end
139   *)
140 let rec needs_semi = function
141     | [] -> true                (* General base case *)
142     | RBRACE::[] -> false       (* The end of bodies do not
    require semicolons *)
143     | SEMI::[] -> false         (* A properly terminated line does
     not require an additional semicolon *)
144     | _::rest -> needs_semi rest (* Go through *)
145
```

```
146 (**
147     Build a block. Consecutive lines of the same indentation
        with only the last ending
148     in a colon are a 'block'. Blocks are just 'lines' merged
        together but joined with
149     a semi colon when necessary.
150     @param lines The full set of lines
151     @return A list of blocks
152   *)
153 let block_merge lines =
154     let add_semi = function
155         | (n, toks, true) -> (n, toks, true, false)
156         | (n, toks, false) -> (n, toks, false, needs_semi toks)
        in
157     let lines = List.map add_semi lines in
158     let rec merge_blocks rblocks = function
159         | (n1, line1, false, s1)::(n2, line2, colon, s2)::rest
        when n1 = n2 ->
160             let newline = line1 @ (if s1 then [SEMI] else []) @
        line2 in
161             merge_blocks rblocks ((n1, newline, colon, s2)::rest
        )
162         | (n, line, colon, _)::rest -> merge_blocks ((n, line,
        colon)::rblocks) rest
163         | [] -> List.rev rblocks in
164     merge_blocks [] lines
165
166 (** Make sure every line is terminated with a semi-colon when
        necessary *)
167 let terminate_blocks blocks =
168     let rec block_terminate rblocks = function
169         | (n, toks, false)::rest ->
170             let terminated = if (needs_semi toks) then toks@[
        SEMI] else toks in
171             block_terminate ((n, terminated, false)::rblocks)
        rest
172         | other::rest ->
173             block_terminate (other::rblocks) rest
174         | [] -> List.rev rblocks in
175     block_terminate [] blocks
176
177 (** Pops the stack and adds rbraces when necessary *)
178 let rec arrange n stack rtokens =
179     match stack with
180         | top::rest when n <= top -> arrange n rest (RBRACE::
        rtokens)
181         | _ -> (stack, rtokens)
182
183 (**
184      Take results of pipeline and finally adds braces. If blocks
         are merged
185     then either consecutive lines differ in scope or there are
        colons.
186     so now everything should be easy peasy (lemon squeezy).
187   *)
188 let space_to_brace = function
189     | [] -> []
```

```
190     | linelist -> let rec despace_enbrace stack rtokens =
        function
191         | [] -> List.rev ((List.map (function _ -> RBRACE) stack
        ) @ rtokens)
192         | (n, line, colon)::rest ->
193             let (stack, rtokens) = arrange n stack rtokens in
194             let (lbrace, stack) = if colon then ([LBRACE], n::
        stack) else ([], stack) in
195             despace_enbrace stack (lbrace@(List.rev line)
        @rtokens) rest
196         in despace_enbrace [] [] linelist
197
198 (** Drop the EOF from a stream of tokens, failing if not
        possible *)
199 let drop_eof program =
200     let rec eof_drop rtokens = function
201         | EOF::[] -> List.rev rtokens
202         | EOF::rest -> raise(Failure("Misplaced EOF"))
203         | [] -> raise(Failure("No EOF available."))
204         | tk::tks -> eof_drop (tk::rtokens) tks in
205     eof_drop [] program
206
207 (** Append an eof token to a program *)
208 let append_eof program =
209     let rec eof_add rtokens = function
210         | [] -> List.rev (EOF::rtokens)
211         | tk::tks -> eof_add (tk::rtokens) tks in
212     eof_add [] program
213
214 (** Run the entire pipeline *)
215 let convert program =
216     (* Get rid of the end of file *)
217     let noeof = drop_eof program in
218     (* Indent in response to blocks *)
219     let indented = indenting_space noeof in
220     (* Collapse whitespace around braces *)
221     let despaced = despace_brace indented in
222     (* Get rid of trailing whitespace *)
223     let trimmed = trim_lines despaced in
224     (* Remove consequetive newlines *)
225     let squeezed = squeeze_lines trimmed in
226     (* Turn tokens into semantics *)
227     let lines = tokens_to_lines squeezed in
228     (* Consolidate those semantics *)
229     let merged = merge_lines lines in
230     (* Turn the semantics into blocks *)
231     let blocks = block_merge merged in
232     (* Put in the semicolons *)
233     let terminated = terminate_blocks blocks in
234     (* Turn the blocks into braces *)
235     let converted = space_to_brace terminated in
236     (* Put the eof on *)
237     append_eof converted
238
239 (** A function to act like a lexfun *)
240 let lextoks toks =
241     let tokens = ref (convert toks) in
```

```
242     function _ ->
243         match !tokens with
244             | [] -> raise(Failure("Not even EOF given."))
245             | tk::tks -> tokens := tks; tk
```

Source 49: `WhiteSpace.ml`

```
1   open Cast
2   open StringModules
3
4   let c_indent = "  "
5
6   let dispatches = ref []
7   let dispatchon = ref []
8   let dispatcharr = ref []
9
10  let matches type1 type2 = String.trim (GenCast.get_tname type1)
        = String.trim type2
11
12  let lit_to_str lit = match lit with
13      | Ast.Int(i) -> "LIT_INT("^(string_of_int i)^")"
14      | Ast.Float(f) -> "LIT_FLOAT("^(string_of_float f)^")"
15      | Ast.String(s) -> "LIT_STRING(\"" ^ s ^ "\")"  (* escapes
        were escaped during lexing *)
16      | Ast.Bool(b) ->if b then "LIT_BOOL(1)" else "LIT_BOOL(0)"
17
18  let stringify_unop op rop rtype =
19      let (is_int, is_flt, is_bool) = (matches "Integer", matches
        "Float", matches "Boolean") in
20      let is_type = (is_int rtype, is_flt rtype, is_bool rtype) in
21      let type_capital = match is_type with
22          | (true, _, _) -> "INTEGER"
23          | (_, true, _) -> "FLOAT"
24          | (_, _, true) -> "BOOLEAN"
25          | (_, _, _)    -> raise(Failure "Imcompatible type with
        unop") in
26      match op with
27      | Ast.Arithmetic(Ast.Neg) -> "NEG_"^type_capital^"( "^rop^"
        )"
28      | Ast.CombTest(Ast.Not)   -> "NOT_"^type_capital^"( "^rop^"
        )"
29      | _   -> raise (Failure "Unknown operator")
30
31  let stringify_arith op suffix =
32      match op with
33      | Ast.Add  -> "ADD_"^suffix
34      | Ast.Sub  -> "SUB_"^suffix
35      | Ast.Prod -> "PROD_"^suffix
36      | Ast.Div  -> "DIV_"^suffix
37      | Ast.Mod  -> "MOD_"^suffix
38      | Ast.Neg  ->  raise(Failure "Unary operator")
39      | Ast.Pow  -> "POW_"^suffix
40    (*| Ast.Pow  -> Format.sprintf "pow(%s,%s)" lop rop*)
41
42  let stringify_numtest op suffix = match op with
```

```
43      | Ast.Eq   -> "NTEST_EQ_"^suffix
44      | Ast.Neq  -> "NTEST_NEQ_"^suffix
45      | Ast.Less -> "NTEST_LESS_"^suffix
46      | Ast.Grtr -> "NTEST_GRTR_"^suffix
47      | Ast.Leq  -> "NTEST_LEQ_"^suffix
48      | Ast.Geq  -> "NTEST_GEQ_"^suffix
49
50  let stringify_combtest op suffix = match op with
51      | Ast.And  -> "CTEST_AND_"^suffix
52      | Ast.Or   -> "CTEST_OR_"^suffix
53      | Ast.Nand -> "CTEST_NAND_"^suffix
54      | Ast.Nor  -> "CTEST_NOR_"^suffix
55      | Ast.Xor  -> "CTEST_XOR_"^suffix
56      | Ast.Not  -> raise(Failure "Unary operator")
57
58  let stringify_binop op lop rop types =
59      let (is_int, is_flt, is_bool) = (matches "Integer", matches
        "Float", matches "Boolean") in
60      let is_type = (is_int (fst types), is_flt (fst types),
        is_bool (fst types), is_int (snd types), is_flt (snd types),
         is_bool (snd types)) in
61      let prefix = match is_type with
62          | (true, _, _, true, _, _) -> "INT_INT"
63          | (_, true, _, _, true, _) -> "FLOAT_FLOAT"
64          | (true, _, _, _, true, _) -> "INT_FLOAT"
65          | (_, true, _, true, _, _) -> "FLOAT_INT"
66          | (_, _, true, _, _, true) -> "BOOL_BOOL"
67          | (_, _, _, _, _, _)       -> raise(Failure(Format.
        sprintf "Binary operator applied to %s, %s" (fst types) (snd
         types))) in
68      let suffix = prefix^"( "^lop^" , "^rop^" )" in
69      match op with
70      | Ast.Arithmetic(arith)  -> stringify_arith arith suffix
71      | Ast.NumTest(numtest)   -> stringify_numtest numtest suffix
72      | Ast.CombTest(combtest) -> stringify_combtest combtest
        suffix
73
74  let stringify_list stmtlist = String.concat "\n" stmtlist
75
76  let rec expr_to_cstr (exptype, expr_detail) = exprdetail_to_cstr
         expr_detail
77
78  and exprdetail_to_cstr castexpr_detail =
79      let generate_deref obj index =
80          let arrtype = fst obj in
81          Format.sprintf "((struct %s*)(%s))[INTEGER_OF((%s))]"
        arrtype (expr_to_cstr obj) (expr_to_cstr index) in
82
83      let generate_field obj field =
84          let exptype = fst obj in
85          Format.sprintf "(%s)->%s.%s" (expr_to_cstr obj) (GenCast
        .from_tname exptype) field in
86
87      let generate_invocation recvr fname args =
88          let this = Format.sprintf "((struct %s*)(%s))" (fst
        recvr) (expr_to_cstr recvr) in
89          let vals = List.map expr_to_cstr args in
```

```
90          Format.sprintf "%s(%s)" fname (String.concat ", " (this
    ::vals)) in
91
92      let generate_vreference vname = function
93          | Sast.Local -> vname
94          | Sast.Instance(klass) -> Format.sprintf "(this->%s).%s"
     klass vname in
95
96      let generate_allocation klass fname args =
97          let vals = List.map expr_to_cstr args in
98          let alloc = Format.sprintf "MAKE_NEW(%s)" klass in
99          Format.sprintf "%s(%s)" fname (String.concat ", " (alloc
    ::vals)) in
100
101     let generate_array_alloc _ fname args =
102         let vals = List.map expr_to_cstr args in
103         Format.sprintf "%s(%s)" fname (String.concat ", " vals)
    in
104
105     let generate_refine args ret = function
106         | Sast.Switch(_, _, dispatch) ->
107           let vals = List.map expr_to_cstr args in
108           Format.sprintf "%s(%s)" dispatch (String.concat ", " (
    "this"::vals))
109         | _ -> raise(Failure("Wrong switch applied to refine --
    compiler error.")) in
110
111     let generate_refinable = function
112         | Sast.Test(_, _, dispatchby) -> Format.sprintf "%s(this
    )" dispatchby
113         | _ -> raise(Failure("Wrong switch applied to refinable
    -- compiler error.")) in
114
115     match castexpr_detail with
116     | This                                -> "this" (* There is
    no way this is right with implicit object passing *)
117     | Null                                -> "NULL"
118     | Id(vname, varkind)                  -> generate_vreference
    vname varkind
119     | NewObj(classname, fname, args)      -> generate_allocation
    classname fname args
120     | NewArr(arrtype, fname, args)        -> generate_array_alloc
     arrtype fname args
121     | Literal(lit)                        -> lit_to_str lit
122     | Assign((vtype, _) as memory, data) -> Format.sprintf "%s =
     ((struct %s*)(%s))" (expr_to_cstr memory) vtype (
    expr_to_cstr data)
123     | Deref(carray, index)                -> generate_deref
    carray index
124     | Field(obj, fieldname)               -> generate_field obj
    fieldname
125     | Invoc(recvr, fname, args)           -> generate_invocation
    recvr fname args
126     | Unop(op, expr)                      -> stringify_unop op (
    expr_to_cstr expr) (fst expr)
127     | Binop(lop, op, rop)                 -> stringify_binop op (
    expr_to_cstr lop) (expr_to_cstr rop) ((fst lop), (fst rop))
```

```
128     | Refine(args, ret, switch)          -> generate_refine args
         ret switch
129     | Refinable(switch)                  -> generate_refinable
        switch
130
131 and vdecl_to_cstr (vtype, vname) = Format.sprintf "struct %s*%s"
         vtype vname
132
133
134 let rec collect_dispatches_exprs exprs = List.iter
        collect_dispatches_expr exprs
135 and collect_dispatches_stmts stmts = List.iter
        collect_dispatches_stmt stmts
136 and collect_dispatches_expr (_, detail) = match detail with
137     | This -> ()
138     | Null -> ()
139     | Id(_,_) -> ()
140     | NewObj(_, _, args) -> collect_dispatches_exprs args
141     | NewArr(arrtype, fname, args) -> collect_dispatch_arr
        arrtype fname args
142     | Literal(_) -> ()
143     | Assign(mem, data) -> collect_dispatches_exprs [mem; data]
144     | Deref(arr, idx) -> collect_dispatches_exprs [arr; idx]
145     | Field(obj, _) -> collect_dispatches_expr obj
146     | Invoc(recvr, _, args) -> collect_dispatches_exprs (recvr::
        args)
147     | Unop(_, expr) -> collect_dispatches_expr expr
148     | Binop(l, _, r) -> collect_dispatches_exprs [l; r]
149     | Refine(args, ret, switch) -> collect_dispatch args ret
        switch
150     | Refinable(switch) -> collect_dispatch_on switch
151 and collect_dispatches_stmt = function
152     | Decl(_, Some(expr), _) -> collect_dispatches_expr expr
153     | Decl(_, None, _) -> ()
154     | If(iflist, env) -> collect_dispatches_clauses iflist
155     | While(pred, body, _) -> collect_dispatches_expr pred;
        collect_dispatches_stmts body
156     | Expr(expr, _) -> collect_dispatches_expr expr
157     | Return(Some(expr), _) -> collect_dispatches_expr expr
158     | Super(_, _, args) -> collect_dispatches_exprs args
159     | Return(None, _) -> ()
160 and collect_dispatches_clauses pieces =
161     let (preds, bodies) = List.split pieces in
162     collect_dispatches_exprs (Util.filter_option preds);
163     collect_dispatches_stmts (List.flatten bodies)
164 and collect_dispatch args ret = function
165     | Sast.Switch(klass, cases, dispatch) -> dispatches := (
        klass, ret, (List.map fst args), dispatch, cases)::(!
        dispatches);
166     | Sast.Test(_, _, _) -> raise(Failure("Impossible (wrong
        switch -- compiler error)"))
167 and collect_dispatch_on = function
168     | Sast.Test(klass, klasses, dispatchby) -> dispatchon := (
        klass, klasses, dispatchby)::(!dispatchon);
169     | Sast.Switch(_, _, _) -> raise(Failure("Impossible (wrong
        switch -- compiler error)"))
170 and collect_dispatch_func func = collect_dispatches_stmts func.
```

```
    body
and collect_dispatch_arr arrtype fname args =
    dispatcharr := (arrtype, fname, args)::(!dispatcharr)

(**
    Takes an element from the dispatchon list and generates the
    test function for refinable.
    @param  klasses - list of klasses in which the refinable
    method is defined for the method
            fuid - unique function name for the test function.
    @return true or false
    Checks if the object on which refinable was invoked has an
    associated refinable method
    dispatched via this function that's being generated in one
    of the classes.
**)


let generate_testsw (klass, klasses, fuid) =
    let test klass = Format.sprintf "\tif ( IS_CLASS(this, \"%s
    \") ) return LIT_BOOL(1);" (String.trim klass) in
    let cases = String.concat "\n" (List.map test klasses) in
    let body = Format.sprintf "%s\n\treturn LIT_BOOL(0);" cases
    in
    Format.sprintf "struct t_Boolean *%s( struct %s*this )\n{\n%
    s\n}\n\n" fuid klass body

(**
     Takes a dispatch element of the global dispatches list
     And generates the dispatch function - dispatcher which
    dispatches
     calls to refinable methods based on the RTTI of the this.
     @param ret - return type of the function
            args - arguments to the dispatcher and the
    dispatched method
            dispatch uid - unique function name for the
    dispatcher
            cases - list of classes and their corresponding uid
    of the invokable refinable methods.
**)

let generate_refinesw (klass, ret, args, dispatchuid, cases) =
    let rettype = match ret with
        | None -> "void "
        | Some(atype) -> Format.sprintf "struct %s*" atype in
    let this = (Format.sprintf "struct %s*" klass, "this") in
    let formals = List.mapi (fun i t -> (Format.sprintf "struct
    %s*" t, Format.sprintf "varg_%d" i)) args in
    let signature = String.concat ", " (List.map (fun (t, v) ->
    t ^ v) (this::formals)) in
    let actuals = List.map snd formals in
    let withthis kname = String.concat ", " ((Format.sprintf "(
    struct %s*) this" kname)::actuals) in
    let invoc fuid kname = Format.sprintf "%s(%s)" fuid (
    withthis kname) in
    let execute fuid kname = match ret with
        | None -> Format.sprintf "%s; return;" (invoc fuid kname
```

```
    )
212         | Some(atype) -> Format.sprintf "return ((struct %s*)(%s
    ));" (String.trim atype) (invoc fuid kname) in
213     let unroll_case (kname, fuid) =
214         Format.sprintf "\tif( IS_CLASS( this, \"%s\") )\n\t\t{ %
    s }\n" (String.trim kname) (execute fuid kname) in
215     let generated = List.map unroll_case cases in
216     let fail = Format.sprintf "REFINE_FAIL(\"%s\")" (String.trim
     klass) in
217     Format.sprintf "%s%s(%s)\n{\n%s\n\t%s\n}\n\n" rettype
    dispatchuid signature (String.concat "" generated) fail
218
219 let generate_arrayalloc (arrtype, fname, args) =
220     let params = List.mapi (fun i _ -> Format.sprintf "struct %s
    *v_dim%d" (GenCast.get_tname "Integer") i) args in
221     match List.length params with
222         | 1 -> Format.sprintf "struct %s*%s(%s) {\n\treturn
    ONE_DIM_ALLOC(struct %s, INTEGER_OF(v_dim0));\n}\n" arrtype
    fname (String.concat ", " params) arrtype
223         | _ -> raise(Failure("Only one dimensional arrays
    currently supported."))
224
225 (**
226     Take a list of cast_stmts and return a body of c statements
227     @param stmtlist A list of statements
228     @return A body of c statements
229 *)
230 let rec cast_to_c_stmt indent cast =
231     let indents = String.make indent '\t' in
232     let stmts = cast_to_c_stmtlist (indent+1) in
233
234     let cstmt = match cast with
235         | Decl((vtype, _) as vdecl, Some(expr), env) -> Format.
    sprintf "%s = ((struct %s*)(%s));" (vdecl_to_cstr vdecl)
    vtype (expr_to_cstr expr)
236         | Decl(vdecl, None, env) -> Format.sprintf "%s;" (
    vdecl_to_cstr vdecl)
237         | If(iflist, env) -> cast_to_c_if_chain indent iflist
238         | While(pred, [], env) -> Format.sprintf "while (
    BOOL_OF( %s ) ) { }" (expr_to_cstr pred)
239         | While(pred, body, env) -> Format.sprintf "while (
    BOOL_OF( %s ) ) {\n%s\n%s}" (expr_to_cstr pred) (stmts body)
     indents
240         | Expr(expr, env) -> Format.sprintf "( %s );" (
    expr_to_cstr expr)
241         | Return(Some(expr), env) -> Format.sprintf "return ( %s
    );" (expr_to_cstr expr)
242         | Return(_, env) -> "return;"
243         | Super(klass, fuid, []) -> Format.sprintf "%s((struct %
    s*)(this));" fuid (GenCast.get_tname klass)
244         | Super(klass, fuid, args) -> Format.sprintf "%s((struct
     %s*)(this), %s);" fuid (GenCast.get_tname klass) (String.
    concat ", " (List.map expr_to_cstr args)) in
245     indents ^ cstmt
246
247 and cast_to_c_stmtlist indent stmts =
248     String.concat "\n" (List.map (cast_to_c_stmt indent) stmts)
```

```
249
250 and cast_to_c_if_pred = function
251     | None -> ""
252     | Some(ifpred) -> Format.sprintf "if ( BOOL_OF( %s ) )" (
    expr_to_cstr ifpred)
253
254 and cast_to_c_if_chain indent pieces =
255     let indents = String.make indent '\t' in
256     let stmts = cast_to_c_stmtlist (indent + 1) in
257     let combine (pred, body) = Format.sprintf "%s {\n%s\n%s}" (
    cast_to_c_if_pred pred) (stmts body) indents in
258     String.concat " else " (List.map combine pieces)
259
260
261 let cast_to_c_class_struct klass_name ancestors =
262     let ancestor_var (vtype, vname) = Format.sprintf "struct %s
    *%s;" vtype vname in
263     let ancestor_vars vars = String.concat "\n\t\t" (List.map
    ancestor_var vars) in
264     let internal_struct (ancestor, vars) = match vars with
265         | [] -> Format.sprintf "struct { BYTE empty_vars; } %s;"
     ancestor
266         | _ -> Format.sprintf "struct {\n\t\t%s\n\t} %s;\n" (
    ancestor_vars vars) ancestor in
267     let internals = String.concat "\n\n\t" (List.map
    internal_struct ancestors) in
268     let meta = "\tClassInfo *meta;" in
269     Format.sprintf "struct %s {\n%s\n\n\t%s\n};\n\n" (String.
    trim klass_name) meta internals
270
271 let cast_to_c_func cfunc =
272     let ret_type = match cfunc.returns with
273         | None -> "void "
274         | Some(atype) -> Format.sprintf "struct %s*" atype in
275     let body = match cfunc.body with
276         | [] -> " { }"
277         | body -> Format.sprintf "\n{\n%s\n}" (
    cast_to_c_stmtlist 1 body) in
278     let params = if cfunc.static = false then (GenCast.get_tname
     cfunc.inklass, "this")::cfunc.formals
279                 else cfunc.formals in
280     let signature = String.concat ", " (List.map (fun (t,v) -> "
    struct " ^ t ^ "*" ^ v) params) in
281     if cfunc.builtin then Format.sprintf "/* Place-holder for %s
    %s(%s) */" ret_type cfunc.name signature
282     else Format.sprintf "\n%s%s(%s)%s\n" ret_type cfunc.name
    signature body
283
284 let cast_to_c_proto cfunc =
285     let ret_type = match cfunc.returns with
286         | None -> "void "
287         | Some(atype) -> Format.sprintf "struct %s*" atype in
288     let first = if cfunc.static then [] else [(GenCast.get_tname
     cfunc.inklass, "this")] in
289     let params = first@cfunc.formals in
290     let types = String.concat ", " (List.map (fun (t,v) -> "
    struct " ^ t ^ "*") params) in
```

```
291     let signature = Format.sprintf "%s%s(%s);" ret_type cfunc.
        name types in
292     if cfunc.builtin then Format.sprintf "" else signature
293
294 let cast_to_c_proto_dispatch_arr (arrtype, fname, args) =
295     let int = Format.sprintf "struct %s*" (GenCast.get_tname "
        Integer") in
296     let params = List.map (fun _ -> int) args in
297     Format.sprintf "struct %s*%s(%s);" arrtype fname (String.
        concat ", " params)
298
299 let cast_to_c_proto_dispatch_on (klass, _, uid) =
300     Format.sprintf "struct t_Boolean *%s(struct %s *);" uid
        klass
301
302 let cast_to_c_proto_dispatch (klass, ret, args, uid, _) =
303     let types = List.map (fun t -> "struct " ^ t ^ "*") (klass::
        args) in
304     let proto rtype = Format.sprintf "struct %s*%s(%s);" rtype
        uid (String.concat ", " types) in
305     match ret with
306         | None -> proto "void"
307         | Some(t) -> proto t
308
309 let cast_to_c_main mains =
310     let main_fmt = ""^^"\tif (!strncmp(gmain, \"%s\", %d)) { %s
        (&global_system, str_args); return 0; }" in
311     let for_main (klass, uid) = Format.sprintf main_fmt klass (
        String.length klass + 1) uid in
312     let switch = String.concat "\n" (List.map for_main mains) in
313     let cases = Format.sprintf "\"%s\"" (String.concat ", " (
        List.map fst mains)) in
314     Format.sprintf "#define CASES %s\n\nint main(int argc, char
        **argv) {\n\tINIT_MAIN(CASES)\n%s\n\tFAIL_MAIN(CASES)\n\
        treturn 1;\n}" cases switch
315
316 let commalines input n =
317     let newline string = String.length string >= n in
318     let rec line_builder line rlines = function
319         | [] -> List.map String.trim (List.rev (line::rlines))
320         | str::rest ->
321             let comma = match rest with [] -> false | _ -> true
        in
322             let str = if comma then str ^ ", " else str in
323             if newline line then line_builder str (line::rlines)
         rest
324             else line_builder (line ^ str) rlines rest in
325     match input with
326         | [] -> []
327         | [one] -> [one]
328         | str::rest -> line_builder (str ^ ", ") [] rest
329
330 let print_class_strings = function
331     | [] -> raise(Failure("Not even built in classes?"))
332     | classes -> commalines (List.map (fun k -> "\"" ^ k ^ "\"")
         classes) 75
333
```

```
334 let print_class_enums = function
335     | [] -> raise(Failure("Not even built in classes?"))
336     | first::rest ->
337         let first = first ^ " = 0" in
338         commalines (List.map String.uppercase (first::rest)) 75
339
340 let setup_meta klass =
341     Format.sprintf "ClassInfo M_%s;" klass
342
343 let meta_init bindings =
344     let to_ptr klass = Format.sprintf "m_classes[%s]" (String.
    trim (String.uppercase (GenCast.get_tname klass))) in
345     let init (klass, ancestors) =
346         let ancestors_strings = String.concat ", " (List.map
    to_ptr ancestors) in
347         Format.sprintf "class_info_init(&M_%s, %d, %s);" klass (
    List.length ancestors) ancestors_strings in
348     let bindings = List.filter (fun (k, _) -> not (StringSet.mem
     (GenCast.get_tname k) GenCast.built_in_names)) bindings in
349     let inits = List.map init bindings in
350     let inits = List.map (Format.sprintf "\t%s") inits in
351     let built_in_init = "\tinit_built_in_infos();" in
352     Format.sprintf "void init_class_infos() {\n%s\n}\n" (String.
    concat "\n" (built_in_init::inits))
353
354 let cast_to_c ((cdefs, funcs, mains, ancestry) : Cast.program)
    channel =
355     let out string = Printf.fprintf channel "%s\n" string in
356     let noblanks = function
357         | "" -> ()
358         | string -> Printf.fprintf channel "%s\n" string in
359     let incl file = out (Format.sprintf "#include \"%s.h\"\n"
    file) in
360
361     let comment string =
362         let comments = Str.split (Str.regexp "\n") string in
363         let commented = List.map (Format.sprintf " * %s")
    comments in
364         out (Format.sprintf "\n\n/*\n%s\n */" (String.concat "\n
    " commented)) in
365
366     let func_compare f g =
367        let strcmp = Pervasives.compare f.name g.name in
368        if f.builtin = g.builtin then strcmp else if f.builtin
    then -1 else 1 in
369     let funcs = List.sort func_compare funcs in
370
371     comment "Passing over code to find dispatch data.";
372     List.iter collect_dispatch_func funcs;
373
374     comment "Gamma preamble -- macros and such needed by various
     things";
375     incl "gamma-preamble";
376
377     comment "Ancestry meta-info to link to later.";
378     let classes = List.map (fun (kls, _) -> String.trim (GenCast
    .get_tname kls)) (StringMap.bindings ancestry) in
```

```
379     let class_strs = List.map (Format.sprintf "\t%s") (
        print_class_strings classes) in
380     out (Format.sprintf "char *m_classes[] = {\n%s\n};" (String.
        concat "\n" class_strs));
381
382     comment "Enums used to reference into ancestry meta-info
        strings.";
383     let class_enums = List.map (Format.sprintf "\t%s") (
        print_class_enums classes) in
384     out (Format.sprintf "enum m_class_idx {\n%s\n};" (String.
        concat "\n" class_enums));
385
386     comment "Header file containing meta information for built
        in classes.";
387     incl "gamma-builtin-meta";
388
389     comment "Meta structures for each class.";
390     let print_meta (klass, ancestors) =
391         if StringSet.mem (GenCast.get_tname klass) GenCast.
        built_in_names then ()
392         else out (setup_meta klass) in
393     List.iter print_meta (StringMap.bindings ancestry);
394     out "";
395     out (meta_init (StringMap.bindings ancestry));
396
397     comment "Header file containing structure information for
        built in classes.";
398     incl "gamma-builtin-struct";
399
400     comment "Structures for each of the objects.";
401     let print_class klass data =
402         if StringSet.mem klass GenCast.built_in_names then ()
403         else out (cast_to_c_class_struct klass data) in
404     StringMap.iter print_class cdefs;
405
406     comment "Header file containing information regarding built
        in functions.";
407     incl "gamma-builtin-functions";
408
409     comment "All of the function prototypes we need to do magic.
        ";
410     List.iter (fun func -> noblanks (cast_to_c_proto func))
        funcs;
411
412     comment "All the dispatching functions we need to continue
        the magic.";
413     List.iter (fun d -> out (cast_to_c_proto_dispatch_on d)) (!
        dispatchon);
414     List.iter (fun d -> out (cast_to_c_proto_dispatch d)) (!
        dispatches);
415
416     comment "Array allocators also do magic.";
417     List.iter (fun d -> out (cast_to_c_proto_dispatch_arr d)) (!
        dispatcharr);
418
419     comment "All of the functions we need to run the program.";
420     List.iter (fun func -> out (cast_to_c_func func)) funcs;
```

```
421
422     comment "Dispatch looks like this.";
423     List.iter (fun d -> out (generate_testsw d)) (!dispatchon);
424     List.iter (fun d -> out (generate_refinesw d)) (!dispatches)
        ;
425
426     comment "Array allocators.";
427     List.iter (fun d -> out (generate_arrayalloc d)) (!
        dispatcharr);
428
429     comment "The main.";
430     out (cast_to_c_main mains);
```

Source 50: `GenC.ml`

```
1  open Ast
2  open Variables
3  open StringModules
4
5  let rec get_vars_formals = function
6      | [] -> StringSet.empty
7      | [(_,var)] -> StringSet.singleton var
8      | (_,var)::tl -> StringSet.add var (get_vars_formals tl)
9
10 let _ =
11     let func = List.hd (Debug.get_example_longest_body "Multi" "
       Collection") in
12     let stmts = func.body in
13     let prebound = get_vars_formals func.formals in
14     let free_variables = free_vars prebound stmts in
15     StringSet.iter (Printf.printf "%s\n") free_variables
```

Source 51: `freevars.ml`

```
1  let debug_print tokens =
2      let ptoken header tokens =
3          Inspector.pprint_token_list header tokens;
4          print_newline () in
5      let plines header lines =
6          Inspector.pprint_token_lines header lines;
7          print_newline () in
8      begin
9          ptoken "Input:      " tokens;
10         let tokens = WhiteSpace.drop_eof tokens in
11         ptoken "No EOF      " tokens;
12         let tokens = WhiteSpace.indenting_space tokens in
13         ptoken "Indented:   " tokens;
14         let tokens = WhiteSpace.despace_brace tokens in
15         ptoken "In-Brace:   " tokens;
16         let tokens = WhiteSpace.trim_lines tokens in
17         ptoken "Trimmed:    " tokens;
18         let tokens = WhiteSpace.squeeze_lines tokens in
19         ptoken "Squeezed:   " tokens;
```

```
        let lines = WhiteSpace.tokens_to_lines tokens in
        plines "Lines:      " lines;
        let lines = WhiteSpace.merge_lines lines in
        plines "Merged:     " lines;
        let lines = WhiteSpace.block_merge lines in
        plines "Blocks:     " lines;
        let tokens = WhiteSpace.space_to_brace lines in
        ptoken "Converted:  " tokens;
        let tokens = WhiteSpace.append_eof tokens in
        ptoken "With EOF:   " tokens
    end

let _ =
    let tokens = Inspector.from_channel stdin in
    match Array.length Sys.argv with
        | 1 -> Inspector.pprint_token_list "" (WhiteSpace.
    convert tokens)
        | _ -> debug_print tokens
```

Source 52: `streams.ml`

```
val built_in_classes : Ast.class_def list
val is_built_in : string -> bool
```

Source 53: `BuiltIns.mli`

```
open Parser

let descan = Inspector.descan

let rec indenter depth indent =
    for i = 1 to depth do print_string indent done

(* Unscan a sequence of tokens. Requires sanitized stream *)
let rec clean_unscan depth indent = function
    (* ARRAY / LBRACKET RBRACKET ambiguity... *)
    | LBRACKET::RBRACKET::rest ->
        print_string ((descan LBRACKET) ^ " " ^ (descan RBRACKET
    ));
        clean_unscan depth indent rest
    | LBRACE::rest ->
        print_string (descan LBRACE);
        print_newline ();
        indenter (depth+1) indent;
        clean_unscan (depth+1) indent rest
    | SEMI::RBRACE::rest ->
        print_string (descan SEMI);
        clean_unscan depth indent (RBRACE::rest)
    | RBRACE::RBRACE::rest ->
        print_newline ();
        indenter (max (depth-1) 0) indent;
        print_string (descan RBRACE);
        clean_unscan (max (depth-1) 0) indent (RBRACE::rest)
```

```
    | RBRACE::rest ->
        print_newline ();
        indenter (depth-1) indent;
        print_string (descan RBRACE);
        print_newline ();
        indenter (depth-1) indent;
        clean_unscan (max (depth-1) 0) indent rest
    | SEMI::rest ->
        print_string (descan SEMI);
        print_newline ();
        indenter depth indent;
        clean_unscan depth indent rest
    | EOF::[] ->
        print_newline ()
    | EOF::_ ->
        raise(Failure("Premature end of file."))
    | token::rest ->
        print_string (descan token);
        print_string " ";
        clean_unscan depth indent rest
    | [] ->
        print_newline ()

let _ =
    let tokens = Inspector.from_channel stdin in
    clean_unscan 0 "  " (WhiteSpace.convert tokens)
```

Source 54: `canonical.ml`

```
open Ast
open StringModules

(** Module to contain global class hierarchy type declarations *)

(** A full class record table as a type *)
type class_data = {
    known : StringSet.t; (** Set of known class names *)
    classes : class_def lookup_map; (** class name -> class def map *)
    parents : string lookup_map; (** class name -> parent name map *)
    children : (string list) lookup_map; (** class name -> children list map *)
    variables : (class_section * string) lookup_table; (** class name -> var name -> (section, type) map *)
    methods : (func_def list) lookup_table; (** class name -> method name -> func_def list map *)
    refines : (func_def list) lookup_table; (** class name -> host.refinement -> func_def list map *)
    mains : func_def lookup_map; (** class name -> main map *)
    ancestors : (string list) lookup_map; (** class name -> ancestor list (given to Object) *)
    distance : int lookup_table; (** subtype -> supertype -> # hops map *)
```

```
18      refinable : (func_def list) lookup_table (** class -> host
        -> refinements (in subclasses) *)
19  }
20
21  (**
22      All the different types of non-compiler errors that can
        occur (programmer errors)
23    *)
24  type class_data_error
25      = HierarchyIssue of string
26      | DuplicateClasses of string list
27      | DuplicateVariables of (string * string list) list
28      | DuplicateFields of (string * (string * string) list) list
29      | UnknownTypes of (string * (string * string) list) list
30      | ConflictingMethods of (string * (string * string list)
        list) list
31      | ConflictingInherited of (string * (string * string list)
        list) list
32      | PoorlyTypedSigs of (string * (string * string option * (
        string * string) list) list) list
33      | Uninstantiable of string list
34      | ConflictingRefinements of (string * (string * string list)
         list) list
35      | MultipleMains of string list
```

Source 55: `GlobalData.mli`

```
1   {
2     open Parser
3
4     (** The general lexographic scanner for Gamma *)
5
6     (**
7         Build a string from a list of characters
8         from: http://caml.inria.fr/mantis/view.php?id=5367
9         @param l The list to be glued
10        @return A string of the characters in the list glued
        together
11    *)
12    let implode l =
13      let res = String.create (List.length l) in
14      let rec imp i = function
15      | [] -> res
16      | c :: l -> res.[i] <- c; imp (i + 1) l in
17      imp 0 l
18
19    (**
20        Explode a string into a list of characters
21        @param s The string to be exploded
22        @return A list of the characters in the string in order
23    *)
24    let explode s =
25      let rec exploder idx l =
26        if idx < 0
27          then l
```

```
28            else exploder (idx-1) (s.[idx] :: l) in
29        exploder (String.length s - 1) []
30
31      (**
32          A generic function to count the character-spaces of a
          character. (I.e. weight tabs more heavily)
33      *)
34      let spacecounter = function
35        | '\t' -> 8
36        | _    -> 1
37
38      (**
39          Count the space width of a string using the spacecounter
          function
40          @param s The string to be evaluated
41          @return The effective width of the string when rendered
42      *)
43      let spacecount s =
44        let spaces = List.map spacecounter (explode s) in
45        List.fold_left (+) 0 spaces
46
47      (**/**)
48      let line_number = ref 1
49      (**/**)
50
51      (**
52        Count the lines in a series of vertical spacing characters.
53        Please note that as of now, it is not intelligent enough to
          understand
54        that \n\r should be counted as one. It seems like an
          oversized-amount
55        of work for something we will never effectively need.
56        @param v The vertical spacing series string
57      *)
58      let count_lines v = (line_number := !line_number + String.
          length v)
59
60      (**
61          Gracefully tell the programmer that they done goofed
62          @param msg The descriptive error message to convey to the
          programmer
63      *)
64      let lexfail msg =
65        raise (Failure("Line " ^ string_of_int !line_number ^ ": " ^
           msg))
66  }
67
68  let digit = ['0'-'9']
69  let lower = ['a'-'z']
70  let upper = ['A'-'Z']
71  let alpha = lower | upper
72  let ualphanum = '_' | alpha | digit
73
74  (* horizontal spacing: space & tab *)
75  let hspace = [' ' '\t']
76
77  (* vertical spaces: newline (line feed), carriage return,
```

```
    vertical tab, form feed *)
let vspace = ['\n' '\r' '\011' '\012']


rule token = parse
  (* Handling whitespace mode *)
  | hspace+ as s                  { SPACE(spacecount s) }
  | ':' hspace* (vspace+ as v)    { count_lines v; COLON }
  | vspace+ as v                  { count_lines v; NEWLINE }

  (* Comments *)
  | "/*"                          { comment 0 lexbuf }

  (* Boolean Tests & Values *)
  | "refinable"                   { REFINABLE }
  | "and"                         { AND }
  | "or"                          { OR }
  | "xor"                         { XOR }
  | "nand"                        { NAND }
  | "nor"                         { NOR }
  | "not"                         { NOT }
  | "true"                        { BLIT(true) }
  | "false"                       { BLIT(false) }
  | "="                           { EQ }
  | "<>"                          { NEQ }
  | "=/="                         { NEQ }
  | '<'                           { LT }
  | "<="                          { LEQ }
  | ">"                           { GT }
  | ">="                          { GEQ }

  (* Grouping [args, arrays, code, etc] *)
  | "[]"                          { ARRAY }
  | '['                           { LBRACKET }
  | ']'                           { RBRACKET }
  | '('                           { LPAREN }
  | ')'                           { RPAREN }
  | '{'                           { LBRACE }
  | '}'                           { RBRACE }

  (* Punctuation for the sytnax *)
  | ';'                           { SEMI }
  | ','                           { COMMA }

  (* Arithmetic operations *)
  | '+'                           { PLUS }
  | '-'                           { MINUS }
  | '*'                           { TIMES }
  | '/'                           { DIVIDE }
  | '%'                           { MOD }
  | '^'                           { POWER }

  (* Arithmetic assignment *)
  | "+="                          { PLUSA }
  | "-="                          { MINUSA }
  | "*="                          { TIMESA }
  | "/="                          { DIVIDEA }
```

```
134     | "%="                          { MODA }
135     | "^="                          { POWERA }
136
137     (* Control flow *)
138     | "if"                          { IF }
139     | "else"                        { ELSE }
140     | "elsif"                       { ELSIF }
141     | "while"                       { WHILE }
142     | "return"                      { RETURN }
143
144     (* OOP Stuff *)
145     | "class"                       { CLASS }
146     | "extends"                     { EXTEND }
147     | "super"                       { SUPER }
148     | "init"                        { INIT }
149
150     (* Pre defined types / values *)
151     | "null"                        { NULL }
152     | "void"                        { VOID }
153     | "this"                        { THIS }
154
155     (* Refinement / specialization related *)
156     | "refine"                      { REFINE }
157     | "refinement"                  { REFINES }
158     | "to"                          { TO }
159
160     (* Access *)
161     | "private"                     { PRIVATE }
162     | "public"                      { PUBLIC }
163     | "protected"                   { PROTECTED }
164
165     (* Miscellaneous *)
166     | '.'                           { DOT }
167     | "main"                        { MAIN }
168     | "new"                         { NEW }
169     | ":="                          { ASSIGN }
170
171     (* Variable and Type IDs *)
172     | '_'? lower ualphanum* as vid    { ID(vid) }
173     | upper ualphanum* as tid         { TYPE(tid) }
174
175     (* Literals *)
176     | digit+ as inum                { ILIT(int_of_string inum) }
177     | digit+ '.' digit+ as fnum     { FLIT(float_of_string fnum) }
178     | '"'                           { stringlit [] lexbuf }
179
180     (* Some type of end, for sure *)
181     | eof                           { EOF }
182     | _ as char { lexfail("Illegal character " ^ Char.escaped char
          ) }
183
184   and comment level = parse
185     (* Comments can be nested *)
186     | "/*"          { comment (level+1) lexbuf }
187     | "*/"          { if level = 0 then token lexbuf else comment
          (level-1) lexbuf }
188     | eof           { lexfail("File ended inside comment.") }
```

```
189     | vspace+ as v  { count_lines v; comment level lexbuf }
190     | _             { comment level lexbuf }
191
192   and stringlit chars = parse
193     (* Accept valid C string literals as that is what we will
          output directly *)
194     | '\\'          { escapechar chars lexbuf }
195     | eof           { lexfail("File ended inside string literal")
          }
196     | vspace as char { lexfail("Line ended inside string literal (
          " ^ Char.escaped char ^ " used): " ^ implode(List.rev chars)
          ) }
197     | '"'           { SLIT(implode(List.rev chars)) }
198     | _ as char     { stringlit (char::chars) lexbuf }
199
200   and escapechar chars = parse
201     (* Accept valid C escape sequences *)
202     | ['a' 'b' 'f' 'n' 'r' 't' 'v' '\\' '"' '0'] as char {
203         stringlit (char :: '\\' :: chars) lexbuf
204       }
205     | eof       { lexfail("File ended while seeking escape
          character") }
206     | _ as char { lexfail("Illegal escape character:  \\" ^ Char.
          escaped(char)) }
```

Source 56: `scanner.mll`

```
1   open Ast
2   open Sast
3   open Klass
4   open StringModules
5   open Util
6   open GlobalData
7
8   (** Module to take an AST and build the sAST out of it. *)
9
10  (**
11      Update an environment to have a variable
12      @param mode The mode the variable is in (instance, local)
13      @param vtype The type of the variable
14      @param vname The name of the variable
15      @return A function that will update an environment passed to
          it.
16    *)
17  let env_update mode (vtype, vname) env = match map_lookup vname
        env, mode with
18      | None, _ -> StringMap.add vname (vtype, mode) env
19      | Some((otype, Local)), Local -> raise(Failure("Local
        variable " ^ vname ^ " loaded twice, once with type " ^
        otype ^ " and then with type " ^ vtype ^ "."))
20      | _, Local -> StringMap.add vname (vtype, mode) env
21      | _, _ -> raise(Failure("Instance variable declared twice in
          ancestry chain -- this should have been detected earlier;
        compiler error."))
22  let env_updates mode = List.fold_left (fun env vdef ->
```

```
    env_update mode vdef env)
let add_ivars klass env level =
    let sects = match level with
        | Publics -> [Publics]
        | Protects -> [Publics; Protects]
        | Privates -> [Publics; Protects; Privates]
        | _ -> raise(Failure("Inappropriate class section -
    access level."))  in
    let filter (s, _) = List.mem s sects in
    let vars = Klass.klass_to_variables klass in
    let eligible = List.flatten (List.map snd (List.filter
    filter vars)) in
    env_updates (Instance(klass.klass)) env eligible

(** Marker for being in the current class -- ADT next time *)
let current_class = "_CurrentClassMarker_"

(** Marker for the null type -- ADT next time *)
let null_class = "_Null_"

(** Empty environment *)
let empty_environment = StringMap.empty

(** Return whether an expression is a valid lvalue or not *)
let is_lvalue (expr : Ast.expr) = match expr with
    | Ast.Id(_) -> true
    | Ast.Field(_, _) -> true
    | Ast.Deref(_, _) -> true
    | _ -> false

(**
    Map a literal value to its type
    @param litparam a literal
    @return A string representing the type.
  *)
let getLiteralType litparam = match litparam with
    | Ast.Int(i) -> "Integer"
    | Ast.Float(f) -> "Float"
    | Ast.String(s) -> "String"
    | Ast.Bool(b) -> "Boolean"

(**
    Map a return type string option to a return type string
    @param ret_type The return type.
    @return The return type -- Void or its listed type.
  *)
let getRetType ret_type = match ret_type with
    | Some(retval) -> retval
    | None -> "Void"

(**
    Update a refinement switch based on updated data.
  *)
let rec update_refinements_stmts klass_data kname mname = List.
    map (update_refinements_stmt klass_data kname mname)
and update_refinements_exprs klass_data kname mname = List.map (
    update_refinements_expr klass_data kname mname)
```

```
75  and update_refinements_expr klass_data kname mname (atype, expr)
        =
76      let doexp = update_refinements_expr klass_data kname mname
        in
77      let doexps = update_refinements_exprs klass_data kname mname
         in
78
79      let get_refine rname arglist desired uid =
80          let argtypes = List.map fst arglist in
81          let refines = Klass.refine_on klass_data kname mname
        rname argtypes desired in
82          let switch = List.map (fun (f : Ast.func_def) -> (f.
        inklass, f.uid)) refines in
83          (getRetType desired, Sast.Refine(rname, arglist, desired
        , Switch(kname, switch, uid))) in
84
85      let get_refinable rname uid =
86          let refines = Klass.refinable_lookup klass_data kname
        mname rname in
87          let klasses = List.map (fun (f : Ast.func_def) -> f.
        inklass) refines in
88          ("Boolean", Sast.Refinable(rname, Test(kname, klasses,
        uid))) in
89
90      match expr with
91          | Sast.Refine(rname, args, desired, Switch(_, _, uid))
        -> get_refine rname args desired uid
92          | Sast.Refine(_, _, _, _) -> raise(Failure("Test in
        switch."))
93          | Sast.Refinable(rname, Test(_, _, uid)) ->
        get_refinable rname uid
94          | Sast.Refinable(_, _) -> raise(Failure("Switch in test.
        "))
95
96          | Sast.Anonymous(_, _, _) -> raise(Failure("Anonymous
        detected during reswitching."))
97
98          | Sast.This -> (atype, Sast.This)
99          | Sast.Null -> (atype, Sast.Null)
100         | Sast.Id(id) -> (atype, Sast.Id(id))
101         | Sast.NewObj(klass, args, uid) -> (atype, Sast.NewObj(
        klass, doexps args, uid))
102         | Sast.Literal(lit) -> (atype, Sast.Literal(lit))
103         | Sast.Assign(l, r) -> (atype, Sast.Assign(doexp l,
        doexp r))
104         | Sast.Deref(l, r) -> (atype, Sast.Deref(doexp l, doexp
        r))
105         | Sast.Field(e, m) -> (atype, Sast.Field(doexp e, m))
106         | Sast.Invoc(r, m, args, uid) -> (atype, Sast.Invoc(
        doexp r, m, doexps args, uid))
107         | Sast.Unop(op, e) -> (atype, Sast.Unop(op, doexp e))
108         | Sast.Binop(l, op, r) -> (atype, Sast.Binop(doexp l, op
        , doexp r))
109 and update_refinements_stmt klass_data kname mname stmt =
110     let doexp = update_refinements_expr klass_data kname mname
        in
111     let doexps = update_refinements_exprs klass_data kname mname
```

```
     in
112      let dostmts = update_refinements_stmts klass_data kname
         mname in
113      let docls = update_refinements_clauses klass_data kname
         mname in
114
115      match stmt with
116          | Sast.Decl(_, None, _) as d -> d
117          | Sast.Decl(vdef, Some(e), env) -> Sast.Decl(vdef, Some(
         doexp e), env)
118          | Sast.If(pieces, env) -> Sast.If(docls pieces, env)
119          | Sast.While(pred, body, env) -> Sast.While(doexp pred,
         dostmts body, env)
120          | Sast.Expr(expr, env) -> Sast.Expr(doexp expr, env)
121          | Sast.Return(None, _) as r -> r
122          | Sast.Return(Some(e), env) -> Sast.Return(Some(doexp e)
         , env)
123          | Sast.Super(args, uid, super, env) -> Sast.Super(doexps
          args, uid, super, env)
124  and update_refinements_clauses (klass_data : class_data) (kname
         : string) (mname : string) (pieces : (Sast.expr option *
         Sast.sstmt list) list) : (Sast.expr option * Sast.sstmt list
         ) list =
125      let dobody = update_refinements_stmts klass_data kname mname
          in
126      let dopred = update_refinements_expr klass_data kname mname
         in
127
128      let mapping = function
129          | (None, body) -> (None, dobody body)
130          | (Some(e), body) -> (Some(dopred e), dobody body) in
131      List.map mapping pieces
132
133  let update_refinements_func klass_data (func : Sast.func_def) =
134      { func with body = update_refinements_stmts klass_data func.
         inklass func.name func.body }
135
136  let update_refinements_member klass_data = function
137      | Sast.InitMem(i) -> Sast.InitMem(update_refinements_func
         klass_data i)
138      | Sast.MethodMem(m) -> Sast.MethodMem(
         update_refinements_func klass_data m)
139      | v -> v
140
141  let update_refinements_klass klass_data (klass : Sast.class_def)
          =
142      let mems = List.map (update_refinements_member klass_data)
         in
143      let funs = List.map (update_refinements_func klass_data) in
144      let s = klass.sections in
145      let sects =
146          { publics = mems s.publics;
147            protects = mems s.protects;
148            privates = mems s.privates;
149            mains = funs s.mains;
150            refines = funs s.refines } in
151      { klass with sections = sects }
```

```
152
153 let update_refinements klass_data (klasses : Sast.class_def list
    ) =
154     List.map (update_refinements_klass klass_data) klasses
155
156 (**
157     Given a class_data record, a class name, an environment, and
     an Ast.expr expression,
158     return a Sast.expr expression.
159     @param klass_data A class_data record
160     @param kname The name of of the current class
161     @param env The local environment (instance and local
    variables so far declared)
162     @param exp An expression to eval to a Sast.expr value
163     @return A Sast.expr expression, failing when there are
    issues.
164   *)
165 let rec eval klass_data kname mname isstatic env exp =
166     let eval' expr = eval klass_data kname mname isstatic env
    expr in
167     let eval_exprlist elist = List.map eval' elist in
168
169     let get_field expr mbr =
170         let (recvr_type, _) as recvr = eval' expr in
171         let this = (recvr_type = current_class) in
172         let recvr_type = if this then kname else recvr_type in
173         let field_type = match Klass.class_field_far_lookup
    klass_data recvr_type mbr this with
174             | Left((_, vtyp, _)) -> vtyp
175             | Right(true) -> raise(Failure("Field " ^ mbr ^ " is
     not accessible in " ^ recvr_type ^ " from " ^ kname ^ "."))
176             | Right(false) -> raise(Failure("Unknown field " ^
    mbr ^ " in the ancestry of " ^ recvr_type ^ ".")) in
177         (field_type, Sast.Field(recvr, mbr)) in
178
179     let cast_to klass (_, v) = (klass, v) in
180
181     let get_invoc expr methd elist =
182         let (recvr_type, _) as recvr = eval' expr in
183         let arglist = eval_exprlist elist in
184         let this = (recvr_type = current_class) in
185         let _ = if (this && isstatic)
186             then raise(Failure(Format.sprintf "Cannot invoke %s
    on %s in %s for %s is static." methd mname kname mname))
187             else () in
188         let recvr_type = if this then kname else recvr_type in
189         let argtypes = List.map fst arglist in
190         let mfdef = match Klass.best_inherited_method klass_data
     recvr_type methd argtypes this with
191             | None when this -> raise(Failure(Format.sprintf "
    Method %s not found ancestrally in %s (this=%b)" methd
    recvr_type this))
192             | None -> raise(Failure("Method " ^ methd ^ " not
    found (publically) in the ancestry of " ^ recvr_type ^ "."))
193             | Some(fdef) -> fdef in
194         let mfid = if mfdef.builtin then BuiltIn mfdef.uid else
    FuncId mfdef.uid in
```

```
195             (getRetType mfdef.returns, Sast.Invoc(cast_to (mfdef.
    inklass) recvr, methd, arglist, mfid)) in
196
197         let get_init class_name exprlist =
198             let arglist = eval_exprlist exprlist in
199             let argtypes = List.map fst arglist in
200             let mfdef = match best_method klass_data class_name "
    init" argtypes [Ast.Publics] with
201                 | None      -> raise(Failure "Constructor not found
    ")
202                 | Some(fdef) -> fdef in
203             let mfid = if mfdef.builtin then BuiltIn mfdef.uid else
    FuncId mfdef.uid in
204             (class_name, Sast.NewObj(class_name, arglist, mfid)) in
205
206         let get_assign e1 e2 =
207             let (t1, t2) = (eval' e1, eval' e2) in
208             let (type1, type2) = (fst t1, fst t2) in
209             match is_subtype klass_data type2 type1, is_lvalue e1
    with
210                 | _, false -> raise(Failure "Assigning to non-lvalue
    ")
211                 | false, _ -> raise(Failure "Assigning to
    incompatible types")
212                 | _ -> (type1, Sast.Assign(t1, t2)) in
213
214         let get_binop e1 op e2 =
215             let isCompatible typ1 typ2 =
216                 if is_subtype klass_data typ1 typ2 then typ2
217                 else if is_subtype klass_data typ2 typ1 then typ1
218                 else raise (Failure (Format.sprintf "Binop takes
    incompatible types: %s %s" typ1 typ2)) in
219             let (t1, t2) = (eval' e1, eval' e2) in
220             let gettype op (typ1,_) (typ2,_) = match op with
221                 | Ast.Arithmetic(Neg) -> raise(Failure("Negation is
    not a binary operation!"))
222                 | Ast.CombTest(Not) -> raise(Failure("Boolean
    negation is not a binary operation!"))
223                 | Ast.Arithmetic(_) -> isCompatible typ1 typ2
224                 | Ast.NumTest(_)
225                 | Ast.CombTest(_) -> ignore(isCompatible typ1 typ2);
     "Boolean" in
226             (gettype op t1 t2, Sast.Binop(t1,op,t2)) in
227
228         let get_refine rname elist desired =
229             let arglist = eval_exprlist elist in
230             let argtypes = List.map fst arglist in
231             let refines = Klass.refine_on klass_data kname mname
    rname argtypes desired in
232             let switch = List.map (fun (f : Ast.func_def) -> (f.
    inklass, f.uid)) refines in
233             (getRetType desired, Sast.Refine(rname, arglist, desired
    , Switch(kname, switch, UID.uid_counter ()))) in
234
235         let get_refinable rname =
236             let refines = Klass.refinable_lookup klass_data kname
    mname rname in
```

```
237         let klasses = List.map (fun (f : Ast.func_def) -> f.
    inklass) refines in
238         ("Boolean", Sast.Refinable(rname, Test(kname, klasses,
    UID.uid_counter ()))) in
239
240     let get_deref e1 e2 =
241         let expectArray typename = match Str.last_chars typename
     2 with
242             | "[]" -> Str.first_chars typename (String.length
    typename - 2)
243             | _ -> raise (Failure "Not an array type") in
244         let (t1, t2) = (eval' e1, eval' e2) in
245         let getArrayType (typ1, _) (typ2, _) = match typ2 with
246             | "Integer" -> expectArray typ1
247             | _ -> raise(Failure "Dereferencing invalid") in
248         (getArrayType t1 t2, Sast.Deref(t1, t2)) in
249     let get_unop op expr = match op with
250         | Ast.Arithmetic(Neg) -> let (typ, _) as evaled = eval'
    expr in (typ, Sast.Unop(op, evaled))
251         | Ast.CombTest(Not) -> ("Boolean", Sast.Unop(op, eval'
    expr))
252         | _ -> raise(Failure("Unknown binary operator " ^
    Inspector.inspect_ast_op op ^ " given.")) in
253
254     let lookup_type id = match map_lookup id env with
255         | None -> raise(Failure("Unknown id " ^ id ^ " in
    environment built around " ^ kname ^ ", " ^ mname ^ "."))
256         | Some((vtype, _)) -> vtype in
257
258     let get_new_arr atype args =
259         let arglist = eval_exprlist args in
260         if List.exists (fun (t, _) -> t <> "Integer") arglist
261            then raise(Failure "Size of an array dimensions does
    not correspond to an integer.")
262            else (atype, Sast.NewObj(atype, arglist, ArrayAlloc(
    UID.uid_counter ()))) in
263
264     let get_new_obj atype args = try
265         let index = String.index atype '[' in
266         let dimensions = (String.length atype - index) / 2 in
267         match List.length args with
268             | n when n > dimensions -> raise(Failure("Cannot
    allocate array, too many dimensions given."))
269             | n when n < dimensions -> raise(Failure("Cannot
    allocate array, too few dimensions given."))
270             | 0 -> (null_class, Sast.Null)
271             | _ -> get_new_arr atype args
272         with Not_found -> get_init atype args in
273
274     match exp with
275         | Ast.This -> (current_class, Sast.This)
276         | Ast.Null -> (null_class, Sast.Null)
277         | Ast.Id(vname) -> (lookup_type vname, Sast.Id(vname))
278         | Ast.Literal(lit) -> (getLiteralType lit, Sast.Literal(
    lit))
279         | Ast.NewObj(s1, elist) -> get_new_obj s1 elist
280         | Ast.Field(expr, mbr) -> get_field expr mbr
```

```
281         | Ast.Invoc(expr, methd, elist) -> get_invoc expr methd
    elist
282         | Ast.Assign(e1, e2) -> get_assign e1 e2
283         | Ast.Binop(e1,op,e2) -> get_binop e1 op e2
284         | Ast.Refine(s1, elist, soption) -> get_refine s1 elist
    soption
285         | Ast.Deref(e1, e2) -> get_deref e1 e2
286         | Ast.Refinable(s1) -> get_refinable s1
287         | Ast.Unop(op, expr) -> get_unop op expr
288         | Ast.Anonymous(atype, args, body) -> (atype, Sast.
    Anonymous(atype, eval_exprlist args, body)) (* Delay
    evaluation *)
289
290 (**
291     Given a class_data record, the name of the current class, a
    list of AST statements,
292     and an initial environment, enumerate the statements and
    attach the environment at
293     each step to that statement, yielding Sast statements. Note
    that when there is an
294     issue the function will raise Failure.
295     @param klass_data A class_data record
296     @param kname The name of the class that is the current
    context.
297     @param stmts A list of Ast statements
298     @param initial_env An initial environment
299     @return A list of Sast statements
300   *)
301 let rec attach_bindings klass_data kname mname meth_ret isstatic
     stmts initial_env =
302     (* Calls that go easy on the eyes *)
303     let eval' = eval klass_data kname mname isstatic in
304     let attach' = attach_bindings klass_data kname mname
    meth_ret isstatic in
305     let eval_exprlist env elist = List.map (eval' env) elist in
306
307     let rec get_superinit kname arglist =
308         let parent = StringMap.find kname klass_data.parents in
309         let argtypes = List.map fst arglist in
310         match best_method klass_data parent "init" argtypes [Ast
    .Publics; Ast.Protects] with
311             | None       -> raise(Failure "Cannot find super
    init")
312             | Some(fdef) -> fdef in
313
314     (* Helper function for building a predicate expression *)
315     let build_predicate pred_env exp = match eval' pred_env exp
    with
316         | ("Boolean", _) as evaled -> evaled
317         | _ -> raise (Failure "Predicates must be boolean") in
318
319     (* Helper function for building an optional expression *)
320     let opt_eval opt_expr opt_env = match opt_expr with
321         | None -> None
322         | Some(exp) -> Some(eval' opt_env exp) in
323
324     (* For each kind of statement, build the associated Sast
```

```
    statment *)
325 let build_ifstmt iflist if_env =
326     let build_block if_env (exp, slist) =
327         let exprtyp = match exp with
328             | None -> None
329             | Some exp -> Some(build_predicate if_env exp)
    in
330         (exprtyp, attach' slist if_env) in
331     Sast.If(List.map (build_block if_env) iflist, if_env) in
332
333 let build_whilestmt expr slist while_env =
334     let exprtyp = build_predicate while_env expr in
335     let stmts = attach' slist while_env in
336     Sast.While(exprtyp, stmts, while_env) in
337
338 let build_declstmt ((vtype, vname) as vdef) opt_expr
    decl_env =
339     if not (Klass.is_type klass_data vtype) then raise(
    Failure(Format.sprintf "%s in %s.%s has unknown type %s."
    vname kname mname vtype))
340     else match opt_eval opt_expr decl_env with
341         | Some((atype, _)) as evaled -> if not (Klass.
    is_subtype klass_data atype vtype)
342             then raise(Failure(Format.sprintf "%s in %s.%s
    is type %s but is assigned a value of type %s." vname kname
    mname vtype atype))
343             else Sast.Decl(vdef, evaled, decl_env)
344         | None -> Sast.Decl(vdef, None, decl_env) in
345
346 let check_ret_type ret_type = match ret_type, meth_ret with
347     | None, Some(_) -> raise(Failure("Void return from non-
    void function " ^ mname ^ " in klass " ^ kname ^ "."))
348     | Some(_), None -> raise(Failure("Non-void return from
    void function " ^ mname ^ " in klass " ^ kname ^ "."))
349     | Some(r), Some(t) -> if not (Klass.is_subtype
    klass_data r t) then raise(Failure(Format.sprintf "Method %s
     in %s returns %s despite being declared returning %s" mname
     kname r t))
350     | _, _ -> () in
351
352 let build_returnstmt opt_expr ret_env =
353     let ret_val = opt_eval opt_expr ret_env in
354     let ret_type = match ret_val with Some(t, _) -> Some(t)
    | _ -> None in
355     check_ret_type ret_type;
356     Sast.Return(ret_val, ret_env) in
357 let build_exprstmt expr expr_env = Sast.Expr(eval' expr_env
    expr, expr_env) in
358 let build_superstmt expr_list super_env =
359     let arglist = eval_exprlist super_env expr_list in
360     let init = get_superinit kname arglist in
361     match map_lookup kname klass_data.parents with
362         | None -> raise(Failure("Error -- getting parent for
     object without parent: " ^ kname))
363         | Some(parent) -> Sast.Super(arglist, init.uid,
    parent, super_env) in
364
```

```
365     (* Ast statement -> (Sast.Statement, Environment Update
        Option) *)
366     let updater in_env = function
367         | Ast.While(expr, slist)   -> (build_whilestmt expr
        slist in_env, None)
368         | Ast.If(iflist)           -> (build_ifstmt iflist
        in_env, None)
369         | Ast.Decl(vdef, opt_expr) -> (build_declstmt vdef
        opt_expr in_env, Some(vdef))
370         | Ast.Expr(expr)           -> (build_exprstmt expr
        in_env, None)
371         | Ast.Return(opt_expr)     -> (build_returnstmt opt_expr
         in_env, None)
372         | Ast.Super(exprs)         -> (build_superstmt exprs
        in_env, None) in
373
374     (* Function to fold a statement into a growing reverse list
        of Sast statements *)
375     let build_env (output, acc_env) stmt =
376         let (node, update) = updater acc_env stmt in
377         let updated_env = match update with
378             | None -> acc_env
379             | Some(vdef) -> env_update Local vdef acc_env in
380         (node::output, updated_env) in
381
382     List.rev (fst(List.fold_left build_env ([], initial_env)
        stmts))
383
384 (**
385     Given a list of statements, return whether every execution
        path therein returns
386     @param stmts A bunch of Ast.stmts
387     @return true or false based on whether everything returns a
        value.
388   *)
389 let rec does_return_stmts (stmts : Ast.stmt list) = match stmts
        with
390     | [] -> false
391     | Return(None)::_ -> false
392     | Return(_)::_ -> true
393     | If(pieces)::rest -> does_return_clauses pieces ||
        does_return_stmts rest
394     | _::rest -> does_return_stmts rest
395 (**
396     Given a collection of if clauses, return whether they
        represent a return from the function.
397     @param pieces If clauses (option expr, stmt list)
398     @return whether or not it can be determined that a return is
         guaranteed here.
399   *)
400 and does_return_clauses pieces =
401     let (preds, bodies) = List.split pieces in
402     List.mem None preds && List.for_all does_return_stmts bodies
403
404 (**
405     Change inits so that they return this
406   *)
```

```
407 let init_returns (func : Sast.func_def) =
408     let body = if func.builtin then [] else func.body @ [Sast.
    Return(None, empty_environment)] in
409     let this_val = (current_class, Sast.This) in
410     let return_this (stmt : Sast.sstmt) = match stmt with
411         | Return(None, env) -> Return(Some(this_val), env)
412         | _ -> stmt in
413     { func with
414         returns = Some(func.inklass);
415         body = List.map return_this body }
416
417 let rec update_current_ref_stmts (kname : string) (stmts : Sast.
    sstmt list) : Sast.sstmt list = List.map (
    update_current_ref_stmt kname) stmts
418 and update_current_ref_exprs (kname : string) (exprs : Sast.expr
     list) = List.map (update_current_ref_expr kname) exprs
419 and update_current_ref_stmt (kname : string) (stmt : Sast.sstmt)
     = match stmt with
420     | Sast.Decl(vdef, None, env) -> Sast.Decl(vdef, None, env)
421     | Sast.Decl(vdef, Some(expr), env) -> Sast.Decl(vdef, Some(
    update_current_ref_expr kname expr), env)
422     | Sast.Expr(expr, env) -> Sast.Expr(update_current_ref_expr
    kname expr, env)
423     | Sast.If(pieces, env) -> Sast.If(update_current_ref_clauses
     kname pieces, env)
424     | Sast.While(expr, body, env) -> Sast.While(
    update_current_ref_expr kname expr, update_current_ref_stmts
     kname body, env)
425     | Sast.Return(None, env) -> Sast.Return(None, env)
426     | Sast.Return(Some(expr), env) -> Sast.Return(Some(
    update_current_ref_expr kname expr), env)
427     | Sast.Super(args, uid, parent, env) -> Sast.Super(
    update_current_ref_exprs kname args, uid, parent, env)
428 and update_current_ref_expr (kname : string) ((atype, detail) :
    string * Sast.expr_detail) : string * Sast.expr_detail =
429     let cleaned = match detail with
430         | Sast.This -> Sast.This
431         | Sast.Null -> Sast.Null
432         | Sast.Id(i) -> Sast.Id(i)
433         | Sast.NewObj(klass, args, uid) -> Sast.NewObj(klass,
    update_current_ref_exprs kname args, uid)
434         | Sast.Anonymous(klass, args, refs) -> Sast.Anonymous(
    klass, args, refs)
435         | Sast.Literal(lit) -> Sast.Literal(lit)
436         | Sast.Assign(mem, data) -> Sast.Assign(
    update_current_ref_expr kname mem, update_current_ref_expr
    kname data)
437         | Sast.Deref(arr, idx) -> Sast.Deref(
    update_current_ref_expr kname arr, update_current_ref_expr
    kname idx)
438         | Sast.Field(expr, member) -> Sast.Field(
    update_current_ref_expr kname expr, member)
439         | Sast.Invoc(expr, meth, args, id) -> Sast.Invoc(
    update_current_ref_expr kname expr, meth,
    update_current_ref_exprs kname args, id)
440         | Sast.Unop(op, expr) -> Sast.Unop(op,
    update_current_ref_expr kname expr)
```

```
441             | Sast.Binop(l, op, r) -> Sast.Binop(
        update_current_ref_expr kname l, op, update_current_ref_expr
         kname r)
442             | Sast.Refine(refine, args, ret, switch) -> Sast.Refine(
        refine, update_current_ref_exprs kname args, ret, switch)
443             | Sast.Refinable(refine, switch) -> Sast.Refinable(refine
        , switch) in
444         let realtype : string = if current_class = atype then kname
        else atype in
445         (realtype, cleaned)
446     and update_current_ref_clauses (kname : string) pieces =
447         let (preds, bodies) = List.split pieces in
448         let preds = List.map (function None -> None | Some(expr) ->
        Some(update_current_ref_expr kname expr)) preds in
449         let bodies = List.map (update_current_ref_stmts kname)
        bodies in
450         List.map2 (fun a b -> (a, b)) preds bodies
451
452     (**
453         Given a class_data record, an Ast.func_def, an an initial
        environment,
454         convert the func_def to a Sast.func_def. Can raise failure
        when there
455         are issues with the statements / expressions in the function
        .
456         @param klass_data A class_data record
457         @param func An Ast.func_def to transform
458         @param initial_env The initial environment
459         @return A Sast.func_def value
460       *)
461     let ast_func_to_sast_func klass_data (func : Ast.func_def)
        initial_env isinit =
462         let with_params = List.fold_left (fun env vdef -> env_update
         Local vdef env) initial_env func.formals in
463         let checked : Sast.sstmt list = attach_bindings klass_data
        func.inklass func.name func.returns func.static func.body
        with_params in
464         let cleaned = update_current_ref_stmts func.inklass checked
        in
465         let sast_func : Sast.func_def =
466             {   returns = func.returns;
467                 host = func.host;
468                 name = func.name;
469                 formals = func.formals;
470                 static = func.static;
471                 body = cleaned;
472                 section = func.section;
473                 inklass = func.inklass;
474                 uid = func.uid;
475                 builtin = func.builtin } in
476         let isvoid = match func.returns with None -> true | _ ->
        false in
477         if not func.builtin && not isvoid && not (does_return_stmts
        func.body)
478             then raise(Failure(Format.sprintf "The function %s in %s
         does not return on all execution paths" (
        full_signature_string func) func.inklass))
```

```
479             else if isinit then init_returns sast_func else
        sast_func
480
481     (**
482         Given a class_data record, an Ast.member_def, and an initial
         environment,
483         convert the member into an Sast.member_def. May raise
        failure when there
484         are issues in the statements / expressions in the member.
485         @param klass_data A class_data record.
486         @param mem An Ast.member_def value
487         @param initial_env An environment of variables
488         @return A Sast.member_def
489       *)
490     let ast_mem_to_sast_mem klass_data (mem : Ast.member_def)
        initial_env =
491         let change isinit func = ast_func_to_sast_func klass_data
        func initial_env isinit in
492         let transformed : Sast.member_def = match mem with
493             | Ast.VarMem(v) -> Sast.VarMem(v)
494             | Ast.MethodMem(m) -> Sast.MethodMem(change false m)
495             | Ast.InitMem(m) -> Sast.InitMem(change true m) in
496         transformed
497
498     let init_calls_super (aklass : Sast.class_def) =
499         let validate_init func_def = match func_def.builtin,
        func_def.body with
500             | true, _ -> true
501             | _, (Super(_,_,_,_)::_) -> true
502             | _, _ -> false in
503         let grab_init = function
504             | InitMem(m) -> Some(m)
505             | _ -> None in
506         let get_inits mems = Util.filter_option (List.map grab_init
        mems) in
507         let s = aklass.sections in
508         let inits = List.flatten (List.map get_inits [s.publics; s.
        protects; s.privates]) in
509         List.for_all validate_init inits
510
511     let check_main (func : Ast.func_def) = match func.formals with
512         | [("System", _); ("String[]", _)] -> func
513         | _ -> raise(Failure(Format.sprintf "Main functions can only
         have two arguments: A system (first) and an array of
        strings (second). -- error in %s" func.inklass))
514
515     (**
516         Given a class_data object and an Ast.class_def, return a
        Sast.class_def
517         object. May fail when there are issues in the statements /
        expressions.
518         @param klass_data A class_data record value
519         @param ast_klass A class to transform
520         @return The transformed class.
521       *)
522     let ast_to_sast_klass klass_data (ast_klass : Ast.class_def) =
523         let s : Ast.class_sections_def = ast_klass.sections in
```

```
524     let rec update_env env sect (klass : Ast.class_def) =
525         let env = add_ivars klass env sect in
526         match klass.klass with
527             | "Object" -> env
528             | _ -> let parent = Klass.klass_to_parent klass in
529                    let pclass = StringMap.find parent klass_data
    .classes in
530                    update_env env Protects pclass in
531     let env = update_env empty_environment Privates ast_klass in
532
533     let mems = List.map (fun m -> ast_mem_to_sast_mem klass_data
     m env) in
534     let funs = List.map (fun f -> ast_func_to_sast_func
    klass_data f env false) in
535
536     let sections : Sast.class_sections_def =
537         {   publics = mems s.publics;
538             protects = mems s.protects;
539             privates = mems s.privates;
540             refines = funs s.refines;
541             mains = funs (List.map check_main s.mains) } in
542
543     let sast_klass : Sast.class_def =
544         {   klass = ast_klass.klass;
545             parent = ast_klass.parent;
546             sections = sections } in
547
548     if init_calls_super sast_klass then sast_klass
549     else raise(Failure(Format.sprintf "%s's inits don't always
    call super as their first statement (maybe empty body, maybe
     something else)." sast_klass.klass))
550
551 (**
552     @param ast An ast program
553     @return A sast program
554 *)
555 let ast_to_sast klass_data =
556     let klasses = StringMap.bindings klass_data.classes in
557     let to_sast (_, klass) = ast_to_sast_klass klass_data klass
    in
558     List.map to_sast klasses
```

Source 57: `BuildSast.ml`

```
1  (**
2      The abstract syntax tree for Gamma
3  *)
4
5  (**
6      The four literal classes of Gamma:
7      - Int - Integer
8      - Float - Floating-point number
9      - String - A sequence of characters
10     - Bool - a boolean value of either true or false
11 *)
```

```
12  type lit =
13      Int of int
14    | Float of float
15    | String of string
16    | Bool of bool
17
18  (** The binary arithmatic operators *)
19  type arith = Add | Sub | Prod | Div | Mod | Neg | Pow
20
21  (** The binary comparison operators *)
22  type numtest = Eq | Neq | Less | Grtr | Leq | Geq
23
24  (** The binary boolean operators *)
25  type combtest = And | Or | Nand | Nor | Xor | Not
26
27  (** All three sets of binary operators *)
28  type op = Arithmetic of arith | NumTest of numtest | CombTest of
        combtest
29
30  (** The various types of expressions we can have. *)
31  type expr =
32      This
33    | Null
34    | Id of string
35    | NewObj of string * expr list
36    | Anonymous of string * expr list * func_def list
37    | Literal of lit
38    | Assign of expr * expr  (* memory := data -- whether memory
        is good is a semantic issue *)
39    | Deref of expr * expr (* road[pavement] *)
40    | Field of expr * string (* road.pavement *)
41    | Invoc of expr * string * expr list (* receiver.method(args)
        *)
42    | Unop of op * expr (* !x *)
43    | Binop of expr * op * expr (* x + y *)
44    | Refine of string * expr list * string option
45    | Refinable of string (* refinable *)
46  (** The basic variable definition, a type and an id*)
47  and var_def = string * string  (* Oh typing, you pain in the ass
        , add a int for array *)
48  (** The basic statements: Variable declarations, control
        statements, assignments, return statements, and super class
        expressions *)
49  and stmt =
50      Decl of var_def * expr option
51    | If of (expr option * stmt list) list
52    | While of expr * stmt list
53    | Expr of expr
54    | Return of expr option
55    | Super of expr list
56
57  (** Three access levels, the refinements, and the main function
        *)
58  and class_section = Publics | Protects | Privates | Refines |
        Mains
59
60  (** We have four different kinds of callable code blocks: main,
```

```
    init, refine, method. *)
and func_def = {
  returns : string option;  (** A return type (method/refine) *)
  host    : string option;  (** A host class (refine) *)
  name    : string;         (** The function name (all) *)
  static  : bool;           (** If the function is static (main)
    *)
  formals : var_def list;   (** A list of all formal parameters
    of the function (all) *)
  body    : stmt list;      (** A list of statements that form
    the function body (all) *)
  section : class_section;  (** A sementic tag of the class
    section in which the function lives (all) *)
  inklass : string;         (** A semantic tag of the class in
    which the function lives (all) *)
  uid     : string;         (** A string for referencing this --
     should be maintained in transformations to later ASTs *)
  builtin : bool;           (** Whether or not the function is
    built in (uid should have _ in it then) *)
}

(** A member is either a variable or some sort of function *)
type member_def = VarMem of var_def | MethodMem of func_def |
    InitMem of func_def

(** Things that can go in a class *)
type class_sections_def = {
  privates : member_def list;
  protects : member_def list;
  publics  : member_def list;
  refines  : func_def list;
  mains    : func_def list;
}

(* Just pop init and main in there? *)
(** The basic class definition *)
type class_def = {
  klass    : string; (** A name string *)
  parent   : string option; (** The parent class name *)
  sections : class_sections_def; (** The five sections *)
}

(** A program, right and proper  *)
type program = class_def list
```

Source 58: `Ast.mli`

```
let _ =
    let tokens = Inspector.from_channel stdin in
    let classes = Parser.cdecls (WhiteSpace.lextoks tokens) (
    Lexing.from_string "") in
    let pp_classes = List.map Pretty.pp_class_def classes in
    print_string (String.concat "\n\n" pp_classes);
    print_newline ()
```

Source 59: `prettify.ml`

```
val deanonymize : GlobalData.class_data -> Sast.class_def list
    -> (GlobalData.class_data * Sast.class_def list, GlobalData.
    class_data_error) Util.either
```

Source 60: `Unanonymous.mli`

```

/* GLOBAL DATA */
struct t_System global_system;
int object_counter;
int global_argc;

/* Prototypes */
struct t_Object *allocate_for(size_t, ClassInfo *);
void *array_allocator(size_t, int);
struct t_Integer *integer_value(int);
struct t_Float *float_value(double);
struct t_Boolean *bool_value(unsigned char);
struct t_String *string_value(char *);
struct t_Boolean *boolean_init(struct t_Boolean *);
struct t_Integer *integer_init(struct t_Integer *);
struct t_Float *float_init(struct t_Float *);
struct t_Object *object_init(struct t_Object *);
struct t_String *string_init(struct t_String *);
struct t_Printer *printer_init(struct t_Printer *, struct
    t_Boolean *);
struct t_Scanner *scanner_init(struct t_Scanner *);
struct t_Integer *float_to_i(struct t_Float *);
struct t_Float *integer_to_f(struct t_Integer *);
struct t_Float *scanner_scan_float(struct t_Scanner *);
struct t_Integer *scanner_scan_integer(struct t_Scanner *);
struct t_String *scanner_scan_string(struct t_Scanner *);
void printer_print_float(struct t_Printer *, struct t_Float *);
void printer_print_integer(struct t_Printer *, struct t_Integer
    *);
void printer_print_string(struct t_Printer *, struct t_String *)
    ;
struct t_String **get_gamma_args(char **argv, int argc);


char *stack_overflow_getline(FILE *);

/* Functions! */

/* Magic allocator. DO NOT INVOKE THIS, USE MAKE_NEW(TYPE)
 * where type is not prefixed (i.e. MAKE_NEW(Integer) not
 * MAKE_NEW(t_Integer))
 */
struct t_Object *allocate_for(size_t s, ClassInfo *meta) {
```

```
41      struct t_Object *this = (struct t_Object *)(malloc(s));
42      if (!this) {
43          fprintf(stderr, "Could not even allocate memory. Exiting
        .\n");
44          exit(1);
45      }
46      this->meta = meta;
47      return this;
48  }
49
50  void *array_allocator(size_t size, int n) {
51      void *mem = malloc(size * n);
52      if (!mem) {
53          fprintf(stderr, "Failure allocating for array.  Exiting
        .\n");
54          exit(1);
55      }
56      memset(mem, 0, size * n);
57      return mem;
58  }
59
60  /* Make basic objects with the given values. */
61  struct t_Integer *integer_value(int in_i) {
62      struct t_Integer *i = MAKE_NEW(Integer);
63      i = integer_init(i);
64      i->Integer.value = in_i;
65      return i;
66  }
67
68  struct t_Float *float_value(double in_f) {
69      struct t_Float *f = MAKE_NEW(Float);
70      f = float_init(f);
71      f->Float.value = in_f;
72      return f;
73  }
74
75  struct t_Boolean *bool_value(unsigned char in_b) {
76      struct t_Boolean *b = MAKE_NEW(Boolean);
77      b = boolean_init(b);
78      b->Boolean.value = in_b;
79      return b;
80  }
81
82  struct t_String *string_value(char *s_in) {
83      size_t length = 0;
84      char *dup = NULL;
85      length = strlen(s_in) + 1;
86
87      struct t_String *s = MAKE_NEW(String);
88      s = string_init(s);
89      dup = malloc(sizeof(char) * length);
90      if (!dup) {
91          fprintf(stderr, "Out of memory in string_value.\n");
92          exit(1);
93      }
94      s->String.value = strcpy(dup, s_in);
95      return s;
```

```
96  }
97
98  struct t_Boolean *boolean_init(struct t_Boolean *this){
99      object_init((struct t_Object *)(this));
100     this->Boolean.value = 0;
101     return this;
102 }
103
104 struct t_Integer *integer_init(struct t_Integer *this){
105     object_init((struct t_Object *)(this));
106     this->Integer.value = 0;
107     return this;
108 }
109
110 struct t_Float *float_init(struct t_Float *this){
111     object_init((struct t_Object *)(this));
112     this->Float.value = 0.0;
113     return this;
114 }
115
116 struct t_Object *object_init(struct t_Object *this){
117     this->Object.v_system = &global_system;
118     return this;
119 }
120
121 struct t_String *string_init(struct t_String *this)
122 {
123     object_init((struct t_Object *)(this));
124     this->String.value = NULL;
125     return this;
126 }
127
128 struct t_System *system_init(struct t_System *this)
129 {
130     this->System.v_err = MAKE_NEW(Printer);
131     this->System.v_in = MAKE_NEW(Scanner);
132     this->System.v_out = MAKE_NEW(Printer);
133     this->System.v_argc = MAKE_NEW(Integer);
134
135     this->System.v_err->Printer.target = stderr;
136     this->System.v_in->Scanner.source = stdin;
137     this->System.v_out->Printer.target = stdout;
138     this->System.v_argc->Integer.value = global_argc;
139     this->Object.v_system =
140         this->System.v_err->Object.v_system =
141         this->System.v_in->Object.v_system =
142         this->System.v_out->Object.v_system =
143         this->System.v_argc->Object.v_system = this;
144     return this;
145 };
146
147 struct t_Printer *printer_init(struct t_Printer *this, struct
      t_Boolean *v_stdout)
148 {
149     object_init((struct t_Object *)(this));
150     this->Printer.target = v_stdout->Boolean.value ? stdout :
      stderr;
```

```
151     return this;
152 }
153 
154 struct t_Scanner *scanner_init(struct t_Scanner *this)
155 {
156     object_init((struct t_Object *)(this));
157     this->Scanner.source = stdin;
158 }
159 
160 struct t_Integer *float_to_i(struct t_Float *this){
161     return integer_value((int)(this->Float.value));
162 }
163 
164 struct t_Float *integer_to_f(struct t_Integer *this){
165     return float_value((double)(this->Integer.value));
166 }
167 
168 void toendl(FILE *in) {
169     int c = 0;
170     while (1) {
171       c = fgetc(in);
172       if (c == '\n' || c == '\r' || c == EOF) break;
173     }
174 }
175 
176 struct t_Float *scanner_scan_float(struct t_Scanner *this)
177 {
178     double dval;
179     fscanf(this->Scanner.source, "%lf", &dval);
180     toendl(this->Scanner.source);
181 
182     return float_value(dval);
183 }
184 
185 struct t_Integer *scanner_scan_integer(struct t_Scanner *this)
186 {
187     int ival;
188     fscanf(this->Scanner.source, "%d", &ival);
189     toendl(this->Scanner.source);
190     return integer_value(ival);
191 }
192 
193 struct t_String *scanner_scan_string(struct t_Scanner *this)
194 {
195     char *inpstr = NULL;
196     struct t_String *astring = NULL;
197 
198     inpstr = stack_overflow_getline(this->Scanner.source);
199     astring = string_value(inpstr);
200 
201     free(inpstr);
202     return astring;
203 }
204 
205 void printer_print_float(struct t_Printer *this, struct t_Float
        *v_arg)
206 {
```

```
207     fprintf(this->Printer.target, "%lf", v_arg->Float.value);
208 }
209
210 void printer_print_integer(struct t_Printer *this, struct
        t_Integer *v_arg)
211 {
212     fprintf(this->Printer.target, "%d", v_arg->Integer.value);
213 }
214
215 void printer_print_string(struct t_Printer *this, struct
        t_String *v_arg)
216 {
217     fprintf(this->Printer.target, "%s", v_arg->String.value);
218 }
219
220 void system_exit(struct t_System *this, struct t_Integer *v_code
        ) {
221     exit(INTEGER_OF(v_code));
222 }
223
224
225 struct t_String **get_gamma_args(char **argv, int argc) {
226     struct t_String **args = NULL;
227     int i = 0;
228
229     if (!argc) return NULL;
230     args = ONE_DIM_ALLOC(struct t_String *, argc);
231     for (i = 0; i < argc; ++i)
232         args[i] = string_value(argv[i]);
233     args[i] = NULL;
234
235     return args;
236 }
237
238
239
240 char *stack_overflow_getline(FILE *in) {
241     char * line = malloc(100), * linep = line;
242     size_t lenmax = 100, len = lenmax;
243     int c;
244
245     if(line == NULL)
246         return NULL;
247
248     for(;;) {
249         c = fgetc(in);
250         if(c == EOF)
251             break;
252
253         if(--len == 0) {
254             len = lenmax;
255             char * linen = realloc(linep, lenmax *= 2);
256
257             if(linen == NULL) {
258                 free(linep);
259                 return NULL;
260             }
```

```
            line = linen + (line - linep);
            linep = linen;
        }

        if((*line++ = c) == '\n')
            break;
    }
    *line = '\0';
    return linep;
}
```

Source 61: `headers/gamma-builtin-functions.h`

```
#include <stdarg.h>
#include <stdlib.h>
#include <stdio.h>

typedef struct {
        int generation;
        char* class;
        char** ancestors;
} ClassInfo;


ClassInfo M_Boolean;
ClassInfo M_Float;
ClassInfo M_Integer;
ClassInfo M_Object;
ClassInfo M_Printer;
ClassInfo M_Scanner;
ClassInfo M_String;
ClassInfo M_System;


/*
        Initializes the given ClassInfo
*/
void class_info_init(ClassInfo* meta, int num_args, ...) {

        int i;
        va_list objtypes;
        va_start(objtypes, num_args);

        meta->ancestors = malloc(sizeof(char *) * num_args);

        if (meta->ancestors == NULL) {
                printf("\nMemory error - class_info_init failed\
    n");
                exit(0);
        }
        for(i = 0; i < num_args; i++) {
                meta->ancestors[i] = va_arg(objtypes, char * );
        }
        meta->generation = num_args - 1;
        meta->class = meta->ancestors[meta->generation];
```

```
42          va_end(objtypes);
43  }
44
45
46  void init_built_in_infos() {
47      class_info_init(&M_Boolean, 2, m_classes[T_OBJECT],
        m_classes[T_BOOLEAN]);
48      class_info_init(&M_Float, 2, m_classes[T_OBJECT], m_classes[
        T_FLOAT]);
49      class_info_init(&M_Integer, 2, m_classes[T_OBJECT],m_classes
        [T_INTEGER]);
50      class_info_init(&M_Object, 1, m_classes[T_OBJECT]);
51      class_info_init(&M_Printer, 2, m_classes[T_OBJECT],m_classes
        [T_PRINTER]);
52      class_info_init(&M_Scanner, 2, m_classes[T_OBJECT],m_classes
        [T_SCANNER]);
53      class_info_init(&M_String, 2, m_classes[T_OBJECT],m_classes[
        T_STRING]);
54      class_info_init(&M_System, 2, m_classes[T_OBJECT],m_classes[
        T_SYSTEM]);
55  }
```

Source 62: `headers/gamma-builtin-meta.h`

```
1
2
3   /*
4    * Structures for each of the objects.
5    */
6   struct t_Boolean;
7   struct t_Float;
8   struct t_Integer;
9   struct t_Object;
10  struct t_Printer;
11  struct t_Scanner;
12  struct t_String;
13  struct t_System;
14
15
16  struct t_Boolean {
17      ClassInfo *meta;
18
19      struct {
20          struct t_System *v_system;
21      } Object;
22
23
24      struct { unsigned char value; } Boolean;
25  };
26
27
28  struct t_Float {
29      ClassInfo *meta;
30
31      struct {
```

```
32          struct t_System *v_system;
33      } Object;
34
35
36      struct { double value; } Float;
37  };
38
39
40  struct t_Integer {
41      ClassInfo *meta;
42
43      struct {
44          struct t_System *v_system;
45      } Object;
46
47
48      struct { int value; } Integer;
49  };
50
51
52  struct t_Object {
53      ClassInfo *meta;
54
55      struct {
56          struct t_System *v_system;
57      } Object;
58  };
59
60
61  struct t_Printer {
62      ClassInfo *meta;
63
64      struct {
65          struct t_System *v_system;
66      } Object;
67
68
69      struct { FILE *target; } Printer;
70  };
71
72
73  struct t_Scanner {
74      ClassInfo *meta;
75
76      struct {
77          struct t_System *v_system;
78      } Object;
79
80
81      struct { FILE *source; } Scanner;
82  };
83
84
85  struct t_String {
86      ClassInfo *meta;
87
88      struct {
```

```
89          struct t_System *v_system;
90      } Object;
91
92
93      struct { char *value; } String;
94  };
95
96
97  struct t_System {
98      ClassInfo *meta;
99
100     struct {
101         struct t_System *v_system;
102     } Object;
103
104
105     struct {
106         struct t_Printer *v_err;
107         struct t_Scanner *v_in;
108         struct t_Printer *v_out;
109         struct t_Integer *v_argc;
110     } System;
111 };
```

Source 63: `headers/gamma-builtin-struct.h`

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <string.h>
4   #include <math.h>
5
6   #define BYTE unsigned char
7
8   #define PROMOTE_INTEGER(ival)    integer_value((ival))
9   #define PROMOTE_FLOAT(fval)      float_value((fval))
10  #define PROMOTE_STRING(sval)     string_value((sval))
11  #define PROMOTE_BOOL(bval)       bool_value((bval))
12
13  #define LIT_INT(lit_int)         PROMOTE_INTEGER(lit_int)
14  #define LIT_FLOAT(lit_flt)       PROMOTE_FLOAT(lit_flt)
15  #define LIT_STRING(lit_str)      PROMOTE_STRING(lit_str)
16  #define LIT_BOOL(lit_bool)       PROMOTE_BOOL(lit_bool)
17
18  #define ADD_INT_INT(l, r)        PROMOTE_INTEGER(INTEGER_OF(l) +
        INTEGER_OF(r))
19  #define ADD_FLOAT_FLOAT(l, r)    PROMOTE_FLOAT(FLOAT_OF(l) +
        FLOAT_OF(r))
20  #define SUB_INT_INT(l, r)        PROMOTE_INTEGER(INTEGER_OF(l) -
        INTEGER_OF(r))
21  #define SUB_FLOAT_FLOAT(l, r)    PROMOTE_FLOAT(FLOAT_OF(l) -
        FLOAT_OF(r))
22  #define PROD_INT_INT(l, r)       PROMOTE_INTEGER(INTEGER_OF(l) *
        INTEGER_OF(r))
23  #define PROD_FLOAT_FLOAT(l, r)   PROMOTE_FLOAT(FLOAT_OF(l) *
        FLOAT_OF(r))
```

```
24 #define DIV_INT_INT(l, r)        PROMOTE_INTEGER(INTEGER_OF(l) /
       INTEGER_OF(r))
25 #define DIV_FLOAT_FLOAT(l, r)    PROMOTE_FLOAT(FLOAT_OF(l) /
       FLOAT_OF(r))
26 #define MOD_INT_INT(l, r)        PROMOTE_INTEGER(INTEGER_OF(l) %
       INTEGER_OF(r))
27 #define POW_INT_INT(l, r)        PROMOTE_INTEGER(( (int)pow(
       INTEGER_OF(l), INTEGER_OF(r)) ))
28 #define POW_FLOAT_FLOAT(l, r)    PROMOTE_FLOAT( pow(FLOAT_OF(l),
       FLOAT_OF(r)) )
29
30 #define MAKE_NEW2(type, meta) ((struct type *)(allocate_for(
       sizeof(struct type), &meta)))
31 #define MAKE_NEW(t_name) MAKE_NEW2(t_##t_name, M_##t_name)
32
33 #define CAST(type, v) ( (struct t_##type *)(v) )
34 #define VAL_OF(type, v) ( CAST(type, v)->type.value )
35 #define BOOL_OF(b)     VAL_OF(Boolean, b)
36 #define FLOAT_OF(f)    VAL_OF(Float, f)
37 #define INTEGER_OF(i) VAL_OF(Integer, i)
38 #define STRING_OF(s)  VAL_OF(String, s)
39
40 #define NEG_INTEGER(i)              PROMOTE_INTEGER(-INTEGER_OF(i)
       )
41 #define NEG_FLOAT(f)                PROMOTE_FLOAT(-FLOAT_OF(f))
42 #define NOT_BOOLEAN(b)              PROMOTE_BOOL(!BOOL_OF(b))
43
44 #define BINOP(type, op, l, r)      ( VAL_OF(type, l) op VAL_OF(
       type, r) )
45 #define PBINOP(type, op, l, r)     PROMOTE_BOOL(BINOP(type, op, l
       , r))
46 #define IBINOP(op, l, r)           PBINOP(Integer, op, l, r)
47 #define FBINOP(op, l, r)           PBINOP(Float, op, l, r)
48 #define BBINOP(op, l, r)           PBINOP(Boolean, op, l, r)
49
50 #define NTEST_EQ_INT_INT(l, r)     IBINOP(==, l, r)
51 #define NTEST_NEQ_INT_INT(l, r)    IBINOP(!=, l, r)
52 #define NTEST_LESS_INT_INT(l, r)   IBINOP(<, l, r)
53 #define NTEST_GRTR_INT_INT(l, r)   IBINOP(>, l, r)
54 #define NTEST_LEQ_INT_INT(l, r)    IBINOP(<=, l, r)
55 #define NTEST_GEQ_INT_INT(l, r)    IBINOP(>=, l, r)
56
57 #define NTEST_EQ_FLOAT_FLOAT(l, r)     FBINOP(==, l, r)
58 #define NTEST_NEQ_FLOAT_FLOAT(l, r)    FBINOP(!=, l, r)
59 #define NTEST_LESS_FLOAT_FLOAT(l, r)   FBINOP(<, l, r)
60 #define NTEST_GRTR_FLOAT_FLOAT(l, r)   FBINOP(>, l, r)
61 #define NTEST_LEQ_FLOAT_FLOAT(l, r)    FBINOP(<=, l, r)
62 #define NTEST_GEQ_FLOAT_FLOAT(l, r)    FBINOP(>=, l, r)
63
64 #define CTEST_AND_BOOL_BOOL(l, r)    BBINOP(&&, l, r)
65 #define CTEST_OR_BOOL_BOOL(l, r)     BBINOP(||, l, r)
66 #define CTEST_NAND_BOOL_BOOL(l, r)   PROMOTE_BOOL(( !(BOOL_OF(l)
       && BOOL_OF(r)) ))
67 #define CTEST_NOR_BOOL_BOOL(l, r)    PROMOTE_BOOL(( !(BOOL_OF(l)
       || BOOL_OF(r)) ))
68 #define CTEST_XOR_BOOL_BOOL(l, r)    PROMOTE_BOOL((!BOOL_OF(l) !=
        !BOOL_OF(r)))
```

```

#define IS_CLASS(obj, kname) ( strcmp((obj)->meta->ancestors[obj
    ->meta->generation], (kname)) == 0 )

#define ONE_DIM_ALLOC(type, len) ((type *) array_allocator(
    sizeof(type), (len)))

#define INIT_MAIN(options) \
struct t_String **str_args = NULL; \
char *gmain = NULL; \
--argc; ++argv; \
if (!argc) { \
    fprintf(stderr, "Please select a main to use.  Available
    options: " options "\n"); \
    exit(1); \
} \
gmain = *argv; ++argv; --argc; \
init_class_infos(); \
global_argc = argc; \
system_init(&global_system); \
str_args = get_gamma_args(argv, argc);


#define FAIL_MAIN(options) \
fprintf(stderr, "None of the available options were selected.
    Options were: " options "\n"); \
exit(1);

#define REFINE_FAIL(parent) \
    fprintf(stderr, "Refinement fail: " parent "\n"); \
    exit(1);
```

Source 64: `headers/gamma-preamble.h`

```

(** Types for the semantic abstract syntax tree *)

(** A switch for refinment or refinable checks *)
type refine_switch =
    | Switch of string * (string * string) list * string (* host
     class,  class/best-uid list, switch uid *)
    | Test of string * string list * string  (* host class,
    class list, uid of switch *)

(** The type of a variable in the environment *)
type varkind = Instance of string | Local

(** The environment at any given statement. *)
type environment = (string * varkind) Map.Make(String).t

(** The ID can be built in (and so won't get mangled) or an
    array allocator. *)
type funcid = BuiltIn of string | FuncId of string | ArrayAlloc
    of string

```

```
18  (** An expression value -- like in AST *)
19  type expr_detail =
20      | This
21      | Null
22      | Id of string
23      | NewObj of string * expr list * funcid
24      | Anonymous of string * expr list * Ast.func_def list (*
        Evaluation is delayed *)
25      | Literal of Ast.lit
26      | Assign of expr * expr  (* memory := data -- whether memory
         is good is a semantic issue *)
27      | Deref of expr * expr (* road[pavement] *)
28      | Field of expr * string (* road.pavement *)
29      | Invoc of expr * string * expr list * funcid (* receiver.
        method(args) * bestmethod_uid  *)
30      | Unop of Ast.op * expr (* !x *)
31      | Binop of expr * Ast.op * expr (* x + y *)
32      | Refine of string * expr list * string option *
        refine_switch (* refinement, arg list, opt ret type, switch
        *)
33      | Refinable of string * refine_switch (* desired refinement,
         list of classes supporting refinement *)
34
35  (** An expression with a type tag *)
36  and expr = string * expr_detail
37
38  (** A statement tagged with an environment *)
39  and sstmt =
40      | Decl of Ast.var_def * expr option * environment
41      | If of (expr option * sstmt list) list * environment
42      | While of expr * sstmt list * environment
43      | Expr of expr * environment
44      | Return of expr option * environment
45      | Super of expr list * string * string * environment (**
        arglist, uidof super init, superclass, env**)
46
47  (** A function definition *)
48  and func_def = {
49      returns : string option;
50      host    : string option;
51      name    : string;
52      static  : bool;
53      formals : Ast.var_def list;
54      body    : sstmt list;
55      section : Ast.class_section;  (* Makes things easier later
        *)
56      inklass : string;
57      uid     : string;
58      builtin : bool;
59  }
60
61  (* A member is either a variable or some sort of function *)
62  type member_def = VarMem of Ast.var_def | MethodMem of func_def
        | InitMem of func_def
63
64  (* Things that can go in a class *)
65  type class_sections_def = {
```

```
    privates : member_def list;
    protects : member_def list;
    publics  : member_def list;
    refines  : func_def list;
    mains    : func_def list;
}

(* Just pop init and main in there? *)
type class_def = {
    klass    : string;
    parent   : string option;
    sections : class_sections_def;
}

type program = class_def list
```

Source 65: `Sast.mli`

```
open StringModules

(* The detail of an expression *)
type cexpr_detail =
    | This
    | Null
    | Id of string * Sast.varkind (* name, local/instance *)
    | NewObj of string * string * cexpr list (* ctype * fname *
    args *)
    | NewArr of string * string * cexpr list (* type (with []'s)
     * fname * args (sizes) *)
    | Literal of Ast.lit
    | Assign of cexpr * cexpr  (* memory := data -- whether
    memory is good is a semantic issue *)
    | Deref of cexpr * cexpr (* road[pavement] *)
    | Field of cexpr * string (* road.pavement *)
    | Invoc of cexpr * string * cexpr list (*Invoc(receiver,
    functionname, args) *)
    | Unop of Ast.op * cexpr (* !x *)
    | Binop of cexpr * Ast.op * cexpr (* x + y *)
    | Refine of cexpr list * string option * Sast.refine_switch
    (* arg list, opt ret type, switch list (class, uids) *)
    | Refinable of Sast.refine_switch (* list of classes
    supporting refinement *)

(* The expression and its type *)
and cexpr = string * cexpr_detail

(* A statement which has cexpr detail *)
and cstmt =
    | Decl of Ast.var_def * cexpr option * Sast.environment
    | If of (cexpr option * cstmt list) list * Sast.environment
    | While of cexpr * cstmt list * Sast.environment
    | Expr of cexpr * Sast.environment
    | Super of string * string * cexpr list (* class, fuid, args
     *)
    | Return of cexpr option * Sast.environment
```

```
31
32  (* A c func is a simplified function (no host, etc) *)
33  and cfunc = {
34      returns : string option;
35      name    : string;  (* Combine uid and name into this *)
36      formals : Ast.var_def list;
37      body    : cstmt list;
38      builtin : bool;
39      inklass : string; (* needed for THIS *)
40      static  : bool;
41  }
42
43  (* The bare minimum for a struct represention *)
44  type class_struct = (string * Ast.var_def list) list (* All the
        data for this object from the root (first item) down, paired
        with class name *)
45
46  (* A main is a class name and a function name for that main *)
47  type main_func = (string * string)
48
49  (* We actually need all the ancestry information, cause we're
        gonna do it the right way [lists should go from object down]
        *)
50  type ancestry_info = (string list) lookup_map
51
52  (* A program is a map from all classes to their struct's, a list
        of all functions, and a list of mainfuncs, and ancestor
        information *)
53  type program = class_struct lookup_map * cfunc list * main_func
        list * ancestry_info
```

Source 66: `Cast.mli`

```
1   #!/bin/bash
2
3   function errwith {
4     echo "$1" >&2
5     exit 1
6   }
7
8   function run_file {
9     test "$#" -lt 1 && errwith "Please give a file to test"
10    file=$1
11
12    test -e "$file" || errwith "File $file does not exist."
13    test -f "$file" || errwith "File $file is not a file."
14
15    echo "
        ================================================================
        "
16    echo "
        ================================================================
        "
17    echo "$file"
18    cat "$file"
```

```
  echo "
    ==========
    "
  echo "
    ==========
    "
  ./bin/ray "$file" > ctest/test.c && ( cd ctest && ./compile &&
     ./a.out Test )
}

for afile in "${@}" ; do
  run_file "$afile"
done
```

Source 67: `run-compiler-test.sh`

```
open Ast

(** Various utility functions *)

(* Types *)
(**
    Paramaterized variable typing for building binary ASTs
    @see <http://caml.inria.fr/pub/docs/oreilly-book/html/book-
    ora016.html#toc19> For more details on paramterized typing
*)
type ('a, 'b) either = Left of 'a | Right of 'b

(** Split a list of 'a 'b either values into a pair of 'a list
    and 'b list *)
let either_split eithers =
    let rec split_eithers (left, right) = function
        | [] -> (List.rev left, List.rev right)
        | (Left(a))::rest -> split_eithers (a::left, right) rest
        | (Right(b))::rest -> split_eithers (left, b::right)
    rest in
    split_eithers ([], []) eithers

(** Reduce a list of options to the values in the Some
    constructors *)
let filter_option list =
    let rec do_filter rlist = function
        | [] -> List.rev rlist
        | None::tl -> do_filter rlist tl
        | (Some(v))::tl -> do_filter (v::rlist) tl in
    do_filter [] list

let option_as_list = function
    | Some(v) -> [v]
    | _ -> []

let decide_option x = function
    | true -> Some(x)
    | _ -> None

```

```
(** Lexically compare two lists of comparable items *)
let rec lexical_compare list1 list2 = match list1, list2 with
    | [], [] -> 0
    | [], _  -> -1
    | _, []  -> 1
    | (x::xs), (y::ys) -> if x < y then -1 else if x > y then 1
    else lexical_compare xs ys

(**
    Loop through a list and find all the items that are minimum
    with respect to the total
    ordering cmp. (If an item is found to be a minimum, any item
     that is found to
    be equal to the item is in the returned list.) Note can
    return any size list.
    @param cmp A comparator function
    @param alist A list of items
    @return A list of one or more items deemed to be the minimum
     by cmp.
*)
let find_all_min cmp alist =
    let rec min_find found items = match found, items with
        | _, [] -> List.rev found (* Return in the same order at
     least *)
        | [], i::is -> min_find [i] is
        | (f::fs), (i::is) -> let result = cmp i f in
            if result = 0 then min_find (i::found) is
            else if result < 0 then min_find [i] is
            else min_find found is in
    min_find [] alist

(**
    Either monad stuffage
    @param value A monad
    @param func A function to run on a monad
    @return The result of func if we're on the left side, or the
     error if we're on the right
*)
let (|->) value func =
    match value with
        | Left(v) -> func(v)
        | Right(problem) -> Right(problem)

(** Sequence a bunch of monadic actions together, piping results
     together *)
let rec seq init actions = match init, actions with
    | Right(issue), _ -> Right(issue)
    | Left(data), [] -> Left(data)
    | Left(data), act::ions -> seq (act data) ions

(**
    Return the length of a block -- i.e. the total number of
    statements (recursively) in it
    @param stmt_list A list of stmt type objects
    @return An int encoding the length of a block
*)
let get_statement_count stmt_list =
```

```
    let rec do_count stmts blocks counts = match stmts, blocks
    with
        | [], [] -> counts
        | [], _  -> do_count blocks [] counts
        | (stmt::rest), _ -> match stmt with
            | Decl(_) -> do_count rest blocks (counts + 1)
            | Expr(_) -> do_count rest blocks (counts + 1)
            | Return(_) -> do_count rest blocks (counts + 1)
            | Super(_) -> do_count rest blocks (counts + 1)
            | While(_, block) -> do_count rest (block @ blocks)
    (counts + 1)
            | If(parts) ->
                let ifblocks = List.map snd parts in
                let ifstmts = List.flatten ifblocks in
                do_count rest (ifstmts @ blocks) (counts + 1) in
    do_count stmt_list [] 0
```

Source 68: `Util.ml`

```
open Parser
open Ast

(** Provides functionality for examining values used in the
    compilation pipeline. *)

(* TOKEN stuff *)
(** Convert a given token to a string representation for output
    *)
let token_to_string = function
    | SPACE(n) -> "SPACE(" ^ string_of_int n ^ ")"
    | COLON -> "COLON"
    | NEWLINE -> "NEWLINE"
    | THIS -> "THIS"
    | ARRAY -> "ARRAY"
    | REFINABLE -> "REFINABLE"
    | AND -> "AND"
    | OR -> "OR"
    | XOR -> "XOR"
    | NAND -> "NAND"
    | NOR -> "NOR"
    | NOT -> "NOT"
    | EQ -> "EQ"
    | NEQ -> "NEQ"
    | LT -> "LT"
    | LEQ -> "LEQ"
    | GT -> "GT"
    | GEQ -> "GEQ"
    | LBRACKET -> "LBRACKET"
    | RBRACKET -> "RBRACKET"
    | LPAREN -> "LPAREN"
    | RPAREN -> "RPAREN"
    | LBRACE -> "LBRACE"
    | RBRACE -> "RBRACE"
    | SEMI -> "SEMI"
    | COMMA -> "COMMA"
```

```
35      | PLUS -> "PLUS"
36      | MINUS -> "MINUS"
37      | TIMES -> "TIMES"
38      | DIVIDE -> "DIVIDE"
39      | MOD -> "MOD"
40      | POWER -> "POWER"
41      | PLUSA -> "PLUSA"
42      | MINUSA -> "MINUSA"
43      | TIMESA -> "TIMESA"
44      | DIVIDEA -> "DIVIDEA"
45      | MODA -> "MODA"
46      | POWERA -> "POWERA"
47      | IF -> "IF"
48      | ELSE -> "ELSE"
49      | ELSIF -> "ELSIF"
50      | WHILE -> "WHILE"
51      | RETURN -> "RETURN"
52      | CLASS -> "CLASS"
53      | EXTEND -> "EXTEND"
54      | SUPER -> "SUPER"
55      | INIT -> "INIT"
56      | NULL -> "NULL"
57      | VOID -> "VOID"
58      | REFINE -> "REFINE"
59      | REFINES -> "REFINES"
60      | TO -> "TO"
61      | PRIVATE -> "PRIVATE"
62      | PUBLIC -> "PUBLIC"
63      | PROTECTED -> "PROTECTED"
64      | DOT -> "DOT"
65      | MAIN -> "MAIN"
66      | NEW -> "NEW"
67      | ASSIGN -> "ASSIGN"
68      | ID(vid) -> Printf.sprintf "ID(%s)" vid
69      | TYPE(tid) -> Printf.sprintf "TYPE(%s)" tid
70      | BLIT(bool) -> Printf.sprintf "BLIT(%B)" bool
71      | ILIT(inum) -> Printf.sprintf "ILIT(%d)" inum
72      | FLIT(fnum) -> Printf.sprintf "FLIT(%f)" fnum
73      | SLIT(str) -> Printf.sprintf "SLIT(\"%s\")" (str)
74      | EOF -> "EOF"
75
76  (** Convert token to its (assumed) lexographical source *)
77  let descan = function
78      | COLON -> ":"
79      | NEWLINE -> "\n"
80      | SPACE(n) -> String.make n ' '
81      | REFINABLE -> "refinable"
82      | AND -> "and"
83      | OR -> "or"
84      | XOR -> "xor"
85      | NAND -> "nand"
86      | NOR -> "nor"
87      | NOT -> "not"
88      | EQ -> "="
89      | NEQ -> "=/="
90      | LT -> "<"
91      | LEQ -> "<="
```

```
92        | GT -> ">"
93        | GEQ -> ">="
94        | ARRAY -> "[]"
95        | LBRACKET -> "["
96        | RBRACKET -> "]"
97        | LPAREN -> "("
98        | RPAREN -> ")"
99        | LBRACE -> "{"
100       | RBRACE -> "}"
101       | SEMI -> ";"
102       | COMMA -> ","
103       | PLUS -> "+"
104       | MINUS -> "-"
105       | TIMES -> "*"
106       | DIVIDE -> "/"
107       | MOD -> "%"
108       | POWER -> "^"
109       | PLUSA -> "+="
110       | MINUSA -> "-="
111       | TIMESA -> "*="
112       | DIVIDEA -> "/="
113       | MODA -> "%="
114       | POWERA -> "^="
115       | IF -> "if"
116       | ELSE -> "else"
117       | ELSIF -> "elsif"
118       | WHILE -> "while"
119       | RETURN -> "return"
120       | CLASS -> "class"
121       | EXTEND -> "extends"
122       | SUPER -> "super"
123       | INIT -> "init"
124       | NULL -> "null"
125       | VOID -> "void"
126       | THIS -> "this"
127       | REFINE -> "refine"
128       | REFINES -> "refinement"
129       | TO -> "to"
130       | PRIVATE -> "private"
131       | PUBLIC -> "public"
132       | PROTECTED -> "protected"
133       | DOT -> "."
134       | MAIN -> "main"
135       | NEW -> "new"
136       | ASSIGN -> ":="
137       | ID(var) -> var
138       | TYPE(typ) -> typ
139       | BLIT(b) -> if b then "true" else "false"
140       | ILIT(i) -> string_of_int(i)
141       | FLIT(f) -> string_of_float(f)
142       | SLIT(s) -> Format.sprintf "\"%s\"" s
143       | EOF -> "eof"
144
145   (**
146       Given a lexing function and a lexing buffer, consume tokesn
          until
147       the end of file is reached. Return the generated tokens.
```

```
148     @param lexfun A function that takes a lexbuf and returns a
        token
149     @param lexbuf A lexographical buffer from Lexing
150     @return A list of scanned tokens
151   *)
152 let token_list (lexfun : Lexing.lexbuf -> token) (lexbuf :
        Lexing.lexbuf) =
153     let rec list_tokens rtokens =
154         match (lexfun lexbuf) with
155             | EOF -> List.rev (EOF::rtokens)
156             | tk -> list_tokens (tk::rtokens) in
157     list_tokens []
158
159 (**
160     Scan a list of tokens from an input file.
161     @param source A channel to get tokens from
162     @return A list of tokens taken from a source
163   *)
164 let from_channel source = token_list Scanner.token (Lexing.
        from_channel source)
165
166 (**
167     Print a list of tokens to stdout.
168     @param tokens A list of tokens
169     @return Only returns a unit
170   *)
171 let print_token_list tokens = print_string (String.concat " " (
        List.map token_to_string tokens))
172
173 (**
174     Used to print out de-whitespacing lines which consist of a
        number (indentation), a list
175     of tokens (the line), and whether there is a colon at the
        end of the line.
176     @return Only returns a unit
177   *)
178 let print_token_line = function
179     | (space, toks, colon) ->
180         print_string ("(" ^ string_of_int space ^ "," ^
        string_of_bool colon ^ ") ");
181         print_token_list toks
182
183 (**
184     Print out a list of tokens with a specific header and some
        extra margins
185     @param header A nonsemantic string to preface our list
186     @param toks A list of tokens
187     @return Only returns a unit
188   *)
189 let pprint_token_list header toks = print_string header ;
        print_token_list toks ; print_newline ()
190
191 (**
192     Print out de-whitespacing lines (see print_token_line) for
        various lines, but with a header.
193     @param header A nonsemantic string to preface our list
194     @param lines A list of line representations (number of
```

```
    spaces, if it ends in a colon, a list of tokens)
    @return Only returns a unit
  *)
let pprint_token_lines header lines =
    let spaces = String.make (String.length header) ' ' in
    let rec lines_printer prefix = function
        | line::rest ->
            print_string prefix;
            print_token_line line;
            print_newline ();
            lines_printer spaces rest
        | [] -> () in
    lines_printer header lines

(** The majority of the following functions are relatively
    direct AST to string operations *)

(* Useful for both sAST and AST *)
let _id x = x
let inspect_str_list stringer a_list = Printf.sprintf "[%s]" (
    String.concat ", " (List.map stringer a_list))
let inspect_opt stringer = function
    | None -> "None"
    | Some(v) -> Printf.sprintf "Some(%s)" (stringer v)

(* AST Parser Stuff *)
let inspect_ast_lit (lit : Ast.lit) = match lit with
    | Int(i)    -> Printf.sprintf "Int(%d)" i
    | Float(f)  -> Printf.sprintf "Float(%f)" f
    | String(s) -> Printf.sprintf "String(\"%s\")" s
    | Bool(b)   -> Printf.sprintf "Bool(%B)" b

let inspect_ast_arith (op : Ast.arith) = match op with
    | Add  -> "Add"
    | Sub  -> "Sub"
    | Prod -> "Prod"
    | Div  -> "Div"
    | Mod  -> "Mod"
    | Neg  -> "Neg"
    | Pow  -> "Pow"

let inspect_ast_numtest (op : Ast.numtest) = match op with
    | Eq   -> "Eq"
    | Neq  -> "Neq"
    | Less -> "Less"
    | Grtr -> "Grtr"
    | Leq  -> "Leq"
    | Geq  -> "Geq"

let inspect_ast_combtest (op : Ast.combtest) = match op with
    | And  -> "And"
    | Or   -> "Or"
    | Nand -> "Nand"
    | Nor  -> "Nor"
    | Xor  -> "Xor"
    | Not  -> "Not"

```

```
249 let inspect_ast_op (op : Ast.op) = match op with
250     | Arithmetic(an_op) -> Printf.sprintf "Arithmetic(%s)" (
        inspect_ast_arith an_op)
251     | NumTest(an_op)    -> Printf.sprintf "NumTest(%s)" (
        inspect_ast_numtest an_op)
252     | CombTest(an_op)   -> Printf.sprintf "CombTest(%s)" (
        inspect_ast_combtest an_op)
253
254 let rec inspect_ast_expr (expr : Ast.expr) = match expr with
255     | Id(id) -> Printf.sprintf "Id(%s)" id
256     | This -> "This"
257     | Null -> "Null"
258     | NewObj(the_type, args) -> Printf.sprintf("NewObj(%s, %s)")
         the_type (inspect_str_list inspect_ast_expr args)
259     | Anonymous(the_type, args, body) -> Printf.sprintf("
        Anonymous(%s, %s, %s)") the_type (inspect_str_list
        inspect_ast_expr args) (inspect_str_list
        inspect_ast_func_def body)
260     | Literal(l) -> Printf.sprintf "Literal(%s)" (
        inspect_ast_lit l)
261     | Invoc(receiver, meth, args) -> Printf.sprintf "Invocation
        (%s, %s, %s)" (inspect_ast_expr receiver) meth (
        inspect_str_list inspect_ast_expr args)
262     | Field(receiver, field) -> Printf.sprintf "Field(%s, %s)" (
        inspect_ast_expr receiver) field
263     | Deref(var, index) -> Printf.sprintf "Deref(%s, %s)" (
        inspect_ast_expr var) (inspect_ast_expr var)
264     | Unop(an_op, exp) -> Printf.sprintf "Unop(%s, %s)" (
        inspect_ast_op an_op) (inspect_ast_expr exp)
265     | Binop(left, an_op, right) -> Printf.sprintf "Binop(%s, %s,
         %s)" (inspect_ast_op an_op) (inspect_ast_expr left) (
        inspect_ast_expr right)
266     | Refine(fname, args, totype) -> Printf.sprintf "Refine(%s,%
        s,%s)" fname (inspect_str_list inspect_ast_expr args) (
        inspect_opt _id totype)
267     | Assign(the_var, the_expr) -> Printf.sprintf "Assign(%s, %s
        )" (inspect_ast_expr the_var) (inspect_ast_expr the_expr)
268     | Refinable(the_var) -> Printf.sprintf "Refinable(%s)"
        the_var
269 and inspect_ast_var_def (var : Ast.var_def) = match var with
270     | (the_type, the_var) -> Printf.sprintf "(%s, %s)" the_type
        the_var
271 and inspect_ast_stmt (stmt : Ast.stmt) = match stmt with
272     | Decl(the_def, the_expr) -> Printf.sprintf "Decl(%s, %s)" (
        inspect_ast_var_def the_def) (inspect_opt inspect_ast_expr
        the_expr)
273     | If(clauses) -> Printf.sprintf "If(%s)" (inspect_str_list
        inspect_ast_clause clauses)
274     | While(pred, body) -> Printf.sprintf "While(%s, %s)" (
        inspect_ast_expr pred) (inspect_str_list inspect_ast_stmt
        body)
275     | Expr(the_expr) -> Printf.sprintf "Expr(%s)" (
        inspect_ast_expr the_expr)
276     | Return(the_expr) -> Printf.sprintf "Return(%s)" (
        inspect_opt inspect_ast_expr the_expr)
277     | Super(args) -> Printf.sprintf "Super(%s)" (
        inspect_str_list inspect_ast_expr args)
```

```
278 and inspect_ast_clause ((opt_expr, body) : Ast.expr option * Ast
        .stmt list) =
279     Printf.sprintf "(%s, %s)" (inspect_opt inspect_ast_expr
        opt_expr) (inspect_str_list inspect_ast_stmt body)
280 and inspect_ast_class_section (sect : Ast.class_section) = match
         sect with
281     | Publics  -> "Publics"
282     | Protects -> "Protects"
283     | Privates -> "Privates"
284     | Refines  -> "Refines"
285     | Mains    -> "Mains"
286 and inspect_ast_func_def (func : Ast.func_def) =
287     Printf.sprintf "{ returns = %s, host = %s, name = %s, static
        = %B, formals = %s, body = %s, section = %s, inklass = %s,
        uid = %s }"
288     (inspect_opt _id func.returns)
289     (inspect_opt _id func.host)
290     func.name
291     func.static
292     (inspect_str_list inspect_ast_var_def func.formals)
293     (inspect_str_list inspect_ast_stmt func.body)
294     (inspect_ast_class_section func.section)
295     func.inklass
296     func.uid
297
298 let inspect_ast_member_def (mem : Ast.member_def) = match mem
        with
299     | VarMem(vmem) -> Printf.sprintf "VarMem(%s)" (
        inspect_ast_var_def vmem)
300     | MethodMem(mmem) -> Printf.sprintf "MethodMem(%s)" (
        inspect_ast_func_def mmem)
301     | InitMem(imem) -> Printf.sprintf "InitMem(%s)" (
        inspect_ast_func_def imem)
302
303 let inspect_ast_class_sections (sections : Ast.
        class_sections_def) =
304     Printf.sprintf "{ privates = %s, protects = %s, publics = %s
        , refines = %s, mains = %s }"
305     (inspect_str_list inspect_ast_member_def sections.privates)
306     (inspect_str_list inspect_ast_member_def sections.protects)
307     (inspect_str_list inspect_ast_member_def sections.publics)
308     (inspect_str_list inspect_ast_func_def sections.refines)
309     (inspect_str_list inspect_ast_func_def sections.mains)
310
311 let inspect_ast_class_def (the_klass : Ast.class_def) =
312     Printf.sprintf "{ klass = %s, parent = %s, sections = %s }"
313     the_klass.klass
314     (inspect_opt _id the_klass.parent)
315     (inspect_ast_class_sections the_klass.sections)
```

Source 69: `Inspector.ml`

```
1 open Util
2
3 module StringSet = Set.Make(String)
```

```
module StringMap = Map.Make(String)

(** A place for StringSet and StringMap to live. *)

(**
    Convenience type to make reading table types easier. A
    lookup_table
    is a primary key -> second key -> value map (i.e. the values
     of the
    first StringMap are themselves StringMap maps...
  *)
type 'a lookup_table = 'a StringMap.t StringMap.t

(**
    Convenience type to make reading string maps easier. A
    lookup_map
    is just a StringMap map.
  *)
type 'a lookup_map = 'a StringMap.t


(** Print the contents of a lookup_map *)
let print_lookup_map map stringer =
    let print_item (secondary, item) =
        print_string (stringer secondary item) in
    List.iter print_item (StringMap.bindings map)

(** Print the contents of a lookup_table *)
let print_lookup_table table stringer =
    let print_lookup_map (primary, table) =
        print_lookup_map table (stringer primary) in
    List.iter print_lookup_map (StringMap.bindings table)


(**
    To put it into symbols, we have builder : (StringMap,
    errorList) -> item -> (StringMap', errorList')
    @param builder A function that accepts a StringMap/(error
    list) pair and a new item
    and returns a new pair with either and updated map or
    updated error list
    @param alist The list of data to build the map out of.
  *)
let build_map_track_errors builder alist =
    match List.fold_left builder (StringMap.empty, []) alist
    with
        | (value, []) -> Left(value)
        | (_, errors) -> Right(errors)

(**
    Look a value up in a map
    @param key The key to look up
    @param map The map to search in
    @return Some(value) or None
  *)
let map_lookup key map = if StringMap.mem key map
    then Some(StringMap.find key map)
```

```
54      else None
55
56  (**
57      Look a list up in a map
58      @param key The key to look up
59      @param map The map to search in
60      @return a list or None
61    *)
62  let map_lookup_list key map = if StringMap.mem key map
63      then StringMap.find key map
64      else []
65
66  (** Updating a string map that has list of possible values *)
67  let add_map_list key value map =
68      let old = map_lookup_list key map in
69      StringMap.add key (value::old) map
70
71  (** Updating a string map that has a list of possible values
        with a bunch of new values *)
72  let concat_map_list key values map =
73      let old = map_lookup_list key map in
74      StringMap.add key (values@old) map
75
76  (** Update a map but keep track of collisions *)
77  let add_map_unique key value (map, collisions) =
78      if StringMap.mem key map
79          then (map, key::collisions)
80          else (StringMap.add key value map, collisions)
```

Source 70: `StringModules.ml`

```
1   val token_to_string : Parser.token -> string
2   val descan : Parser.token -> string
3   val token_list : (Lexing.lexbuf -> Parser.token) -> Lexing.
        lexbuf -> Parser.token list
4   val from_channel : Pervasives.in_channel -> Parser.token list
5   val pprint_token_list : string -> Parser.token list -> unit
6   val pprint_token_lines : string -> (int * Parser.token list *
        bool) list -> unit
7   val inspect_ast_lit : Ast.lit -> string
8   val inspect_ast_arith : Ast.arith -> string
9   val inspect_ast_numtest : Ast.numtest -> string
10  val inspect_ast_combtest : Ast.combtest -> string
11  val inspect_ast_op : Ast.op -> string
12  val inspect_ast_expr : Ast.expr -> string
13  val inspect_ast_var_def : Ast.var_def -> string
14  val inspect_ast_stmt : Ast.stmt -> string
15  val inspect_ast_clause : Ast.expr option * Ast.stmt list ->
        string
16  val inspect_ast_class_section : Ast.class_section -> string
17  val inspect_ast_func_def : Ast.func_def -> string
18  val inspect_ast_member_def : Ast.member_def -> string
19  val inspect_ast_class_sections : Ast.class_sections_def ->
        string
20  val inspect_ast_class_def : Ast.class_def -> string
```

Source 71: `Inspector.mli`

```
let _ =
    let tokens = Inspector.from_channel stdin in
    let classes = Parser.cdecls (WhiteSpace.lextoks tokens) (Lexing.from_string "") in
    let inspect_classes = List.map Inspector.inspect_ast_class_def classes in
    print_string (String.concat "\n\n" inspect_classes);
    print_newline ()
```

Source 72: `inspect.ml`

```
open Parser
open Ast

(**
    A collection of pretty printing functions.
    I don't believe it actually needs the Parser dependency.
    Should probably absorb a fair margin from other files like Inspector.ml
  *)

let indent level = String.make (level*2) ' '
let _id x = x

let pp_lit = function
    | Int(i)    -> Printf.sprintf "Int(%d)" i
    | Float(f)  -> Printf.sprintf "Float(%f)" f
    | String(s) -> Printf.sprintf "String(%s)" s
    | Bool(b)   -> Printf.sprintf "Bool(%B)" b

let pp_arith = function
    | Add  -> "Add"
    | Sub  -> "Sub"
    | Prod -> "Prod"
    | Div  -> "Div"
    | Mod  -> "Mod"
    | Neg  -> "Neg"
    | Pow  -> "Pow"

let pp_numtest = function
    | Eq   -> "Eq"
    | Neq  -> "Neq"
    | Less -> "Less"
    | Grtr -> "Grtr"
    | Leq  -> "Leq"
    | Geq  -> "Geq"

let pp_combtest = function
    | And  -> "And"
```

```
38      | Or    -> "Or"
39      | Nand -> "Nand"
40      | Nor   -> "Nor"
41      | Xor   -> "Xor"
42      | Not   -> "Not"
43
44  let pp_op = function
45      | Arithmetic(an_op) -> Printf.sprintf "Arithmetic(%s)" (
        pp_arith an_op)
46      | NumTest(an_op)    -> Printf.sprintf "NumTest(%s)" (
        pp_numtest an_op)
47      | CombTest(an_op)   -> Printf.sprintf "CombTest(%s)" (
        pp_combtest an_op)
48
49  let pp_str_list stringer a_list depth = Printf.sprintf "[ %s ]"
        (String.concat ", " (List.map stringer a_list))
50  let pp_opt stringer = function
51      | None -> "None"
52      | Some(v) -> Printf.sprintf "Some(%s)" (stringer v)
53
54  let rec pp_expr depth = function
55      | Id(id) -> Printf.sprintf "Id(%s)" id
56      | This -> "This"
57      | Null -> "Null"
58      | NewObj(the_type, args) -> Printf.sprintf("\n%sNewObj(%s, %
        s)") (indent depth) the_type (pp_str_list (pp_expr depth)
        args depth)
59      | Anonymous(the_type, args, body) -> Printf.sprintf("\n%
        sAnonymous(%s, %s, %s)") (indent depth) the_type (
        pp_str_list (pp_expr depth) args depth) (pp_str_list (
        pp_func_def depth) body depth)
60      | Literal(l) -> Printf.sprintf "\n%sLiteral(%s)" (indent
        depth) (pp_lit l)
61      | Invoc(receiver, meth, args) -> Printf.sprintf "\n%
        sInvocation(%s, %s, %s)" (indent depth) ((pp_expr (depth+1))
         receiver) meth (pp_str_list (pp_expr (depth+1)) args depth)
62      | Field(receiver, field) -> Printf.sprintf "\n%sField(%s, %s
        )" (indent depth) ((pp_expr depth) receiver) field
63      | Deref(var, index) -> Printf.sprintf "\n%sDeref(%s, %s)" (
        indent depth) ((pp_expr depth) var) ((pp_expr depth) var)
64      | Unop(an_op, exp) -> Printf.sprintf "\n%sUnop(%s, %s)" (
        indent depth) (pp_op an_op) ((pp_expr depth) exp)
65      | Binop(left, an_op, right) -> Printf.sprintf "\n%sBinop(%s,
         %s, %s)" (indent depth) (pp_op an_op) ((pp_expr depth) left
        ) ((pp_expr depth) right)
66      | Refine(fname, args, totype) -> Printf.sprintf "Refine(%s,
        %s, %s)" fname (pp_str_list (pp_expr (depth+1)) args (depth
        +1)) (pp_opt _id  totype)
67      | Assign(the_var, the_expr) -> Printf.sprintf "\n%sAssign(%s
        , %s)" (indent depth) ((pp_expr (depth+1)) the_var) ((
        pp_expr (depth+1)) the_expr)
68      | Refinable(the_var) -> Printf.sprintf "\n%sRefinable(%s)" (
        indent depth) the_var
69  and pp_var_def depth (the_type, the_var) = Printf.sprintf "\n%s
        (%s, %s)" (indent depth) the_type the_var
70  and pp_stmt depth = function
71      | Decl(the_def, the_expr) -> Printf.sprintf "\n%sDecl(%s, %s
```

```
    )" (indent depth) ((pp_var_def (depth+1)) the_def) (pp_opt (
    pp_expr depth) the_expr)
72  | If(clauses) -> Printf.sprintf "\n%sIf(%s)" (indent depth)
    (pp_str_list (inspect_clause depth) clauses depth)
73  | While(pred, body) -> Printf.sprintf "\n%sWhile(%s, %s)" (
    indent depth) ((pp_expr depth) pred) (pp_str_list (pp_stmt (
    depth+1)) body depth)
74  | Expr(the_expr) -> Printf.sprintf "\n%sExpr(%s)" (indent
    depth) ((pp_expr (depth+1)) the_expr)
75  | Return(the_expr) -> Printf.sprintf "\n%sReturn(%s)" (
    indent depth) (pp_opt (pp_expr depth) the_expr)
76  | Super(args) -> Printf.sprintf "\n%sSuper(%s)" (indent
    depth) (pp_str_list (pp_expr depth) args depth)
77 and inspect_clause depth (opt_expr, body) = Printf.sprintf "(%s,
     %s)" (pp_opt (pp_expr depth) opt_expr) (pp_str_list (
    pp_stmt (depth+1)) body depth)
78 and class_section = function
79  | Publics  -> "Publics"
80  | Protects -> "Protects"
81  | Privates -> "Privates"
82  | Refines  -> "Refines"
83  | Mains    -> "Mains"
84 and pp_func_def depth func = Printf.sprintf "\n%s{\n%sreturns =
    %s,\n%shost = %s,\n%sname = %s,\n%sstatic = %B,\n%sformals =
     %s,\n%sbody = %s,\n%ssection = %s,\n%sinklass = %s,\n%suid
    = %s\n%s}"
85  (indent (depth-1))
86  (indent depth)
87  (pp_opt _id func.returns)
88  (indent depth)
89  (pp_opt _id func.host)
90  (indent depth)
91  func.name
92  (indent depth)
93  func.static
94  (indent depth)
95  (pp_str_list (pp_var_def (depth+1)) func.formals depth)
96  (indent depth)
97  (pp_str_list (pp_stmt (depth+1)) func.body depth)
98  (indent depth)
99  (class_section func.section)
100 (indent depth)
101 func.inklass
102 (indent depth)
103 func.uid
104 (indent (depth-1))
105
106 let pp_member_def depth = function
107  | VarMem(vmem) -> Printf.sprintf "\n%sVarMem(%s)" (indent
    depth) (pp_var_def (depth+1) vmem)
108  | MethodMem(mmem) -> Printf.sprintf "\n%sMethodMem(%s)" (
    indent depth) (pp_func_def (depth+1) mmem)
109  | InitMem(imem) ->  (*let fmt = "@[<v " ^^ (string_of_int
    depth) ^^ ">@,InitMem(%s)@]" in*)
        Format.sprintf "\n%sInitMem(%s)@]"
        (indent depth) (pp_func_def (depth+1) imem)
        (*Format.sprintf fmt
```

```
        (pp_func_def (depth+1) imem)*)

let pp_class_sections sections depth =
    Format.sprintf "@[<v 3>@,{@[<v 2>@,privates = %s,@,protects
    = %s,@,publics = %s,@,refines = %s,@,mains = %s@]@,}@]"
    (pp_str_list (pp_member_def (depth+1)) sections.privates
    depth)
    (pp_str_list (pp_member_def (depth+1)) sections.protects
    depth)
    (pp_str_list (pp_member_def (depth+1)) sections.publics
    depth)
    (pp_str_list (pp_func_def (depth+1)) sections.refines depth)
    (pp_str_list (pp_func_def (depth+1)) sections.mains depth)

let pp_class_def the_klass =
    Format.sprintf "@[<v>@,{@[<v 2>@,klass = %s,@,parent = %s,@,
    sections = %s@]@,}@]"
    the_klass.klass
    (pp_opt _id the_klass.parent)
    (pp_class_sections the_klass.sections 3)
```

Source 73: `Pretty.ml`

```
(** A global UID generator *)

(** The number of digits in a UID [error after rollover] *)
let uid_digits = 8

(**
    A function to return the a fresh UID. Note that UIDs are
    copies,
    so they need not be copied on their own
  *)
let uid_counter =
    let counter = String.make uid_digits '0' in
    let inc () =
        let i = ref (uid_digits - 1) in
        while (!i >= 0) && (String.get counter (!i) = 'z') do
            String.set counter (!i) '0';
            i := !i - 1
        done;
        String.set counter (!i) (match String.get counter (!i)
    with
            | '9' -> 'A'
            | 'Z' -> 'a'
            | c -> char_of_int (int_of_char c + 1));
        String.copy counter in
    inc
```

Source 74: `UID.ml`

```

if [ "${#@}" -eq 0 ] ; then
```

```
  # Read from stdin when there are no arguments (runtool)
  cat
  exit 0
fi

dir="$1"
file="$2"
shift 2

type="Brace"
if [ ${#@} -ne 0 ] ; then
  case "$1" in
    -b) type="Brace"
        ;;
    -s) type="Space"
        ;;
    -m1) type="Mixed1"
        ;;
    *)  echo "Unknown meta-directory $1" >&2
        exit 1
        ;;
  esac
fi

cat "test/tests/${type}/${dir}/${file}"
```

Source 75: `tools/show-example`

```

program="$( basename "$0" )"
if [ ${#@} -lt 3 ] ; then
  echo "Usage: $program dir file tool [-s|-b|-m1]" >&2
  exit 1
fi

dir="$1"
file="$2"
tool="$3"
shift 3

type="Brace"
if [ ${#@} -ne 0 ] ; then
  case "$1" in
    -b) type="Brace"
        ;;
    -s) type="Space"
        ;;
    -m1) type="Mixed1"
        ;;
    *)  echo "Unknown meta-directory $1" >&2
        exit 1
        ;;
  esac
fi

```

```
tool="$( basename "$tool" )"
if [ ! -e "tools/${tool}" ] ; then
  echo "Cannot find tool '${tool}' to execute." >&2
  exit 1
fi

test -e "tools/${tool}"
cat "test/tests/${type}/${dir}/${file}" | "tools/${tool}" "$@"
```

Source 76: `tools/runtool`

```
open Ast
open Sast
open Cast
open Klass
open StringModules
open GlobalData

let to_fname fuid fname = Format.sprintf "f_%s_%s" fuid fname
let to_aname fuid fname = Format.sprintf "a_%s_%s" fuid fname
let to_rname fuid fhost fname = Format.sprintf "f_%s_%s_%s" fuid
    fhost fname
let to_dispatch fuid fhost fname = Format.sprintf "d_%s_%s_%s"
    fuid fhost fname

let get_fname (f : Sast.func_def) = to_fname f.uid f.name
let get_rname (f : Sast.func_def) = match f.host with
    | None -> raise(Failure("Generating refine name for non-
    refinement " ^ f.name ^ " in class " ^ f.inklass ^ "."))
    | Some(host) -> to_rname f.uid host f.name
let get_vname vname = "v_" ^ vname
let get_pointer typ = ("t_"^(Str.global_replace (Str.regexp "
    \\[\\]") "*" typ));;

let get_tname tname =
    let fixtypes str = try
        let splitter n = (String.sub str 0 n, String.sub str n (
    String.length str - n)) in
        let (before, after) = splitter (String.index str '*') in
     (String.trim before) ^ " " ^ (String.trim after)
    with Not_found -> str ^ " " in
fixtypes (get_pointer tname)


let from_tname tname = String.sub tname 2 (String.length tname -
    3)
let opt_tname = function
    | None -> None
    | Some(atype) -> Some(get_tname atype)
let get_vdef (vtype, vname) = (get_tname vtype, get_vname vname)

let cast_switch meth refine =
    let update_klass klass = get_tname klass in
    let update_dispatch (klass, uid) = (get_tname klass,
    to_rname uid meth refine) in
```

```
37      let update_test klass = get_tname klass in
38      function
39          | Switch(klass, cases, uid) -> Switch(update_klass klass
        , List.map update_dispatch cases, to_dispatch uid meth
        refine)
40          | Test(klass, klasses, uid) -> Test(update_klass klass,
        List.map update_test klasses, to_dispatch uid meth refine)
41
42  (*Convert the sast expr to cast expr*)
43  let rec sast_to_castexpr mname env (typetag, sastexpr) = (
        get_tname typetag, c_expr_detail mname sastexpr env)
44  and sast_to_castexprlist mname env explist = List.map (
        sast_to_castexpr mname env) explist
45
46  (* Convert the sast expr_detail to cast_expr detail; convert
        names / types / etc *)
47  and c_expr_detail mname sastexp env = match sastexp with
48      | Sast.This                                     -> Cast.This
49      | Sast.Null                                     -> Cast.Null
50      | Sast.Id(vname)                                -> Cast.Id(
        get_vname vname, snd (StringMap.find vname env))
51      | Sast.NewObj(klass, args, BuiltIn(fuid))       -> Cast.
        NewObj(klass, fuid, sast_to_castexprlist mname env args)
52      | Sast.NewObj(klass, args, FuncId(fuid))        -> Cast.
        NewObj(klass, to_fname fuid "init", sast_to_castexprlist
        mname env args)
53      | Sast.NewObj(klass, args, ArrayAlloc(fuid))    -> Cast.
        NewArr(get_tname klass, to_aname fuid "array_alloc",
        sast_to_castexprlist mname env args)
54      | Sast.Literal(lit)                             -> Cast.
        Literal(lit)
55      | Sast.Assign(e1, e2)                           -> Cast.
        Assign(sast_to_castexpr mname env e1, sast_to_castexpr mname
         env e2)
56      | Sast.Deref(e1, e2)                            -> Cast.
        Deref(sast_to_castexpr mname env e1, sast_to_castexpr mname
        env e2)
57      | Sast.Field(e1, field)                         -> Cast.
        Field(sast_to_castexpr mname env e1, get_vname field)
58      | Sast.Invoc(recv, fname, args, BuiltIn(fuid))  -> Cast.
        Invoc(sast_to_castexpr mname env recv, fuid,
        sast_to_castexprlist mname env args)
59      | Sast.Invoc(recv, fname, args, FuncId(fuid))   -> Cast.
        Invoc(sast_to_castexpr mname env recv, to_fname fuid fname,
        sast_to_castexprlist mname env args)
60      | Sast.Invoc(_, _, ArrayAlloc(_))               -> raise(
        Failure "Cannot allocate an array in an invocation, that is
        nonsensical.")
61      | Sast.Unop(op, expr)                           -> Cast.Unop
        (op, sast_to_castexpr mname env expr)
62      | Sast.Binop(e1, op, e2)                        -> Cast.
        Binop(sast_to_castexpr mname env e1, op, sast_to_castexpr
        mname env e2)
63      | Sast.Refine(name, args, rtype, switch)        -> Cast.
        Refine(sast_to_castexprlist mname env args, opt_tname rtype,
         cast_switch mname name switch)
64      | Sast.Refinable(name, switch)                  -> Cast.
```

```
    Refinable(cast_switch mname name switch)
    | Anonymous(_, _, _)                                -> raise(
    Failure("Anonymous objects should have been deanonymized."))

(*Convert the statement list by invoking cstmt on each of the
    sast stmt*)
let rec cstmtlist mname slist =  List.map (cstmt mname) slist

(* Prepend suffixes *)
and cdef vdef = get_vdef vdef

(*convert sast statement to c statements*)
and cstmt mname sstmt =
    let getoptexpr env = function
        | Some exp -> Some(sast_to_castexpr mname env exp)
        | None     -> None in

    let rec getiflist env = function
        | []                    -> []
        | [(optexpr, slist)]    -> [(getoptexpr env optexpr,
    cstmtlist mname slist)]
        | (optexpr, slist)::tl -> (getoptexpr env optexpr,
    cstmtlist mname slist)::(getiflist env tl) in

    let getsuper args fuid parent env =
        let init = if BuiltIns.is_built_in parent then fuid else
     to_fname fuid "init" in
        let cargs = sast_to_castexprlist mname env args in
        Cast.Super(parent, init, cargs) in

    match sstmt with
        | Sast.Decl(var_def, optexpr, env)      -> Cast.Decl(
    cdef var_def, getoptexpr env optexpr, env)
        | Sast.If(iflist, env)                  -> Cast.If(
    getiflist env iflist, env)
        | Sast.While(expr, sstmtlist, env)      -> Cast.While(
    sast_to_castexpr mname env expr, cstmtlist mname sstmtlist,
    env)
        | Sast.Expr(exp, env)                   -> Cast.Expr(
    sast_to_castexpr mname env exp, env)
        | Sast.Return(optexpr, env)             -> Cast.Return(
    getoptexpr env optexpr, env)
        | Sast.Super(args, fuid, parent, env)   -> getsuper args
     fuid parent env

(**
    Trim up the sast func_def to the cast cfunc_def
    @param func It's a sast func_def. Woo.
    @return It's a cast cfunc_def. Woo.
*)
let sast_to_cast_func (func : Sast.func_def) : cfunc =
    let name = match func.host, func.builtin with
        | _, true -> func.uid
        | None, _ -> get_fname func
        | Some(host), _ -> get_rname func in
    {   returns = opt_tname func.returns;
        name = name;
```

```
109             formals = List.map get_vdef func.formals;
110             body = cstmtlist func.name func.body;
111             builtin = func.builtin;
112             inklass = func.inklass;
113             static  = func.static;
114         }
115 
116     let build_class_struct_map klass_data (sast_classes : Sast.
        class_def list) =
117         (* Extract the ancestry and variables from a class into a
        cdef *)
118         let klass_to_struct klass_name (aklass : Ast.class_def) =
119             let compare (_, n1) (_, n2) = Pervasives.compare n1 n2
        in
120             let ivars = List.flatten (List.map snd (Klass.
        klass_to_variables aklass)) in
121             let renamed = List.map get_vdef ivars in
122             [(klass_name, List.sort compare renamed)] in
123 
124         (* Map each individial class to a basic class_struct *)
125         let struct_map = StringMap.mapi klass_to_struct klass_data.
        classes in
126 
127         (* Now, assuming we get parents before children, update the
        maps appropriately *)
128         let folder map = function
129             | "Object" -> StringMap.add (get_tname "Object") (
        StringMap.find "Object" struct_map) map
130             | aklass ->
131                 let parent = StringMap.find aklass klass_data.
        parents in
132                 let ancestors = StringMap.find (get_tname parent)
        map in
133                 let this = StringMap.find aklass struct_map in
134                 StringMap.add (get_tname aklass) (this @ ancestors)
        map in
135 
136         (* Update the map so that each child has information from
        parents *)
137         let struct_map = List.fold_left folder StringMap.empty (
        Klass.get_class_names klass_data) in
138 
139         (* Reverse the values so that they start from the root *)
140         StringMap.map List.rev struct_map
141 
142     let sast_functions (klasses : Sast.class_def list) =
143         (* Map a Sast class to its functions *)
144         let get_functions (klass : Sast.class_def) =
145             let s = klass.sections in
146             let funcs = function
147                 | Sast.MethodMem(m) -> Some(m)
148                 | Sast.InitMem(i) -> Some(i)
149                 | _ -> None in
150             let get_funcs mems = Util.filter_option (List.map funcs
        mems) in
151             List.flatten [ get_funcs s.publics ; get_funcs s.
        protects ; get_funcs s.privates ; s.refines ; s.mains ] in
```

```
152
153     let all_functions = List.flatten (List.map get_functions
        klasses) in
154     let all_mains = List.flatten (List.map (fun k -> k.sections.
        mains) klasses) in
155
156     (all_functions, all_mains)
157
158 let leaf_ancestors klass_data =
159     let leaves = get_leaves klass_data in
160     let mangled l = List.map get_tname (map_lookup_list l
        klass_data.ancestors) in
161     let ancestors l = (l, List.rev (mangled l)) in
162     List.map ancestors leaves
163
164 let sast_to_cast klass_data (klasses : Sast.class_def list) :
        Cast.program =
165     let (funcs, mains) = sast_functions klasses in
166     let main_case (f : Sast.func_def) = (f.inklass, get_fname f)
         in
167     let cfuncs = List.map sast_to_cast_func funcs in
168     let main_switch = List.map main_case mains in
169     let struct_map = build_class_struct_map klass_data klasses
        in
170     let ancestor_data = klass_data.ancestors in
171
172     (struct_map, cfuncs, main_switch, StringMap.map List.rev
        ancestor_data)
173
174 let built_in_names =
175     let klass_names = List.map (fun (f : Ast.class_def) ->
        get_tname f.klass) BuiltIns.built_in_classes in
176     List.fold_left (fun set i -> StringSet.add i set) StringSet.
        empty klass_names
```

Source 77: `GenCast.ml`

```
1  open Util
2
3  val klass_to_parent : Ast.class_def -> string
4  val section_string : Ast.class_section -> string
5  val klass_to_variables : Ast.class_def -> (Ast.class_section *
       Ast.var_def list) list
6  val klass_to_methods : Ast.class_def -> (Ast.class_section * Ast
       .func_def list) list
7  val klass_to_functions : Ast.class_def -> (Ast.class_section *
       Ast.func_def list) list
8  val conflicting_signatures : Ast.func_def -> Ast.func_def ->
       bool
9  val signature_string : Ast.func_def -> string
10 val full_signature_string : Ast.func_def -> string
11 val class_var_lookup : GlobalData.class_data -> string -> string
        -> (Ast.class_section * string) option
12 val class_field_lookup : GlobalData.class_data -> string ->
       string -> (string * string * Ast.class_section) option
```

```
13 val class_field_far_lookup : GlobalData.class_data -> string ->
       string -> bool -> ((string * string * Ast.class_section),
       bool) either
14 val class_method_lookup : GlobalData.class_data -> string ->
       string -> Ast.func_def list
15 val class_ancestor_method_lookup : GlobalData.class_data ->
       string -> string -> bool -> Ast.func_def list
16 val refine_lookup : GlobalData.class_data -> string -> string ->
        string -> Ast.func_def list
17 val refinable_lookup : GlobalData.class_data -> string -> string
        -> string -> Ast.func_def list
18 val get_distance : GlobalData.class_data -> string -> string ->
       int option
19 val is_type : GlobalData.class_data -> string -> bool
20 val is_subtype : GlobalData.class_data -> string -> string ->
       bool
21 val is_proper_subtype : GlobalData.class_data -> string ->
       string -> bool
22 val compatible_formals : GlobalData.class_data -> string list ->
        string list -> bool
23 val compatible_function : GlobalData.class_data -> string list
      -> Ast.func_def -> bool
24 val compatible_return : GlobalData.class_data -> string option
      -> Ast.func_def -> bool
25 val compatible_signature : GlobalData.class_data -> string
       option -> string list -> Ast.func_def -> bool
26 val best_matching_signature : GlobalData.class_data -> string
       list -> Ast.func_def list -> Ast.func_def list
27 val best_method : GlobalData.class_data -> string -> string ->
       string list -> Ast.class_section list -> Ast.func_def option
28 val best_inherited_method : GlobalData.class_data -> string ->
       string -> string list -> bool -> Ast.func_def option
29 val refine_on : GlobalData.class_data -> string -> string ->
       string -> string list -> string option -> Ast.func_def list
30 val get_class_names : GlobalData.class_data -> string list
31 val get_leaves : GlobalData.class_data -> string list
```

Source 78: `Klass.mli`

```
1  open Ast
2  open Str
3
4  (** Built in classes *)
5
6  let built_in cname : Ast.func_def = match Str.split (regexp "_")
        cname with
7      | [] -> raise(Failure "Bad cname -- empty.")
8      | [klass] -> raise(Failure("Bad cname -- just class: " ^
       klass))
9      | klass::func ->
10         let methname = match func with
11             | [] -> raise(Failure("Impossible!"))
12             | func::rest -> func ^ (String.concat "" (List.map
       String.capitalize rest)) in
13         { returns = None;
```

```
14            host = None;
15            name = methname;
16            static = false;
17            formals = [];
18            body = [];
19            section = Publics;
20            inklass = String.capitalize klass;
21            uid = cname;
22            builtin = true }
23  let breturns cname atype = { (built_in cname) with returns =
        Some(atype) }
24  let btakes cname formals = { (built_in cname) with formals =
        formals }
25
26  let sections : Ast.class_sections_def =
27      { publics = [];
28        protects = [];
29        privates = [];
30        refines = [];
31        mains = [] }
32
33  let func f = if f.name = "init" then InitMem(f) else MethodMem(f
        )
34  let var v = VarMem(v)
35  let variables = List.map var
36  let functions = List.map func
37  let members f v = (functions f) @ (variables v)
38
39  let class_object : Ast.class_def =
40      let name = "Object" in
41
42      let init_obj : Ast.func_def = { (built_in "object_init")
        with section = Protects } in
43      let system = ("System", "system") in
44
45      let sections : Ast.class_sections_def =
46          { sections with
47            publics = [];
48            protects = [func init_obj; var system] } in
49
50      { klass = name; parent = None; sections = sections }
51
52  let class_scanner : Ast.class_def =
53      let name = "Scanner" in
54
55      let scan_line : Ast.func_def = breturns "scanner_scan_string
        " "String" in
56      let scan_int : Ast.func_def = breturns "scanner_scan_integer
        " "Integer" in
57      let scan_float : Ast.func_def = breturns "scanner_scan_float
        " "Float" in
58      let scan_init : Ast.func_def = built_in "scanner_init" in
59
60      let sections : Ast.class_sections_def =
61          { sections with
62            publics = functions [scan_line; scan_int; scan_float;
        scan_init] } in
```

```
63
64      { klass = name; parent = None; sections = sections }
65
66  let class_printer : Ast.class_def =
67      let name = "Printer" in
68
69      let print_string : Ast.func_def = btakes "
        printer_print_string" [("String", "arg")] in
70      let print_int : Ast.func_def = btakes "printer_print_integer
        " [("Integer", "arg")] in
71      let print_float : Ast.func_def = btakes "printer_print_float
        " [("Float", "arg")] in
72      let print_init : Ast.func_def = btakes "printer_init" [("
        Boolean", "stdout")] in
73
74      let sections : Ast.class_sections_def =
75          { sections with
76            publics = functions [print_string; print_int;
        print_float; print_init] } in
77
78      { klass = name; parent = None; sections = sections }
79
80  let class_string : Ast.class_def =
81      let name = "String" in
82
83      let string_init : Ast.func_def = built_in "string_init" in
84
85      let sections : Ast.class_sections_def =
86          { sections with
87            protects = [func string_init] } in
88
89      { klass = name; parent = None; sections = sections }
90
91
92  let class_boolean : Ast.class_def =
93      let name = "Boolean" in
94
95      let boolean_init : Ast.func_def = built_in "boolean_init" in
96
97      let sections : Ast.class_sections_def =
98          { sections with
99            protects = [func boolean_init] } in
100
101     { klass = name; parent = None; sections = sections }
102
103 let class_integer : Ast.class_def =
104     let name = "Integer" in
105
106     let integer_init : Ast.func_def = built_in "integer_init" in
107     let integer_float : Ast.func_def = breturns "integer_to_f" "
        Float" in
108
109     let sections : Ast.class_sections_def =
110         { sections with
111           publics = [func integer_float];
112           protects = [func integer_init] } in
113
```

```
    { klass = name; parent = None; sections = sections }

let class_float : Ast.class_def =
    let name = "Float" in

    let float_init : Ast.func_def = built_in "float_init" in
    let float_integer : Ast.func_def = breturns "float_to_i" "
    Integer" in

    let sections : Ast.class_sections_def =
        { sections with
          publics = [func float_integer];
          protects = [func float_init] } in

    { klass = name; parent = None; sections = sections }

let class_system : Ast.class_def =
    let name = "System" in

    let system_init : Ast.func_def = built_in "system_init" in
    let system_exit : Ast.func_def = btakes "system_exit" [("
    Integer", "code")] in

    let system_out = ("Printer", "out") in
    let system_err = ("Printer", "err") in
    let system_in = ("Scanner", "in") in
    let system_argc = ("Integer", "argc") in

    let sections : Ast.class_sections_def =
        { sections with
          publics = members [system_init; system_exit] [
    system_out; system_err; system_in; system_argc]; } in

    { klass = name; parent = None; sections = sections }

(** The list of built in classes and their methods *)
let built_in_classes =
  [ class_object; class_string; class_boolean; class_integer;
    class_float; class_printer; class_scanner; class_system ]

(** Return whether a class is built in or not *)
let is_built_in name =
  List.exists (fun klass -> klass.klass = name) built_in_classes
```

Source 79: `BuiltIns.ml`

```
open Ast
open Util
open StringModules

(** Module for getting sets of variables *)

(** Get the formal variables of a function *)
let formal_vars func =
    let add_param set (_, v) = StringSet.add v set in
```

```
    List.fold_left add_param StringSet.empty func.formals

(** Get the free variables of a list of statements *)
let free_vars bound stmts =
    let rec get_free_vars free = function
        | [] -> free
        | (bound, Left(stmts))::todo -> get_free_stmts free bound todo stmts
        | (bound, Right(exprs))::todo -> get_free_exprs free bound todo exprs
    and get_free_stmts free bound todo = function
        | [] -> get_free_vars free todo
        | stmt::rest ->
            let (expr_block_list, stmt_block_list, decl) = match stmt with
                | Decl(((_, var), e)) -> ([option_as_list e], [], Some(var))
                | Expr(e)             -> ([[e]], [], None)
                | Return(e)           -> ([option_as_list e], [], None)
                | Super(es)           -> ([es], [], None)
                | While(e, body)      -> ([[e]], [body], None)
                | If(parts)           -> let (es, ts) = List.split parts in
                  ([filter_option es], ts, None) in
            let expressions = List.map (function exprs -> (bound, Right(exprs))) expr_block_list in
            let statements  = List.map (function stmts -> (bound, Left(stmts))) stmt_block_list in
            let bound = match decl with
                | Some(var) -> StringSet.add var bound
                | _ -> bound in
            get_free_stmts free bound (expressions @ statements @ todo) rest
    and get_free_exprs free bound todo = function
        | [] -> get_free_vars free todo
        | expr::rest ->
            let func_to_task bound func =
                (StringSet.union (formal_vars func) bound, Left(func.body)) in

            let (exprs, tasks, id) = match expr with
                | NewObj(_, args)          -> (args, [], None)
                | Assign(l, r)             -> ([l; r], [], None)
                | Deref(v, i)              -> ([v; i], [], None)
                | Field(e, _)              -> ([e], [], None)
                | Invoc(e, _, args)        -> (e::args, [], None)
                | Unop(_, e)               -> ([e], [], None)
                | Binop(l, _, r)           -> ([l; r], [], None)
                | Refine(_, args, _)       -> (args, [], None)
                | This                     -> ([], [], None)
                | Null                     -> ([], [], None)
```

```
                | Refinable(_)              -> ([], [], None)
                | Literal(_)                -> ([], [], None)
                | Id(id)                    -> ([], [],
    decide_option id (not (StringSet.mem id bound)))
                | Anonymous(_, args, funcs) -> (args, List.map (
    func_to_task bound) funcs, None) in

            let rest = exprs @ rest in
            let todo = tasks @ todo in
            let free = match id with
                | Some(id) -> StringSet.add id free
                | None -> free in
            get_free_exprs free bound todo rest in

    get_free_vars StringSet.empty [(bound, Left(stmts))]

(** Get the free variables in a function. *)
let free_vars_func bound func =
    let params = formal_vars func in
    free_vars (StringSet.union bound params) func.body

(** Get the free variables in a whole list of functions. *)
let free_vars_funcs bound funcs =
    let sets = List.map (free_vars_func bound) funcs in
    List.fold_left StringSet.union StringSet.empty sets
```

Source 80: `Variables.ml`

```
gcc -g -I ../headers -lm -o a.out test.c
```

Source 81: `ctest/compile`

```
open Util

let show_classes builder classes = match builder classes with
    | Left(data) -> KlassData.print_class_data data; exit(0)
    | Right(issue) -> Printf.fprintf stderr "%s\n" (KlassData.
    errstr issue); exit(1)

let from_input builder =
    let tokens = Inspector.from_channel stdin in
    let classes = Parser.cdecls (WhiteSpace.lextoks tokens) (
    Lexing.from_string "") in
    show_classes builder classes
let from_basic builder = show_classes builder []

let basic_info_test () = from_basic KlassData.
    build_class_data_test
let basic_info () = from_basic KlassData.build_class_data

let test_info () = from_input KlassData.build_class_data_test
let normal_info () = from_input KlassData.build_class_data

```

```
let exec name func = Printf.printf "Executing mode %s\n" name;
    flush stdout; func ()

let _ = try
    Printexc.record_backtrace true;
    match Array.to_list Sys.argv with
        | []     -> raise(Failure("Not even program name given
    as argument."))
        | [_]    -> exec "Normal Info" normal_info
        | _::arg::_ -> match arg with
        | "-"    -> exec "Basic Info"  basic_info
        | "--"   -> exec "Basic Test"  basic_info_test
        | _      -> exec "Test Info"   test_info
with _ ->
    Printexc.print_backtrace stderr
```

Source 82: `classinfo.ml`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "inspect" "expect-parser" "$@"
```

Source 83: `test/parser`

```
test types:
  * Brace  -- these should be with {, }, and ;
  * Mixed1 -- these should be mixed (closer to Space for now)
  * Space  -- these should be with :

in each type there are test folders:
  * Empty   -- structurally empty tests
  * Trivial -- just above empty, should do something... trivial
  * Simple  -- some basic programs, more than just trivial

each test type requires the same tests. at the end, the outputs
    are compared
```

Source 84: `test/README`

```
#!/bin/bash

program="$( basename "$1" )"
scriptdir="$( dirname "$1" )"
exe="./tools/$2"
old="$3"
shift 3

# Arguments
```

```
10  justrun=
11  save=
12  verbose=
13  pattern=*
14  folderpattern=*
15
16  # Calculated values change in each iteration
17  current=
18  results=
19
20  # Don't change per iteration
21  tmpfile="test/check"
22  tmperr="test/err"
23  testdir="test/tests"
24  maxlength=0
25  oneline=0
26  files=()
27  folders=()
28  temp=()
29  errored=0
30  dropadj=1
31
32  # Formatting values
33  bold=`tput bold`
34  normal=`tput sgr0`
35  uline=`tput smul`
36  green=`tput setaf 2`
37  red=`tput setaf 1`
38  blue=`tput setaf 4`
39  backblue=`tput setab 4`
40
41  function errWith {
42    echo "$1" >&2
43    exit 1
44  }
45
46  function execerror {
47    echo "${bold}${uline}${red}ERROR${normal} $1"
48    errored=1
49  }
50
51  function dots {
52    local len=`echo "$current" | wc -c`
53    for i in `seq $len $maxlength` ; do
54      echo -n '.'
55    done
56    echo -n ' '
57  }
58
59  function contains {
60    local elem
61    for elem in "${@:2}" ; do
62      test "$elem" = "$1" && return 0
63    done
64    return 1
65  }
66
```

```
67  function dropdirprefix {
68    echo "$1" | cut -c $(( ${#2} + $dropadj ))-
69  }
70
71  function setdropadj {
72    local result=$( dropdirprefix "/dev/null" "/dev/" )
73    local null="null"
74    dropadj=$(( dropadj + (${#null} - ${#result}) ))
75  }
76
77  function show_standard {
78    echo "${red}Standard -- START${normal}"
79    cat "$results"
80    echo "${red}Stadard -- END${normal}"
81  }
82
83  function testit {
84    local testing="${bold}Testing:${normal} ${uline}${current}${
        normal}"
85    test "$oneline" -eq 0 && echo "$testing"
86    test "$oneline" -ne 0 && echo -n "$testing"
87    test "$oneline" -ne 0 && dots
88    test -n "$verbose" && cat "$1"
89    if [ -n "$justrun" ] ; then
90      cat "$1" | "$exe"
91      return 0
92    fi
93    cat "$1" | "$exe" 1> "$tmpfile" 2> "$tmperr"
94    if [ $? -ne 0 ] ; then
95      execerror "Error testing $program with $current"
96      cat "$tmperr"
97    elif [ -n "$save" ] ; then
98      echo "${bold}Saving${normal} $current"
99      mkdir -p $( dirname "$results" )
100     mv "$tmpfile" "$results"
101   elif [ ! -e "$results" ] ; then
102     execerror "Cannot check results -- standard does not exist"
103   else
104     if [ -n "$verbose" ] ; then
105       echo -n "${bold}Output:${normal} "
106       cat "$tmpfile"
107     fi
108     test "$oneline" -eq 0 && echo -n "${bold}Results:${normal} "
109     diff -q "$tmpfile" "$results" &> /dev/null
110     if [ $? -eq 0 ] ; then
111       echo "${bold}${green}PASS${normal}"
112     else
113       echo "${bold}${red}MISMATCH${normal}"
114       test -n "$verbose" && show_standard
115     fi
116   fi
117
118   test -e "$tmpfile" && rm "$tmpfile"  # Sometimes happens
119   test -e "$tmperr" && rm "$tmperr"    # Always happens
120
121   test "$oneline" -eq 0 && echo ""
122 }
```

```
123
124 function listandexit {
125   for afile in $( find "$testdir" -type f -name "$pattern" ) ;
        do
126     current=$( dropdirprefix "$afile" "$testdir" )
127     echo "$current"
128   done
129   exit 0
130 }
131
132 function usage {
133 cat <<USAGE
134 $program -[chlpsv]
135   -f pattern
136      Filter meta-folders by pattern
137
138   -h
139      Display this help
140
141   -l
142      Display the name of all tests; note that pattern can be
       used
143
144   -p pattern
145      Filter tests to be used based on pattern (as in find -name)
146
147   -R
148      merely run the driving exe and output the result to stdout
       (no checking anything)
149
150   -s
151      save results
152
153   -v
154      verbose output
155 USAGE
156   exit 0
157 }
158
159 setdropadj
160
161 while getopts "f:hlRsvp:" OPTION ; do
162   case "$OPTION" in
163     f) folderpattern=$OPTARG ;;
164     h) usage ;;
165     R) justrun=1 ;;
166     s) save=1 ;;
167     v) verbose=1 ;;
168     p) pattern=$OPTARG ;;
169     l) list=1;;
170     ?) errWith "Unknown option; aborting" ;;
171   esac
172 done
173 shift $(($OPTIND - 1))
174
175 test -n "$list" && listandexit
176
```

```
177 test -e "$exe" || errWith "Testing $program but $exe unavailable
    "
178 test -f "$exe" || errWith "Testing $program but $exe is not a
    file"
179 test -x "$exe" || errWith "Testing $program but $exe
    unexecutable"
180
181 test -z "$verbose" && oneline=1
182
183 for adir in $( find "$testdir" -mindepth 1 -maxdepth 1 -type d -
    name "$folderpattern" ) ; do
184   adir=$( dropdirprefix "$adir" "$testdir/" )
185   folders+=( "$adir" )
186 done
187 test "${#folders[@]}" -eq 0 && errWith "No folders in test
    directory. Good-bye."
188
189 for afolder in "${folders[@]}" ; do
190   test -d "$testdir/$afolder" || errWith "$afolder is not a
    directory ($testdir)"
191 done
192
193 for afile in $( find "$testdir/${folders[0]}" -type f -name "
    $pattern" ) ; do
194   test "README" = $( basename "$afile" ) || files+=( $(
    dropdirprefix "$afile" "$testdir/${folders[0]}/" ) )
195 done
196
197 for afolder in "${folders[@]}" ; do
198   temp=()
199   for afile in $( find "$testdir/$afolder" -type f -name "
    $pattern" ) ; do
200     test "README" = $( basename "$afile" ) || temp+=( $(
    dropdirprefix "$afile" "$testdir/$afolder/" ) )
201   done
202
203   for afile in "${files[@]}" ; do
204     contains "$afile" "${temp[@]}" || errWith "$afolder does not
     contain $afile but ${folders[0]} does"
205   done
206   for bfile in "${temp[@]}" ; do
207     contains "$bfile" "${files[@]}" || errWith "$afolder
    contains $bfile but ${folders[0]} does not"
208   done
209 done
210 test "${#files[@]}" -eq 0 && errWith "No files match the given
    pattern. Good-bye."
211
212 # All the test directories have the same structure.
213 for current in "${files[@]}" ; do
214   len=`echo "$current" | wc -c`
215   test $len -gt $maxlength && maxlength="$len"
216 done
217 maxlength=$(( maxlength + 5 ))
218
219 for afolder in "${folders[@]}" ; do
220   echo "${bold}${blue}Testing:${normal} $afolder"
```

```
  for current in "${files[@]}" ; do
    results="test/$old/$afolder/$current"
    testit "$testdir/$afolder/$current"
  done
done

test $errored -eq 1 && exit 1
test -n "$justrun" && exit 0

# Ensure that all the results are the same.
for current in "${files[@]}" ; do
  master="test/$old/${folders[0]}/$current"
  matched=1

  for afolder in "${folders[@]}" ; do
    target="test/$old/$afolder/$current"
    diff -q "$master" "$target" &> /dev/null
    if [ $? -ne 0 ] ; then
      echo "$current ${bold}${red}DIFFERS${normal} between ${folders[0]} (reference) and $afolder"
      matched=0
    fi
  done
  test $matched -eq 1 && echo "$current ${bold}${green}MATCHES${normal} across all folders"
done
```

Source 85: `test/.testdrive`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "prettify" "expect-ast-pretty" "$@"
```

Source 86: `test/ast-pretty`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "streams" "expect-scanner" "$@"
```

Source 87: `test/scanner`

```
class List {
}
```

Source 88: `test/tests/Brace/Empty/Class`

```
class List {
  public {
    init() {
    }
    void noop() {
    }
  }
}
```

Source 89: `test/tests/Brace/Empty/InitMethod`

```
class List {
  refinement {
  }
}
```

Source 90: `test/tests/Brace/Empty/Refinements`

```
class List {
  public {
    void noop() {
    }
  }
}
```

Source 91: `test/tests/Brace/Empty/Method`

```
class List {
  private {
  }
}
```

Source 92: `test/tests/Brace/Empty/Private`

```
class List {
  public {
    void noop() {
      while(true) {
      }
    }
  }
}
```

Source 93: `test/tests/Brace/Empty/WhileMethod`

```
class List {
  public {
    init() {
    }
  }
}
```

Source 94: `test/tests/Brace/Empty/Init`

```
class List {
  public {
  }
}
```

Source 95: `test/tests/Brace/Empty/Public`

```
class List {
  protected {
  }
}
```

Source 96: `test/tests/Brace/Empty/Protected`

```
class List {
  public {
    void noop() {
      if(true) {
      }
    }
  }
}
```

Source 97: `test/tests/Brace/Empty/IfMethod`

```
class Collection {
  protected {
    init() {
    }
  }

  public {
    Boolean mutable() {
      return refine answer() to Boolean;
```

```
    }

    void add(Object item) {
      refine do(item) to void;
    }

    void addAll(Collection other) {
      if(refinable(do)) {
        refine combine(other) to void;
      } else {
        Iterator items := other.iterator();
        while(not items.done()) {
          add(items.next());
        }
      }
    }

    void clear() {
      refine do() to void;
    }

    Boolean contains(Object item) {
      if(refinable(check)) {
        return refine check(item) to Boolean;
      }

      Iterator items := this.iterator();
      while(not items.done()) {
        if(items.next() = item) {
          return true;
        }
      }
      return false;
    }

    Boolean containsAll(Collection other) {
      if(refinable(check)) {
        return refine check(other) to Boolean;
      }

      Iterator items := other.iterator();
      while(not items.done()) {
        if(not this.contains(items.next())) {
          return false;
        }
      }
      return true;
    }
  }
}
```

Source 98: `test/tests/Brace/Multi/Collection`

```
class List extends Node {
  public {
```

```
    init() {
      Int c;
      c := 1234;
    }
  }
}
```

Source 99: `test/tests/Brace/Trivial/InitStatement`

```
class List extends Node {
  main {
    List l = new List();
    Int mac = l.macguffin();
  }
  private {
    init() {
    }
  }
  public {
    Int macguffin() {
      return 4;
    }
  }
}
```

Source 100: `test/tests/Brace/Trivial/MainWithBuilding`

```
class Rectangle extends Shape {
  public {
    init(Int width, Int height) {
      this.width := width;
      this.height := height;
    }
    Int area() {
      return width * height;
    }
    Int perimeter() {
      return 2 * (width + height);
    }
  }
  protected {
    Int width;
    Int height;
  }
}
```

Source 101: `test/tests/Brace/Simple/Rectangle`

```
class List:
```

Source 102: `test/tests/Mixed1/Empty/Class`

```
class List:
  public:
    init():
    void noop() {
    }
```

Source 103: `test/tests/Mixed1/Empty/InitMethod`

```
class List:
  refinement {
  }
```

Source 104: `test/tests/Mixed1/Empty/Refinements`

```
class List:
  public:
    void noop() {
    }
```

Source 105: `test/tests/Mixed1/Empty/Method`

```
class List:
  private {
  }
```

Source 106: `test/tests/Mixed1/Empty/Private`

```
class List:
  public:
    void noop():
      while(true){

      }
```

Source 107: `test/tests/Mixed1/Empty/WhileMethod`

```
class List:
  public:
    init() {
    }
```

Source 108: `test/tests/Mixed1/Empty/Init`

```
class List:
  public {
  }
```

Source 109: `test/tests/Mixed1/Empty/Public`

```
class List:
  protected {
  }
```

Source 110: `test/tests/Mixed1/Empty/Protected`

```
class List:
  public:
    void noop(){
      if(true){}
    }
```

Source 111: `test/tests/Mixed1/Empty/IfMethod`

```
class Collection:
  protected:
    init() {
    }

  public:
    Boolean mutable() {
      return refine answer() to Boolean;
    }

    void add(Object item):
      refine do(item) to void

    void addAll(Collection other):
      if(refinable(do)) {
        refine combine(other) to void;
      } else:
        Iterator items := other.iterator()
        while(not items.done()) {
          add(items.next());
        }

    void clear():
      refine do() to void

```

```
    Boolean contains(Object item):
      if(refinable(check)):
        return refine check(item) to Boolean

      Iterator items := this.iterator()
      while(not items.done()):
        if(items.next() = item) {
          return true;
        }
      return false

    Boolean containsAll(Collection other):
      if(refinable(check)) {
        return refine check(other) to Boolean;
      }

      Iterator items := other.iterator()
      while(not items.done()):
        if(not this.contains(items.next())):
          return false
      return true
```

Source 112: `test/tests/Mixed1/Multi/Collection`

```
class List extends Node:
  public:
    init() {
      Int c;
      c := 1234;
    }
```

Source 113: `test/tests/Mixed1/Trivial/InitStatement`

```
class Rectangle extends Shape:
  public:
    init(Int width, Int height) {
      this.width := width;
      this.height := height;
    }

    Int area():
      return width * height

    Int perimeter():
      return 2 * (width + height)

  protected {
    Int width;
    Int height;
  }
```

Source 114: `test/tests/Mixed1/Simple/Rectangle`

```
class List:
```

Source 115: `test/tests/Space/Empty/Class`

```
class List:
  public:
    init():
    void noop():
```

Source 116: `test/tests/Space/Empty/InitMethod`

```
class List:
  refinement:
```

Source 117: `test/tests/Space/Empty/Refinements`

```
class List:
  public:
    void noop():
```

Source 118: `test/tests/Space/Empty/Method`

```
class List:
  private:
```

Source 119: `test/tests/Space/Empty/Private`

```
class List:
  public:
    void noop():
      while(true):
```

Source 120: `test/tests/Space/Empty/WhileMethod`

```
class List:
  public:
    init():
```

Source 121: `test/tests/Space/Empty/Init`

```
class List:
  public:
```

Source 122: `test/tests/Space/Empty/Public`

```
class List:
  protected:
```

Source 123: `test/tests/Space/Empty/Protected`

```
class List:
  public:
    void noop():
      if(true):
```

Source 124: `test/tests/Space/Empty/IfMethod`

```
class Collection:
  protected:
    /* Only subclasses can be created */
    init():

  public:
    Boolean mutable():
      return refine answer() to Boolean

    void add(Object item):
      refine do(item) to void

    void addAll(Collection other):
      if (refinable(do)):
        refine combine(other) to void
      else:
        Iterator items := other.iterator()
        while (not items.done()):
          add(items.next())

    void clear():
      refine do() to void

    Boolean contains(Object item):
      if (refinable(check)):
        return refine check(item) to Boolean

      Iterator items := this.iterator()
      while (not items.done()):
        if (items.next() = item):
          return true
      return false

    Boolean containsAll(Collection other):
      if (refinable(check)):
```

```
          return refine check(other) to Boolean

        Iterator items := other.iterator()
        while (not items.done()):
          if (not this.contains(items.next())):
            return false
        return true
```

Source 125: `test/tests/Space/Multi/Collection`

```
class List extends Node:
  public:
    init():
      Int c;
      c := 1234;
```

Source 126: `test/tests/Space/Trivial/InitStatement`

```
class Rectangle extends Shape:
  public:
    init(Int width, Int height):
      this.width := width
      this.height := height

    Int area():
      return width * height

    Int perimeter():
      return 2 * (width + height)

  protected:
    Int width
    Int height
```

Source 127: `test/tests/Space/Simple/Rectangle`

```
open StringModules
open Sast
open Ast
open Util

(** Take a collection of Sast class_defs and deanonymize them.
    *)


(** The data needed to deanonymize a list of classes and store
    the results. *)
type anon_state = {
    labeler : int lookup_map ;      (** Label deanonymized
    classes *)
    deanon : Ast.class_def list ;   (** List of Ast.class_def
```

```
    classes that are deanonymized. *)
    clean : Sast.class_def list ;   (** List of clean Sast.
    class_def classes *)
    data : GlobalData.class_data ;  (** A class_data record used
     for typing *)
    current : string ;              (** The class that is
    currently being examined *)
}

(**
    Given the initial anon_state, an environment, and an
    expr_detail, remove all
    anonymous object instantiations from the expr and replace
    them with the
    instantiation of a newly constructed class. This returns a
    changed expr_detail
    value and an updated state -- i.e. maybe a new ast class is
    added to it.
    @param init_state anon_state value
    @param env an environment (like those attached to statements
     in sAST)
    @param expr_deets an expr_detail to transform
    @return (new expr detail, updated state)
  *)
let rec deanon_expr_detail init_state env expr_deets =
    let get_label state klass =
        let (n, labeler) = match map_lookup klass state.labeler
    with
            | None -> (0, StringMap.add klass 0 state.labeler)
            | Some(n) -> (n+1, StringMap.add klass (n+1) state.
    labeler) in
        (Format.sprintf "anon_%s_%d" klass n, { state with
    labeler = labeler }) in

    let get_var_type state env var_name =
        match map_lookup var_name env with
            | Some(vinfo) -> Some(fst vinfo)
            | None -> match Klass.class_field_lookup state.data
    state.current var_name with
                | Some((_, vtype, _)) -> Some(vtype)
                | _ -> None in

    let deanon_init args formals klass : Ast.func_def =
        let givens = List.map (fun (t, _) -> (t, "Anon_v_" ^ UID
    .uid_counter ())) args in
        let all_formals = givens @ formals in
        let super = Ast.Super(List.map (fun (_, v) -> Ast.Id(v))
     givens) in
        let assigner (_, vname) = Ast.Expr(Ast.Assign(Ast.Field(
    Ast.This, vname), Ast.Id(vname))) in
        {   returns = None;
            host = None;
            name = "init";
            static = false;
            formals = all_formals;
            body = super::(List.map assigner formals);
            section = Publics;
```

```
54              inklass = klass;
55              uid = UID.uid_counter ();
56              builtin = false } in
57
58      let deanon_klass args freedefs klass parent refines =
59          let init = deanon_init args freedefs klass in
60          let vars = List.map (fun vdef -> Ast.VarMem(vdef))
        freedefs in
61          let sections =
62              {   privates = vars;
63                  protects = [];
64                  publics = [InitMem(init)];
65                  refines = List.map (fun r -> { r with inklass=
        klass }) refines;
66                  mains = []; } in
67          let theklass =
68              {   klass = klass;
69                  parent = Some(parent);
70                  sections = sections } in
71          (init.uid, theklass) in
72
73      let deanon_freedefs state env funcs =
74          let freeset = Variables.free_vars_funcs StringSet.empty
        funcs in
75          let freevars = List.sort compare (StringSet.elements
        freeset) in
76
77          let none_snd = function
78            | (None, v) -> Some(v)
79            | _ -> None in
80          let some_fst = function
81            | (Some(t), v) -> Some((t, v))
82            | _ -> None in
83          let add_type v = (get_var_type state env v, v) in
84
85          let typed = List.map add_type freevars in
86          let unknowns = List.map none_snd typed in
87          let knowns = List.map some_fst typed in
88
89          match Util.filter_option unknowns with
90              | [] -> Util.filter_option knowns
91              | vs -> raise(Failure("Unknown variables " ^ String.
        concat ", " vs ^ " within anonymous object definition.")) in
92
93      match expr_deets with
94          | Sast.Anonymous(klass, args, refines) ->
95              let (newklass, state) = get_label init_state klass
        in
96              let freedefs = deanon_freedefs state env refines in
97              let (init_id, ast_class) = deanon_klass args
        freedefs newklass klass refines in
98              let freeargs = List.map (fun (t, v) -> (t, Sast.Id(v
        ))) freedefs in
99              let instance = Sast.NewObj(newklass, args @ freeargs
        , Sast.FuncId init_id) in
100             let state = { state with deanon = ast_class::state.
        deanon } in
```

```
101             (instance, state)
102         | Sast.This -> (Sast.This, init_state)
103         | Sast.Null -> (Sast.Null, init_state)
104         | Sast.Id(id) -> (Sast.Id(id), init_state)
105         | Sast.NewObj(klass, args, funcid) ->
106             let (args, state) = deanon_exprs init_state env args
        in
107             (Sast.NewObj(klass, args, funcid), state)
108         | Sast.Literal(lit) -> (Sast.Literal(lit), init_state)
109         | Sast.Assign(mem, data) ->
110             let (mem, state) = deanon_expr init_state env mem in
111             let (data, state) = deanon_expr state env data in
112             (Sast.Assign(mem, data), state)
113         | Sast.Deref(arr, idx) ->
114             let (arr, state) = deanon_expr init_state env arr in
115             let (idx, state) = deanon_expr state env idx in
116             (Sast.Deref(arr, idx), state)
117         | Sast.Field(expr, mbr) ->
118             let (expr, state) = deanon_expr init_state env expr
        in
119             (Sast.Field(expr, mbr), state)
120         | Sast.Invoc(recvr, klass, args, funcid) ->
121             let (recvr, state) = deanon_expr init_state env
        recvr in
122             let (args, state) = deanon_exprs state env args in
123             (Sast.Invoc(recvr, klass, args, funcid), state)
124         | Sast.Unop(op, expr) ->
125             let (expr, state) = deanon_expr init_state env expr
        in
126             (Sast.Unop(op, expr), state)
127         | Sast.Binop(l, op, r) ->
128             let (l, state) = deanon_expr init_state env l in
129             let (r, state) = deanon_expr state env r in
130             (Sast.Binop(l, op, r), state)
131         | Sast.Refine(refine, args, ret, switch) ->
132             let (args, state) = deanon_exprs init_state env args
        in
133             (Sast.Refine(refine, args, ret, switch), state)
134         | Sast.Refinable(refine, switch) ->
135             (Sast.Refinable(refine, switch), init_state)
136
137 (**
138     Update an type-tagged sAST expression to be deanonymized.
139     Returns the deanonymized expr and a possibly updated
        anon_state
140     @param init_state anon_state value
141     @param env an environment like those attached to stmts in
        the sAST
142     @param t the type of the expr_detail exp
143     @param exp an expression detail
144     @return ((t, exp'), state') where exp' is exp but
        deanonymized and
145     state' is an updated version of init_state
146   *)
147 and deanon_expr init_state env (t, exp) =
148     let (deets, state) = deanon_expr_detail init_state env exp
        in
```

```
149         ((t, deets), state)
150
151     (**
152         Deanonymize a list of expressions maintaining the state
            properly throughout.
153         Returns the list of expressions (deanonymized) and the
            updated state.
154         @param init_state an anon_state value
155         @param env an environment like those attached to statments (
            sAST)
156         @param list a list of expressions (sAST exprs)
157         @return (list', state') where list' is the deanonymized list
             and
158         state' is the updated state
159       *)
160     and deanon_exprs init_state env list =
161         let folder (rexprs, state) expr =
162             let (deets, state) = deanon_expr state env expr in
163             (deets::rexprs, state) in
164         let (rexprs, state) = List.fold_left folder ([], init_state)
             list in
165         (List.rev rexprs, state)
166
167     (**
168         Deanonymize a statement.
169         Returns the deanonymized statement and the updated state.
170         @param input_state an anon_state value
171         @param stmt a statement to deanonymize
172         @return (stmt', state') the statement and state, updated.
173       *)
174     and deanon_stmt input_state stmt =
175         let deanon_decl init_state env = function
176             | (vdef, Some(expr)) ->
177                 let (deets, state) = deanon_expr init_state env expr
                 in
178                 (Sast.Decl(vdef, Some(deets), env), state)
179             | (vdef, _) -> (Sast.Decl(vdef, None, env), init_state)
            in
180
181         let deanon_exprstmt init_state env expr =
182             let (deets, state) = deanon_expr init_state env expr in
183             (Sast.Expr(deets, env), state) in
184
185         let deanon_return init_state env = function
186             | None -> (Sast.Return(None, env), init_state)
187             | Some(expr) ->
188                 let (deets, state) = deanon_expr init_state env expr
                 in
189                 (Sast.Return(Some(deets), env), state) in
190
191         let deanon_super init_state env args built_in init_id =
192             let (deets, state) = deanon_exprs init_state env args in
193             (Sast.Super(deets, init_id, built_in, env), state) in
194
195         let deanon_while init_state env (expr, stmts) =
196             let (test, state) = deanon_expr init_state env expr in
197             let (body, state) = deanon_stmts state stmts in
```

```
198             (Sast.While(test, body, env), state) in
199
200         let deanon_if init_state env pieces =
201             let folder (rpieces, state) piece =
202                 let (piece, state) = match piece with
203                     | (None, stmts) ->
204                         let (body, state) = deanon_stmts state stmts
     in
205                         ((None, body), state)
206                     | (Some(expr), stmts) ->
207                         let (test, state) = deanon_expr state env
    expr in
208                         let (body, state) = deanon_stmts state stmts
     in
209                         ((Some(test), body), state) in
210                 (piece::rpieces, state) in
211             let (rpieces, state) = List.fold_left folder ([],
    init_state) pieces in
212             (Sast.If(List.rev rpieces, env), state) in
213
214         match stmt with
215             | Sast.Decl(vdef, opt_expr, env) -> deanon_decl
    input_state env (vdef, opt_expr)
216             | Sast.If(pieces, env) -> deanon_if input_state env
    pieces
217             | Sast.While(test, body, env) -> deanon_while
    input_state env (test, body)
218             | Sast.Expr(expr, env) -> deanon_exprstmt input_state
    env expr
219             | Sast.Return(opt_expr, env) -> deanon_return
    input_state env opt_expr
220             | Sast.Super(args, init_id, built_in, env) ->
    deanon_super input_state env args built_in init_id
221
222     (**
223         Update an entire list of statements to be deanonymized.
224         Maintains the update to the state throughout the computation
        .
225         Returns a deanonymized list of statements and an updated
        state.
226         @param init_state an anon_state value
227         @param stmts a list of statements
228         @return (stmts', state') the updated statements and state
229       *)
230     and deanon_stmts init_state stmts =
231         let folder (rstmts, state) stmt =
232             let (stmt, state) = deanon_stmt state stmt in
233             (stmt::rstmts, state) in
234         let (rstmts, state) = List.fold_left folder ([], init_state)
         stmts in
235         (List.rev rstmts, state)
236
237     (**
238         Deanonymize the body of a function.
239         Return the updated function and updated state.
240         @param init_state an anon_state value
241         @param func a func_def (sAST)
```

```
242       @return (func', state') the updated function and state
243     *)
244   let deanon_func init_state (func : Sast.func_def) =
245       let (stmts, state) = deanon_stmts init_state func.body in
246       ({ func with body = stmts }, state)
247
248   (**
249       Deanonymize an entire list of functions, threading the state
250       throughout and maintaining the changes. Returns the list of
251       functions, updated, and the updated state.
252       @param init_state an anon_state value
253       @param funcs a list of functions
254       @return (funcs', state') the updated functions and state
255     *)
256   let deanon_funcs init_state funcs =
257       let folder (rfuncs, state) func =
258           let (func, state) = deanon_func state func in
259           (func::rfuncs, state) in
260       let (funcs, state) = List.fold_left folder ([], init_state)
          funcs in
261       (List.rev funcs, state)
262
263   (**
264       Deanonymize an Sast member_def
265       Returns the deanonymized member and a possibly updated state
          .
266       @param init_state an anon_state value
267       @param mem a member to deanonymize
268       @return (mem', state') the updated member and state
269     *)
270   let deanon_member init_state mem = match mem with
271       | Sast.MethodMem(f) ->
272           let (func, state) = deanon_func init_state f in
273           (Sast.MethodMem(func), state)
274       | Sast.InitMem(f) ->
275           let (func, state) = deanon_func init_state f in
276           (Sast.InitMem(func), state)
277       | mem -> (mem, init_state)
278
279   (**
280       Deanonymize a list of members.  Return the deanonymized list
281       and a possibly updated state.
282       @param init_state an anon_state value
283       @param members a list of members to deanonymize
284       @return (mems', state') the updated members and state
285     *)
286   let deanon_memlist (init_state : anon_state) (members : Sast.
          member_def list) : (Sast.member_def list * anon_state) =
287       let folder (rmems, state) mem =
288           let (mem, state) = deanon_member state mem in
289           (mem::rmems, state) in
290       let (rmems, state) = List.fold_left folder ([], init_state)
          members in
291       (List.rev rmems, state)
292
293   (**
294       Deanonymize an entire class. Return the deanonymized class
```

```
295     and an updated state.
296     @param init_state an anon_state value
297     @param aklass an sAST class to deanonymize
298     @return (class', state') the udpated class and state.
299   *)
300 let deanon_class init_state (aklass : Sast.class_def) =
301     let s = aklass.sections in
302     let state = { init_state with current = aklass.klass } in
303     let (publics, state) = deanon_memlist state s.publics in
304     let (protects, state) = deanon_memlist state s.protects in
305     let (privates, state) = deanon_memlist state s.privates in
306     let (refines, state) = deanon_funcs state s.refines in
307     let (mains, state) = deanon_funcs state s.mains in
308     let sections : Sast.class_sections_def =
309         {   publics = publics;
310             protects = protects;
311             privates = privates;
312             refines = refines;
313             mains = mains } in
314     let cleaned = { aklass with sections = sections } in
315     (state.deanon, { state with clean = cleaned::state.clean;
    current = ""; deanon = [] })
316
317 (** A startng state for deanonymization. *)
318 let empty_deanon_state data =
319     {   labeler = StringMap.empty;
320         deanon = [];
321         clean = [];
322         data = data;
323         current = ""; }
324
325 (**
326     Given global class information and parsed and tagged classes
    ,
327     deanonymize the classes. This will add more classes to the
328     global data, which will be updated accordingly.
329     @param klass_data global class_data info
330     @param sast_klasses tagged sAST class list
331     @return If everything goes okay with updating the global
    data
332     for each deanonymization, then left((state', data')) will be
333     returned where state' contains all (including newly created)
334     sAST classes in its clean list and data' has been updated to
335     reflect any new classes. If anything goes wrong, Right(issue
    )
336     is returned, where the issue is just as in building the
    global
337     class_data info to begin with, but now specific to what goes
338     on in deanonymization (i.e. restricted to those restricted
339     classes themselves).
340   *)
341 let deanonymize klass_data sast_klasses =
342     let is_empty = function
343         | [] -> true
344         | _ -> false in
345
346     let rec run_deanon init_state asts sasts = match asts, sasts
```

```
     with
347      (* Every sAST has been deanonymized, even the
    deanonymized ones converted into sASTs
348       * Every Ast has been sAST'd too. So we are done.
349       *)
350      | [], [] ->
351          if is_empty init_state.deanon then Left((init_state.
    data, init_state.clean))
352          else raise(Failure("Deanonymization somehow did not
    recurse properly."))
353
354      | [], klass::rest ->
355          let (asts, state) = deanon_class init_state klass in
356          run_deanon state asts rest
357
358      | klass::rest, _ -> match KlassData.append_leaf
    init_state.data klass with
359          | Left(data) ->
360              let sast_klass = BuildSast.ast_to_sast_klass
    data klass in
361              let state = { init_state with data = data } in
362              run_deanon state rest (sast_klass::sasts)
363          | Right(issue) -> Right(issue) in
364
365  run_deanon (empty_deanon_state klass_data) [] sast_klasses
```

Source 128: `Unanonymous.ml`

```
1  open StringModules
2  open Util
3
4  val fold_classes : GlobalData.class_data -> ('a -> Ast.class_def
       -> 'a) -> 'a -> 'a
5  val map_classes : GlobalData.class_data -> ('a StringMap.t ->
       Ast.class_def -> 'a StringMap.t) -> 'a StringMap.t
6  val dfs_errors : GlobalData.class_data -> (string -> 'a -> 'b ->
       ('a * 'b)) -> 'a -> 'b -> 'b
7
8  val build_class_data : Ast.class_def list -> (GlobalData.
       class_data, GlobalData.class_data_error) either
9  val build_class_data_test : Ast.class_def list -> (GlobalData.
       class_data, GlobalData.class_data_error) either
10
11 val append_leaf : GlobalData.class_data -> Ast.class_def -> (
       GlobalData.class_data, GlobalData.class_data_error) either
12 val append_leaf_test : GlobalData.class_data -> Ast.class_def ->
       (GlobalData.class_data, GlobalData.class_data_error) either
13
14 val print_class_data : GlobalData.class_data -> unit
15 val errstr : GlobalData.class_data_error -> string
```

Source 129: `KlassData.mli`

```
open Ast
open Util
open StringModules
open GlobalData
open Klass

(** Build a class_data object. *)

(** Construct an empty class_data object *)
let empty_data : class_data = {
    known = StringSet.empty;
    classes = StringMap.empty;
    parents = StringMap.empty;
    children = StringMap.empty;
    variables = StringMap.empty;
    methods = StringMap.empty;
    refines = StringMap.empty;
    mains = StringMap.empty;
    ancestors = StringMap.empty;
    distance = StringMap.empty;
    refinable = StringMap.empty;
}

(**
    Map function collisions to the type used for collection that
     information.
    This lets us have a 'standard' form of method / refinement
    collisions and so
    we can easily build up a list of them.
    @param aklass the class we are currently examining (class
    name -- string)
    @param funcs a list of funcs colliding in aklass
    @param reqhost are we requiring a host (compiler error if no
     host and true)
    @return a tuple representing the collisons - (class name,
    collision tuples)
    where collision tuples are ([host.]name, formals)
  *)
let build_collisions aklass funcs reqhost =
    let to_collision func =
        let name = match func.host, reqhost with
            | None, true -> raise(Invalid_argument("Cannot build
     refinement collisions -- refinement without host [compiler
    error]."))
            | None, _ -> func.name
            | Some(host), _ -> host ^ "." ^ func.name in
        (name, List.map fst func.formals) in
    (aklass, List.map to_collision funcs)

(** Fold over the values in a class_data record's classes map.
    *)
let fold_classes data folder init =
    let do_fold _ aklass result = folder result aklass in
    StringMap.fold do_fold data.classes init

(**
    Fold over the values in a class_data record's classes map,
```

```
    but
    enforce building up a StringMap.
  *)
let map_classes data folder = fold_classes data folder StringMap
    .empty

(**
    Recursively explore the tree starting at the root,
    accumulating errors
    in a list as we go. The explorer function should take the
    current class
    the current state, the current errors and return a new state
     / errors
    pair (updating state when possible if there are errors for
    further
    accumulation). This is the state that will be passed to all
    children,
    and the errors will accumulate across all children.
    @param data A class_data record value
    @param explore Something that goes from the current node to
    a new state/error pair
    @init_state the initial state of the system
    @init_error the initial errors of the system
    @return The final accumulated errors
  *)
let dfs_errors data explore init_state init_error =
    let rec recurse aklass state errors =
        let (state, errors) = explore aklass state errors in
        let explore_kids errors child = recurse child state
    errors in
        let children = map_lookup_list aklass data.children in
        List.fold_left explore_kids errors children in
    recurse "Object" init_state init_error

(**
    Given a list of classes, build an initial class_data object
    with
    the known and classes fields set appropriately. If there are
     any
    duplicate class names a StringSet of the collisions will
    then be
    returned in Right, otherwise the data will be returned in
    Left.
    @param klasses A list of classes
    @return Left(data) which is a class_data record with the
    known
    set filled with names or Right(collisions) which is a set of
    collisions (StringSet.t)
  *)
let initialize_class_data klasses =
    let build_known (set, collisions) aklass =
        if StringSet.mem aklass.klass set
            then (set, StringSet.add aklass.klass collisions)
            else (StringSet.add aklass.klass set, collisions) in
    let klasses = BuiltIns.built_in_classes @ klasses in
    let build_classes map aklass = StringMap.add aklass.klass
    aklass map in
```

```
92      let (known, collisions) = List.fold_left build_known (
        StringSet.empty, StringSet.empty) klasses in
93      let classes = List.fold_left build_classes StringMap.empty
        klasses in
94      if StringSet.is_empty collisions
95          then Left({ empty_data with known = known; classes =
        classes })
96          else Right(collisions)
97
98  (**
99      Given an initialized class_data record, build the children
        map
100     from the classes that are stored within it.
101     The map is from parent to children list.
102     @param data A class_data record
103     @return data but with the children.
104   *)
105 let build_children_map data =
106     let map_builder map aklass = match aklass.klass with
107         | "Object" -> map
108         | _ -> add_map_list (klass_to_parent aklass) aklass.
        klass map in
109     let children_map = map_classes data map_builder in
110     { data with children = children_map }
111
112 (**
113     Given an initialized class_Data record, build the parent map
114     from the classes that are stored within it.
115     The map is from child to parent.
116     @param data A class_data record
117     @return data but with the parent map updated.
118   *)
119 let build_parent_map data =
120     let map_builder map aklass = match aklass.klass with
121         | "Object" -> map
122         | _ -> StringMap.add (aklass.klass) (klass_to_parent
        aklass) map in
123     let parent_map = map_classes data map_builder in
124     { data with parents = parent_map }
125
126 (**
127     Validate that the parent map in a class_data record
        represents a tree rooted at object.
128     @param data a class_data record
129     @return An optional string (Some(string)) when there is an
        issue.
130   *)
131 let is_tree_hierarchy data =
132     let rec from_object klass checked =
133         match map_lookup klass checked with
134             | Some(true) -> Left(checked)
135             | Some(false) -> Right("Cycle detected.")
136             | _ -> match map_lookup klass data.parents with
137                 | None -> Right("Cannot find parent after
        building parent map: " ^ klass)
138                 | Some(parent) -> match from_object parent (
        StringMap.add klass false checked) with
```

```
                    | Left(updated) -> Left(StringMap.add klass
    true updated)
                    | issue -> issue in
    let folder result aklass = match result with
        | Left(checked) -> from_object aklass.klass checked
        | issue -> issue in
    let checked = StringMap.add "Object" true StringMap.empty in
    match fold_classes data folder (Left(checked)) with
        | Right(issue) -> Some(issue)
        | _ -> None

(**
    Add the class (class name - string) -> ancestors (list of
    ancestors - string list) map to a
    class_data record. Note that the ancestors go from 'youngest
    ' to 'oldest' and so should start
    with the given class (hd) and end with Object (last item in
    the list).
    @param data The class_data record to update
    @return An updated class_data record with the ancestor map
    added.
  *)
let build_ancestor_map data =
    let rec ancestor_builder klass map =
        if StringMap.mem klass map then map
        else
            let parent = StringMap.find klass data.parents in
            let map = ancestor_builder parent map in
            let ancestors = StringMap.find parent map in
            StringMap.add klass (klass::ancestors) map in
    let folder map aklass = ancestor_builder aklass.klass map in
    let map = StringMap.add "Object" ["Object"] StringMap.empty
    in
    let ancestor_map = fold_classes data folder map in
    { data with ancestors = ancestor_map }

(**
    For a given class, build a map of variable names to variable
     information.
    If all instance variables are uniquely named, returns Left (
    map) where map
    is  var name -> (class_section, type)  otherwise returns
    Right (collisions)
    where collisions are the names of variables that are
    multiply declared.
    @param aklass A parsed class
    @return a map of instance variables in the class
  *)
let build_var_map aklass =
    let add_var section map (typeId, varId) = add_map_unique
    varId (section, typeId) map in
    let map_builder map (section, members) = List.fold_left (
    add_var section) map members in
    build_map_track_errors map_builder (klass_to_variables
    aklass)

(**
```

```
183     Add the class (class name - string) -> variable (var name -
        string) -> info (section/type
184     pair - class_section * string) table to a class_data record.
185     @param data A class_data record
186     @return Either a list of collisions (in Right) or the
        updated record (in Left).
187     Collisions are pairs (class name, collisions (var names) for
         that class)
188   *)
189 let build_class_var_map data =
190     let map_builder (klass_map, collision_list) (_, aklass) =
191         match build_var_map aklass with
192             | Left(var_map) -> (StringMap.add (aklass.klass)
        var_map klass_map, collision_list)
193             | Right(collisions) -> (klass_map, (aklass.klass,
        collisions)::collision_list) in
194     match build_map_track_errors map_builder (StringMap.bindings
         data.classes) with
195         | Left(variable_map) -> Left({ data with variables =
        variable_map })
196         | Right(collisions) -> Right(collisions) (* Same value
        different types parametrically *)
197
198 (**
199     Given a class_data record and a class_def value, return the
        instance variables (just the
200     var_def) that have an unknown type.
201     @param data A class_data record value
202     @param aklass A class_def value
203     @return A list of unknown-typed instance variables in the
        class
204   *)
205 let type_check_variables data aklass =
206     let unknown_type (var_type, _) = not (is_type data var_type)
         in
207     let vars = List.flatten (List.map snd (klass_to_variables
        aklass)) in
208     List.filter unknown_type vars
209
210 (**
211     Given a class_data record, verify that all instance
        variables of all classes are of known
212     types. Returns the Left of the data if everything is okay,
        or the Right of a list of pairs,
213     first item being a class, second being variables of unknown
        types (type, name pairs).
214     @param data A class_data record value.
215     @return Left(data) if everything is okay, otherwise Right(
        unknown types) where unknown types
216     is a list of (class, var_def) pairs.
217   *)
218 let verify_typed data =
219     let verify_klass klass_name aklass unknowns = match
        type_check_variables data aklass with
220         | [] -> unknowns
221         | bad -> (klass_name, bad)::unknowns in
222     match StringMap.fold verify_klass data.classes [] with
```

```
223         | [] -> Left(data)
224         | bad -> Right(bad)
225
226 (**
227     Given a function, type check the signature (Return, Params).
228     @param data A class_data record value.
229     @param func An Ast.func_def record
230     @return Left(data) if everything is alright; Right([host.]
    name, option string, (type, name)
231     list) if wrong.
232   *)
233 let type_check_func data func =
234     let atype = is_type data in
235     let check_ret = match func.returns with
236         | Some(vtype) -> if atype vtype then None else Some(
    vtype)
237         | _ -> None in
238     let check_param (vtype, vname) = if not (atype vtype) then
    Some((vtype, vname)) else None in
239     let bad_params = filter_option (List.map check_param func.
    formals) in
240     match check_ret, bad_params, func.host with
241         | None, [], _ -> Left(data)
242         | _, _, None -> Right((func.name, check_ret, bad_params)
    )
243         | _, _, Some(host) -> Right((host ^ "." ^ func.name,
    check_ret, bad_params))
244
245 (**
246     Given a class_data object and a klass, verify that all of
    its methods have good types
247     (Return and parameters).
248     @param data A class_data record object
249     @param aklass A class_def object
250     @return Left(data) if everything went okay; Right((klass
    name, (func name, option string,
251     (type, name) list) list))
252   *)
253 let type_check_class data aklass =
254     let folder bad func = match type_check_func data func with
255         | Left(data) -> bad
256         | Right(issue) -> issue::bad in
257     let funcs = List.flatten (List.map snd (klass_to_functions
    aklass)) in
258     match List.fold_left folder [] funcs with
259         | [] -> Left(data)
260         | bad -> Right((aklass.klass, bad))
261
262 (**
263     Given a class_data object, verify that all classes have
    methods with good signatures
264     (Return and parameters)
265     @param data A class_data record object
266     @param aklass A class_def object
267     @return Left(data) if everything went okay; Right((klass
    name, bad_sig list) list)
268     where bad_sig is (func_name, string option, (type, var) list
```

```
    ))
  *)
let type_check_signatures data =
    let folder klass_name aklass bad = match type_check_class
    data aklass with
        | Left(data) -> bad
        | Right(issue) -> issue::bad in
    match StringMap.fold folder data.classes [] with
        | [] -> Left(data)
        | bad -> Right(bad)

(**
    Build a map of all the methods within a class, returing
    either a list of collisions
    (in Right) when there are conflicting signatures or the map
    (in Left) when there
    are not. Keys to the map are function names and the values
    are lists of func_def's.
    @param aklass A klass to build a method map for
    @return Either a list of collisions or a map of function
    names to func_def's.
  *)
let build_method_map aklass =
    let add_method (map, collisions) fdef =
        if List.exists (conflicting_signatures fdef) (
    map_lookup_list fdef.name map)
            then (map, fdef::collisions)
            else (add_map_list fdef.name fdef map, collisions)
    in
    let map_builder map funcs = List.fold_left add_method map
    funcs in
    build_map_track_errors map_builder (List.map snd (
    klass_to_methods aklass))

(**
    Add the class name (string) -> method name (string) ->
    methods  (func_def list)
    methods table to a class_data record, given a list of
    classes. If there are no
    collisions, the updated record is returned (in Left),
    otherwise the collision
    list is returned (in Right).
    @param data A class data record
    @return Either a list of collisions (in Right) or the
    updated record (in Left).
    Collisions are pairs (class name, colliding methods for that
     class). Methods collide
    if they have conflicting signatures (ignoring return type).
  *)
let build_class_method_map data =
    let map_builder (klass_map, collision_list) (_, aklass) =
        match build_method_map aklass with
            | Left(method_map) -> (StringMap.add aklass.klass
    method_map klass_map, collision_list)
            | Right(collisions) -> (klass_map, (build_collisions
     aklass.klass collisions false)::collision_list) in
    match build_map_track_errors map_builder (StringMap.bindings
```

```
     data.classes) with
309          | Left(method_map) -> Left({ data with methods =
     method_map })
310          | Right(collisions) -> Right(collisions) (* Same value
     different types parametrically *)
311
312  (**
313      Build the map of refinements for a given class. Keys to the
     map are 'host.name'
314      @param aklass aklass A class to build a refinement map out
     of
315      @return Either a list of collisions (in Right) or the map (
     in left). Refinements
316      conflict when they have the same name ('host.name' in this
     case) and have the same
317      argument type sequence.
318    *)
319  let build_refinement_map aklass =
320      let add_refinement (map, collisions) func = match func.host
     with
321          | Some(host) ->
322              let key = func.name ^ "." ^ host in
323              if List.exists (conflicting_signatures func) (
     map_lookup_list key map)
324                  then (map, func::collisions)
325                  else (add_map_list key func map, collisions)
326          | None -> raise(Failure("Compilation error -- non-
     refinement found in searching for refinements.")) in
327      build_map_track_errors add_refinement aklass.sections.
     refines
328
329  (**
330      Add the class name (string) -> refinement ('host.name' -
     string) -> func list
331      map to a class_data record. If there are no collisions (
     conflicting signatures
332      given the same host), then the updated record is returned (
     in Left) otherwise
333      a list of collisions is returned (in Right).
334      @param data A class_data record
335      @param klasses A list of parsed classes
336      @return either a list of collisions (in Right) or the
     updated record (in Left).
337      Collisions are (class, (host, method, formals) list)
338    *)
339  let build_class_refinement_map data =
340      let map_builder (klass_map, collision_list) (_, aklass) =
341          match build_refinement_map aklass with
342              | Left(refinement_map) -> (StringMap.add aklass.
     klass refinement_map klass_map, collision_list)
343              | Right(collisions) -> (klass_map, (build_collisions
      aklass.klass collisions true)::collision_list) in
344      match build_map_track_errors map_builder (StringMap.bindings
      data.classes) with
345          | Left(refinement_map) -> Left({ data with refines =
     refinement_map })
346          | Right(collisions) -> Right(collisions) (* Same value
```

```
    different types parametrically *)

(**
    Add a map of main functions, from class name (string) to
    main (func_def) to the
    class_data record passed in. Returns a list of collisions if
     any class has more
    than one main (in Right) or the updated record (in Left)
    @param data A class_data record
    @param klasses A list of parsed classes
    @return Either the collisions (Right) or the updated record
    (Left)
  *)
let build_main_map data =
    let add_klass (map, collisions) (_, aklass) = match aklass.
    sections.mains with
        | [] -> (map, collisions)
        | [main] -> (StringMap.add aklass.klass main map,
    collisions)
        | _ -> (map, aklass.klass :: collisions) in
    match build_map_track_errors add_klass (StringMap.bindings
    data.classes) with
        | Left(main_map) -> Left({ data with mains = main_map })
        | Right(collisions) -> Right(collisions) (* Same value
    different types parametrically *)

(**
    Given a class_data record, verify that there are no double
    declarations of instance
    variables as you go up the tree. This means that no two
    classes along the same root
    leaf path can have the same public / protected variables,
    and a private cannot be
    a public/protected variable of an ancestor.
    @param data A class_data record.
    @return Left(data) if everything was okay or Right(
    collisions) where collisions is
    a list of pairs of collision information - first item class,
     second item a list of
    colliding variables for that class (name, ancestor where
    they collide)
  *)
let check_field_collisions data =
    let check_vars aklass var (section, _) (fields, collisions)
    = match map_lookup var fields, section with
        | Some(ancestor), _ -> (fields, (ancestor, var)::
    collisions)
        | None, Privates -> (fields, collisions)
        | None, _ -> (StringMap.add var aklass fields,
    collisions) in

    let check_class_vars aklass fields =
        let vars = StringMap.find aklass data.variables in
        StringMap.fold (check_vars aklass) vars (fields, []) in

    let dfs_explorer aklass fields collisions =
        match check_class_vars aklass fields with
```

```
387                 | (fields, []) -> (fields, collisions)
388                 | (fields, cols) -> (fields, (aklass, cols)::
    collisions) in
389
390     match dfs_errors data dfs_explorer StringMap.empty [] with
391         | [] -> Left(data)
392         | collisions -> Right(collisions)
393
394 (**
395     Check to make sure that we don't have conflicting signatures
     as we go down the class tree.
396     @param data A class_data record value
397     @return Left(data) if everything is okay, otherwise a list
    of (string
398   *)
399 let check_ancestor_signatures data =
400     let check_sigs meth_name funcs (methods, collisions) =
401         let updater (known, collisions) func =
402             if List.exists (conflicting_signatures func) known
403                 then (known, func::collisions)
404                 else (func::known, collisions) in
405         let apriori = map_lookup_list meth_name methods in
406         let (known, collisions) = List.fold_left updater (
    apriori, collisions) funcs in
407         (StringMap.add meth_name known methods, collisions) in
408
409     let skip_init meth_name funcs acc = match meth_name with
410         | "init" -> acc
411         | _ -> check_sigs meth_name funcs acc in
412
413     let check_class_meths aklass parent_methods =
414         let methods = StringMap.find aklass data.methods in
415         StringMap.fold skip_init methods (parent_methods, []) in
416
417     let dfs_explorer aklass methods collisions =
418        match check_class_meths aklass methods with
419             | (methods, []) -> (methods, collisions)
420             | (methods, cols) -> (methods, (build_collisions
    aklass cols false)::collisions) in
421
422     match dfs_errors data dfs_explorer StringMap.empty [] with
423         | [] -> Left(data)
424         | collisions -> Right(collisions)
425
426 (**
427     Verifies that each class is able to be instantiated.
428     @param data A class_data record
429     @return Either the data is returned in Left or a list of
    uninstantiable classes in Right
430   *)
431 let verify_instantiable data =
432     let uninstantiable klass =
433         let inits = class_method_lookup data klass "init" in
434         not (List.exists (fun func -> func.section <> Privates)
    inits) in
435     let klasses = StringSet.elements data.known in
436     match List.filter uninstantiable klasses with
```

```
437             | [] -> Left(data)
438             | bad -> Right(bad)
439
440     (**
441         Given a class and a list of its ancestors, build a map
            detailing the distance
442         between the class and any of its ancestors. The distance is
            the number of hops
443         one must take to get from the given class to the ancestor.
            The distance between
444         an Object and itself should be 0, and the largest distance
            should be to object.
445         @param klass The class to build the table for
446         @param ancestors The list of ancestors of the given class.
447         @return A map from class names to integers
448       *)
449     let build_distance klass ancestors =
450         let map_builder (map, i) item = (StringMap.add item i map, i
            +1) in
451         fst (List.fold_left map_builder (StringMap.empty, 0)
            ancestors)
452
453     (**
454         Add a class (class name - string) -> class (class name -
            string) -> distance (int option)
455         table a given class_data record. The distance is always a
            positive integer and so the
456         first type must be either the same as the second or a
            subtype, else None is returned.
457         Note that this requires that the ancestor map be built.
458         @param data The class_data record to update.
459         @return The class_data record with the distance map added.
460       *)
461     let build_distance_map data =
462         let distance_map = StringMap.mapi build_distance data.
            ancestors in
463         { data with distance = distance_map }
464
465     (**
466         Update the refinement dispatch uid table with a given set of
             refinements.
467         @param parent The class the refinements will come from
468         @param refines A list of refinements
469         @param table The refinement dispatch table
470         @return The updated table
471       *)
472     let update_refinable parent refines table =
473         let toname f = match f.host with
474             | Some(host) -> host
475             | _ -> raise(Invalid_argument("Compiler error; we have
            refinement without host for " ^ f.name ^ " in " ^ f.inklass
            ^ "."))) in
476         let folder amap f = add_map_list (toname f) f amap in
477         let map = if StringMap.mem parent table then StringMap.find
            parent table else StringMap.empty in
478         let map = List.fold_left folder map refines in
479         StringMap.add parent map table
```

```
480
481 (**
482     Add the refinable (class name -> host.name -> refinables
        list) table to the
483     given class_data record, returning the updated record.
484     @param data A class_data record info
485     @return A class_data object with the refinable updated
486   *)
487 let build_refinable_map data =
488     let updater klass_name aklass table = match klass_name with
489         | "Object" -> table
490         | _ -> let parent = klass_to_parent aklass in
        update_refinable parent aklass.sections.refines table in
491     let refinable = StringMap.fold updater data.classes
        StringMap.empty in
492     { data with refinable = refinable}
493
494 (** These are just things to pipe together building a class_data
        record pipeline *)
495 let initial_data klasses = match initialize_class_data klasses
        with
496     | Left(data) -> Left(data)
497     | Right(collisions) -> Right(DuplicateClasses(StringSet.
        elements collisions))
498 let append_children data = Left(build_children_map data)
499 let append_parent data = Left(build_parent_map data)
500 let test_tree data = match is_tree_hierarchy data with
501     | None -> Left(data)
502     | Some(problem) -> Right(HierarchyIssue(problem))
503 let append_ancestor data = Left(build_ancestor_map data)
504 let append_distance data = Left(build_distance_map data)
505 let append_variables data = match build_class_var_map data with
506     | Left(data) -> Left(data)
507     | Right(collisions) -> Right(DuplicateVariables(collisions))
508 let test_types data = match verify_typed data with
509     | Left(data) -> Left(data)
510     | Right(bad) -> Right(UnknownTypes(bad))
511 let test_fields data = match check_field_collisions data with
512     | Left(data) -> Left(data)
513     | Right(collisions) -> Right(DuplicateFields(collisions))
514 let append_methods data = match build_class_method_map data with
515     | Left(data) -> Left(data)
516     | Right(collisions) -> Right(ConflictingMethods(collisions))
517 let test_init data = match verify_instantiable data with
518     | Left(data) -> Left(data)
519     | Right(bad) -> Right(Uninstantiable(bad))
520 let test_inherited_methods data = match
        check_ancestor_signatures data with
521     | Left(data) -> Left(data)
522     | Right(collisions) -> Right(ConflictingInherited(collisions
        ))
523 let append_refines data = match build_class_refinement_map data
        with
524     | Left(data) -> Left(data)
525     | Right(collisions) -> Right(ConflictingRefinements(
        collisions))
526 let test_signatures data = match type_check_signatures data with
```

```
527     | Left(data) -> Left(data)
528     | Right(bad) -> Right(PoorlyTypedSigs(bad))
529 let append_refinable data = Left(build_refinable_map data)
530 let append_mains data = match build_main_map data with
531     | Left(data) -> Left(data)
532     | Right(collisions) -> Right(MultipleMains(collisions))
533
534 let test_list =
535     [ append_children ; append_parent ; test_tree ;
    append_ancestor ;
536       append_distance ; append_variables ; test_fields ;
    test_types ;
537       append_methods ; test_init ; test_inherited_methods ;
    append_refines ;
538       test_signatures ; append_refinable ; append_mains ]
539
540 let production_list =
541     [ append_children ; append_parent ; test_tree ;
    append_ancestor ;
542       append_distance ; append_variables ; test_fields ;
    append_methods ;
543       test_init ; append_refines ; append_mains ]
544
545 let build_class_data klasses = seq (initial_data klasses)
    test_list (*production_list*)
546 let build_class_data_test klasses = seq (initial_data klasses)
    test_list
547
548 let append_leaf_known aklass data =
549     let updated = StringSet.add aklass.klass data.known in
550     if StringSet.mem aklass.klass data.known
551         then Right(DuplicateClasses([aklass.klass]))
552         else Left({ data with known = updated })
553 let append_leaf_classes aklass data =
554     let updated = StringMap.add aklass.klass aklass data.classes
     in
555     Left({ data with classes = updated })
556 let append_leaf_tree aklass data =
557     (* If we assume data is valid and data has aklass's parent
    then we should be fine *)
558     let parent = klass_to_parent aklass in
559     if StringMap.mem parent data.classes
560         then Left(data)
561         else Right(HierarchyIssue("Appending a leaf without a
    known parent."))
562 let append_leaf_children aklass data =
563     let parent = klass_to_parent aklass in
564     let updated = add_map_list parent aklass.klass data.children
     in
565     Left({ data with children = updated })
566 let append_leaf_parent aklass data =
567     let parent = klass_to_parent aklass in
568     let updated = StringMap.add aklass.klass parent data.parents
     in
569     Left({ data with parents = updated })
570 let append_leaf_variables aklass data = match build_var_map
    aklass with
```

```
571         | Left(vars) ->
572             let updated = StringMap.add aklass.klass vars data.
            variables in
573             Left({ data with variables = updated })
574         | Right(collisions) -> Right(DuplicateVariables([(aklass.
            klass, collisions)]))
575     let append_leaf_test_fields aklass data =
576         let folder collisions var = match class_field_lookup data (
            klass_to_parent aklass) var with
577             | Some((_, _, Privates)) -> collisions
578             | Some((ancestor, _, section)) -> (ancestor, var)::
            collisions
579             | _ -> collisions in
580         let variables = List.flatten (List.map snd (
            klass_to_variables aklass)) in
581         let varnames = List.map snd variables in
582         match List.fold_left folder [] varnames with
583             | [] -> Left(data)
584             | collisions -> Right(DuplicateFields([(aklass.klass,
            collisions)]))
585     let append_leaf_type_vars aklass data =
586         match type_check_variables data aklass with
587             | [] -> Left(data)
588             | bad -> Right(UnknownTypes([(aklass.klass, bad)]))
589     let append_leaf_methods aklass data = match build_method_map
            aklass with
590         | Left(meths) ->
591             let updated = StringMap.add aklass.klass meths data.
            methods in
592             Left({ data with methods = updated })
593         | Right(collisions) -> Right(ConflictingMethods([
            build_collisions aklass.klass collisions false]))
594     let append_leaf_test_inherited aklass data =
595         let folder collisions meth = match
            class_ancestor_method_lookup data aklass.klass meth.name
            true with
596             | [] -> collisions
597             | funcs -> match List.filter (conflicting_signatures
            meth) funcs with
598                 | [] -> collisions
599                 | cols -> cols in
600         let skipinit (func : Ast.func_def) = match func.name with
601             | "init" -> false
602             | _ -> true in
603         let functions = List.flatten (List.map snd (klass_to_methods
             aklass)) in
604         let noninits = List.filter skipinit functions in
605         match List.fold_left folder [] noninits with
606             | [] -> Left(data)
607             | collisions -> Right(ConflictingInherited([
            build_collisions aklass.klass collisions false]))
608     let append_leaf_instantiable aklass data =
609         let is_init mem = match mem with
610             | InitMem(_) -> true
611             | _ -> false in
612         if List.exists is_init (aklass.sections.protects) then Left(
            data)
```

```
613       else if List.exists is_init (aklass.sections.publics) then
          Left(data)
614       else Right(Uninstantiable([aklass.klass]))
615   let append_leaf_refines aklass data = match build_refinement_map
           aklass with
616       | Left(refs) ->
617           let updated = StringMap.add aklass.klass refs data.
          refines in
618           Left({ data with refines = updated })
619       | Right(collisions) -> Right(ConflictingRefinements([
          build_collisions aklass.klass collisions true]))
620   let append_leaf_mains aklass data = match aklass.sections.mains
          with
621       | [] -> Left(data)
622       | [main] ->
623           let updated = StringMap.add aklass.klass main data.mains
           in
624           Left({ data with mains = updated })
625       | _ -> Right(MultipleMains([aklass.klass]))
626   let append_leaf_signatures aklass data = match type_check_class
          data aklass with
627       | Left(data) -> Left(data)
628       | Right(bad) -> Right(PoorlyTypedSigs([bad]))
629   let append_leaf_ancestor aklass data =
630       let parent = klass_to_parent aklass in
631       let ancestors = aklass.klass::(StringMap.find parent data.
          ancestors) in
632       let updated = StringMap.add aklass.klass ancestors data.
          ancestors in
633       Left({ data with ancestors = updated })
634   let append_leaf_distance aklass data =
635       let ancestors = StringMap.find aklass.klass data.ancestors
          in
636       let distance = build_distance aklass.klass ancestors in
637       let updated = StringMap.add aklass.klass distance data.
          distance in
638       Left({ data with distance = updated })
639   let append_leaf_refinable aklass data =
640       let parent = klass_to_parent aklass in
641       let updated = update_refinable parent aklass.sections.
          refines data.refinable in
642       Left({ data with refinable = updated })
643
644   let production_leaf =
645       [ append_leaf_known ; append_leaf_classes ;
          append_leaf_children ; append_leaf_parent ;
646         append_leaf_ancestor ; append_leaf_distance ;
          append_leaf_variables ; append_leaf_test_fields ;
647         append_leaf_methods ; append_leaf_instantiable ;
          append_leaf_refines ; append_leaf_signatures ;
648         append_leaf_mains ]
649   let test_leaf =
650       [ append_leaf_known ; append_leaf_classes ;
          append_leaf_children ; append_leaf_parent ;
651         append_leaf_ancestor ; append_leaf_distance ;
          append_leaf_variables ; append_leaf_test_fields ;
652         append_leaf_type_vars ; append_leaf_methods ;
```

```
    append_leaf_instantiable ; append_leaf_test_inherited ;
653       append_leaf_refines ; append_leaf_refinable ;
    append_leaf_mains ]
654
655 let leaf_with_klass actions data klass = seq (Left(data)) (List.
    map (fun f -> f klass) actions)
656 let append_leaf = leaf_with_klass test_leaf (* production_leaf
    *)
657 let append_leaf_test = leaf_with_klass test_leaf
658
659 let append_leaf_test data aklass =
660     let with_klass f = f aklass in
661     let actions =
662         [ append_leaf_known ; append_leaf_classes ;
    append_leaf_children ; append_leaf_parent ;
663           append_leaf_ancestor ; append_leaf_distance ;
    append_leaf_variables ; append_leaf_test_fields ;
664           append_leaf_type_vars ; append_leaf_methods ;
    append_leaf_instantiable ; append_leaf_test_inherited ;
665           append_leaf_refines ; append_leaf_refinable ;
    append_leaf_mains ] in
666     seq (Left(data)) (List.map with_klass actions)
667
668 (**
669     Print class data out to stdout.
670   *)
671 let print_class_data data =
672     let id x = x in
673     let from_list lst = Format.sprintf "[%s]" (String.concat ",
    " lst) in
674     let table_printer tbl name stringer =
675         let printer p s i = Format.sprintf "\t%s : %s => %s\n" p
     s (stringer i) in
676         print_string (name ^ ":\n");
677         print_lookup_table tbl printer in
678     let map_printer map name stringer =
679         let printer k i = Format.sprintf "\t%s => %s\n" k (
    stringer i) in
680         print_string (name ^ ":\n");
681         print_lookup_map map printer in
682
683     let func_list = function
684         | [one] -> full_signature_string one
685         | list -> let sigs = List.map (fun f -> "\n\t\t" ^ (
    full_signature_string f)) list in
686             String.concat "" sigs in
687
688     let func_of_list funcs =
689         let sigs = List.map (fun f -> "\n\t\t" ^ f.inklass ^ "->
    " ^ (full_signature_string f)) funcs in
690         String.concat "" sigs in
691
692     let class_printer cdef =
693         let rec count sect = function
694             | (where, members)::_ when where = sect -> List.
    length members
695             | _::rest -> count sect rest
```

```
696             | [] -> raise(Failure("The impossible happened --
    searching for a section that should exist doesn't exist."))
    in
697         let vars = klass_to_variables cdef in
698         let funcs = klass_to_functions cdef in
699         let format = ""^^"from %s:  M(%d/%d/%d) F(%d/%d/%d) R(%d
    ) M(%d)" in
700         let parent = match cdef.klass with
701             | "Object" -> "------"
702             | _ -> klass_to_parent cdef in
703         Format.sprintf format parent
704             (count Privates funcs) (count Protects funcs) (count
     Publics funcs)
705             (count Privates vars) (count Protects vars) (count
    Publics vars)
706             (count Refines funcs) (count Mains funcs) in
707
708     let print_list list =
709         let rec list_printer spaces endl space = function
710             | [] -> if endl then () else print_newline ()
711             | list when spaces = 0 -> print_string "\t";
    list_printer 8 false false list
712             | list when spaces > 60 -> print_newline ();
    list_printer 0 true false list
713             | item::rest ->
714               if space then print_string " " else ();
715               print_string item;
716               list_printer (spaces + String.length item) false
    true rest in
717         list_printer 0 true false list in
718
719     Printf.printf "Types:\n";
720     print_list (StringSet.elements data.known);
721     print_newline ();
722     map_printer data.classes "Classes" class_printer;
723     print_newline ();
724     map_printer data.parents "Parents" id;
725     print_newline ();
726     map_printer data.children "Children" from_list;
727     print_newline ();
728     map_printer data.ancestors "Ancestors" from_list;
729     print_newline ();
730     table_printer data.distance "Distance" string_of_int;
731     print_newline ();
732     table_printer data.variables "Variables" (fun (sect, t) ->
    Format.sprintf "%s %s" (section_string sect) t);
733     print_newline ();
734     table_printer data.methods "Methods" func_list;
735     print_newline ();
736     table_printer data.refines "Refines" func_list;
737     print_newline ();
738     map_printer data.mains "Mains" full_signature_string;
739     print_newline ();
740     table_printer data.refinable "Refinable" func_of_list
741
742
743 (* ERROR HANDLING *)
```

```
744
745 let args lst = Format.sprintf "(%s)" (String.concat ", " lst)
746 let asig (name, formals) = Format.sprintf "%s %s" name (args
    formals)
747 let aref (name, formals) = asig (name, formals)
748
749 let dupvar (klass, vars) = match vars with
750     | [var] -> "Class " ^ klass ^ "'s instance variable " ^ var
    ^ " is multiply declared"
751     | _ -> "Class " ^ klass ^ " has multiply declared variables:
     [" ^ (String.concat ", " vars) ^ "]"
752
753 let dupfield (klass, fields) = match fields with
754     | [(ancestor, var)] -> "Class " ^ klass ^ "'s instance
    variable " ^ var ^ " was declared in ancestor " ^ ancestor ^
     "."
755     | _ -> "Class " ^ klass ^ " has instance variables declared
    in ancestors: [" ^ String.concat ", " (List.map (fun (a, v)
    -> v ^ " in " ^ a) fields) ^ "]"
756
757 let show_vdecls vs = "[" ^ String.concat ", " (List.map (fun (t,
    v) -> t ^ ":" ^ v) vs) ^ "]"
758
759 let unknowntypes (klass, types) = match types with
760     | [(vtype, vname)] -> "Class " ^ klass ^ "'s
    instancevariable " ^ vname ^ " has unknown type " ^ vtype ^
    "."
761     | _ -> "Class " ^ klass ^ " has instance variables with
    unknown types: " ^ show_vdecls types
762
763 let badsig1 klass (func, ret, params) = match ret, params with
764     | None, params -> "Class " ^ klass ^ "'s " ^ func ^ " has
    poorly typed parameters: " ^ show_vdecls params
765     | Some(rval), [] -> "Class " ^ klass ^ "'s " ^ func ^ " has
    an invalid return type: " ^ rval ^ "."
766     | Some(rval), p -> "Class " ^ klass ^ "'s " ^ func ^ " has
    invalid return type " ^ rval ^ " and poorly typed parameters
    : " ^ show_vdecls p
767 let badsig (klass, badfuncs) = String.concat "\n" (List.map (
    badsig1 klass) badfuncs)
768
769 let dupmeth (klass, meths) =
770     match meths with
771         | [(name, formals)] -> Format.sprintf "Class %s's method
     %s has multiple implementations taking %s" klass name (args
     formals)
772         | _ -> Format.sprintf "Class %s has multiple methods
    with conflicting signatures:\n\t%s" klass (String.concat "\n
    \t" (List.map asig meths))
773
774 let dupinherit (klass, meths) =
775     match meths with
776         | [(name, formals)] -> Format.sprintf "Class %s's method
     %s has conflicts with an inherited method taking %s" klass
    name (args formals)
777         | _ -> Format.sprintf "Class %s has multiple methods
    with conflicting with inherited methods:\n\t%s" klass (
```

```
    String.concat "\n\t" (List.map asig meths))
778
779 let dupref (klass, refines) =
780     match refines with
781         | [refine] -> Format.sprintf "Class %s refinment %s is
        multiply defined." klass (aref refine)
782         | _ -> Format.sprintf "Class %s has multiple refinements
         multiply defined:\n\t%s" klass (String.concat "\n\t" (List.
        map aref refines))
783
784 let errstr = function
785     | HierarchyIssue(s) -> s
786     | DuplicateClasses(klasses) -> (match klasses with
787         | [klass] -> "Multiple classes named " ^ klass
788         | _ -> "Multiple classes share the names [" ^ (String.
        concat ", " klasses) ^ "]")
789     | DuplicateVariables(list) -> String.concat "\n" (List.map
        dupvar list)
790     | DuplicateFields(list) -> String.concat "\n" (List.map
        dupfield list)
791     | UnknownTypes(types) -> String.concat "\n" (List.map
        unknowntypes types)
792     | ConflictingMethods(list) -> String.concat "\n" (List.map
        dupmeth list)
793     | ConflictingInherited(list) -> String.concat "\n" (List.map
         dupinherit list)
794     | PoorlyTypedSigs(list) -> String.concat "\n" (List.map
        badsig list)
795     | Uninstantiable(klasses) -> (match klasses with
796         | [klass] -> "Class " ^ klass ^ " does not have a usable
         init."
797         | _ -> "Multiple classes are not instantiable: [" ^
        String.concat ", " klasses ^ "]")
798     | ConflictingRefinements(list) -> String.concat "\n" (List.
        map dupref list)
799     | MultipleMains(klasses) -> (match klasses with
800         | [klass] -> "Class " ^ klass ^ " has multiple mains
        defined."
801         | _ -> "Multiple classes have more than one main: [" ^
        String.concat ", " klasses ^ "]")
```

Source 130: `KlassData.ml`