
GAMMA
Γαγ

GAMMA: A Strict yet Fair Programming Language

Ben Caimano - blc2129@columbia.edu
Weiyuan Li - wl2453@columbia.edu
Matthew H Maycock - mhm2159@columbia.edu
Arthy Padma Anandhi Sundaram - as4304@columbia.edu

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.

Contents

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 LRM

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.

```
    <<stmt1_statement>>
    <<stmt2_statement>>
    <<...>>
```

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:

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

Table 1: Operator Precedence

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.

```
{{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⟩ ⇒
:=
| **+=**
| **-=**
| ***=**
| **/=**
| **%=**
| **ˆ=**

• *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 Planning

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.)

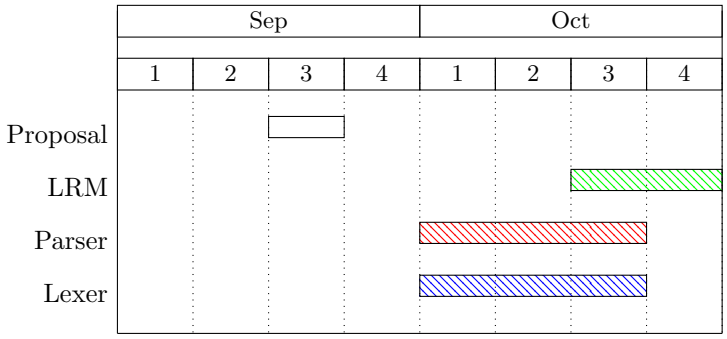
```
let unify_it var =
    match var with
    | X(y)       ->   y                          (* pop out *)
    | Y(y) :: _ ->   to_X y                      (* convert *)
    | Z(y)       ->
        to_X (to_Y (List.hd (List.rest y))   (* mangle *)
```

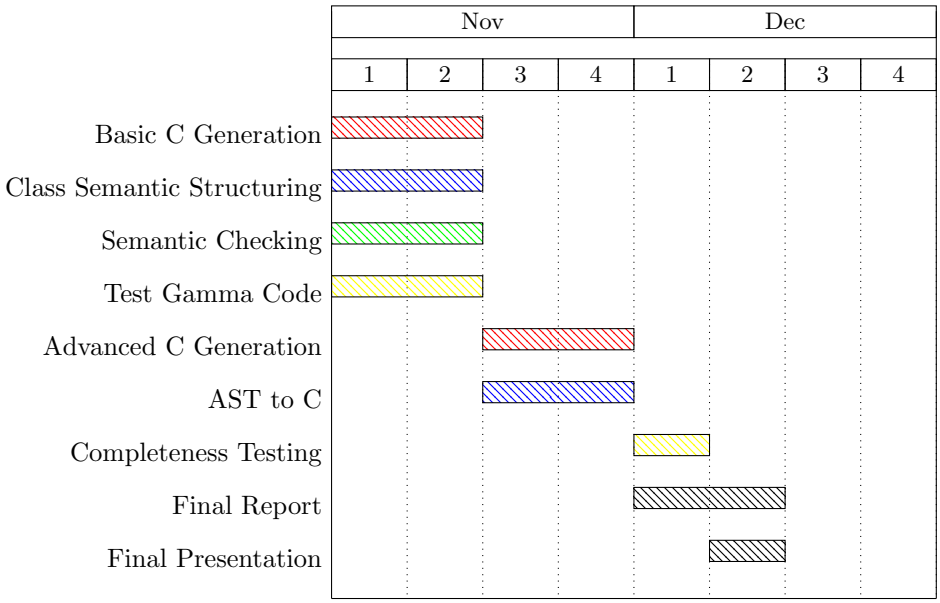
All records should maintain a basic standard of alignement and indentation for readibility. (Field names, colons, and type specs should all be aligned to like.)

```
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

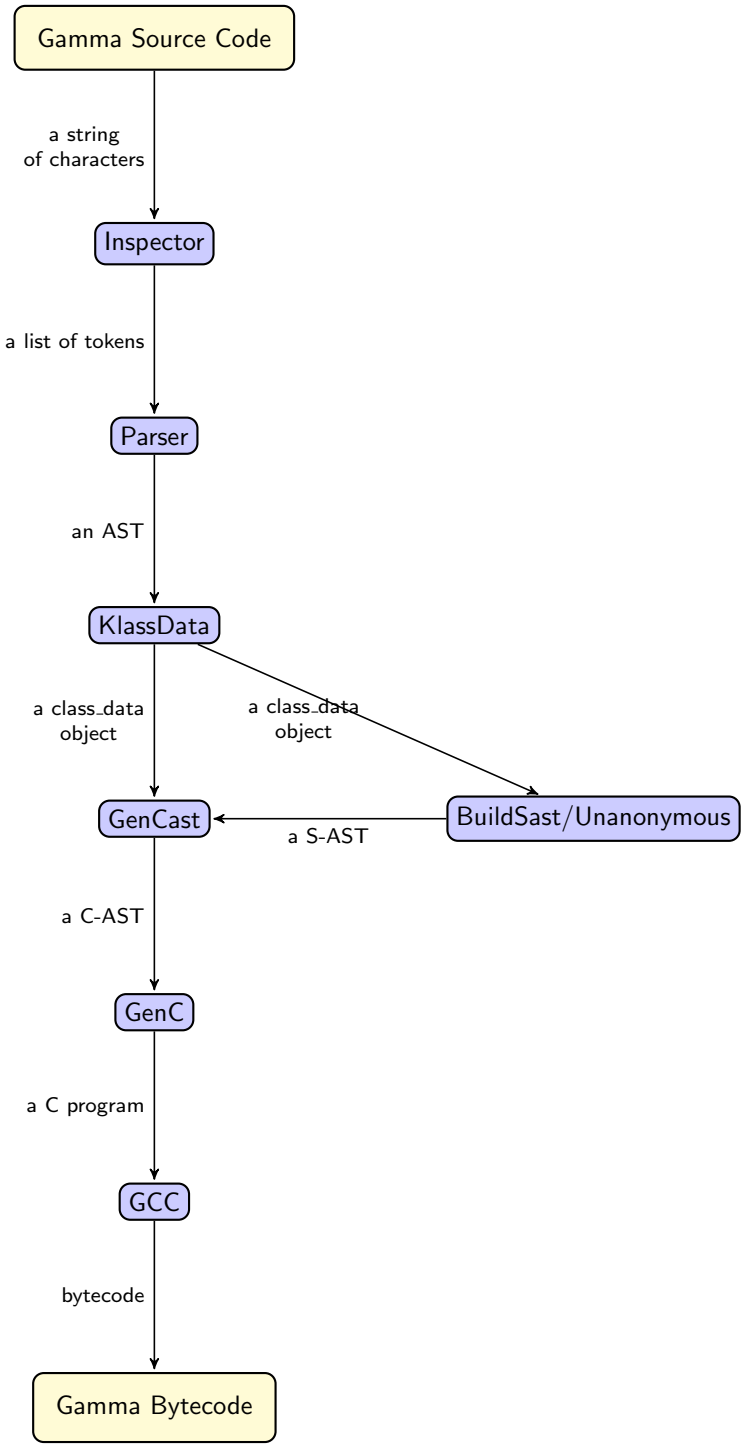
4.6 Project Log

- 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

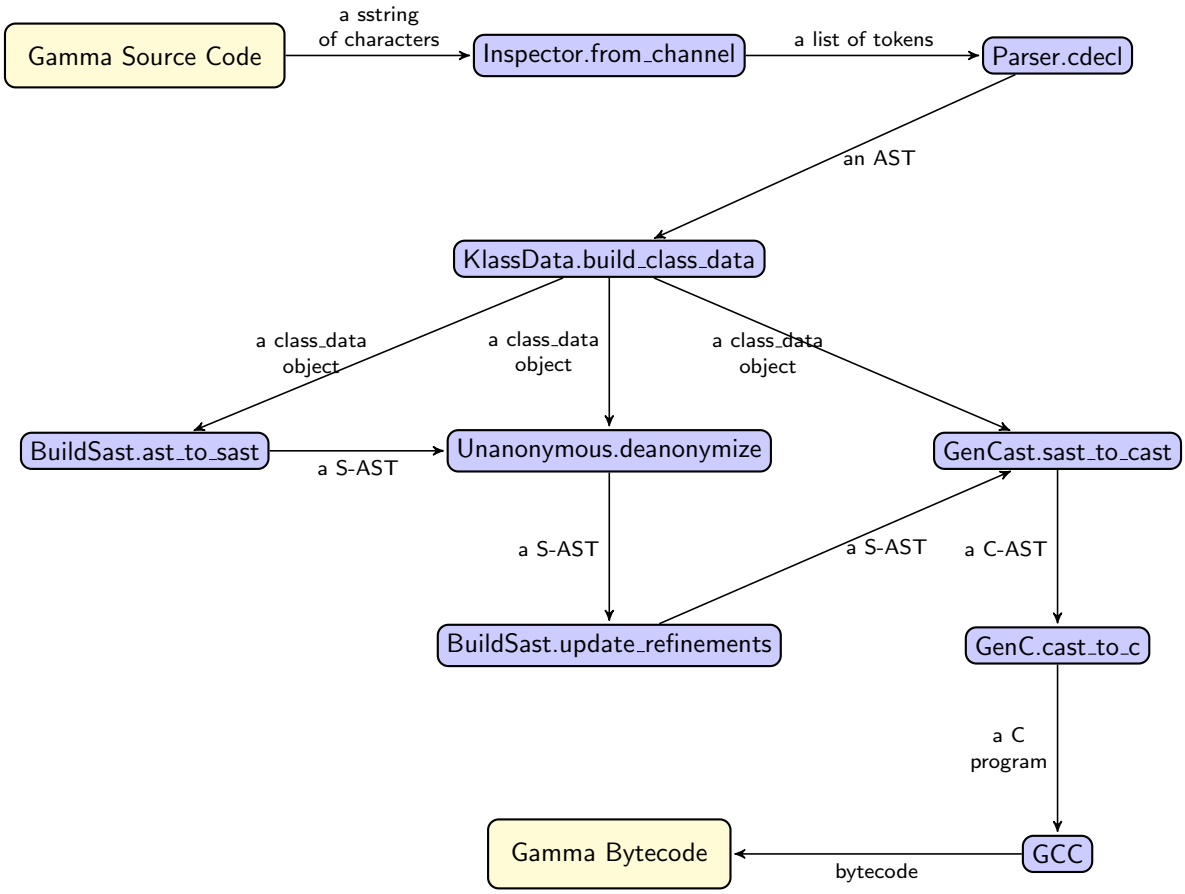
5 Architectural Design

5.1 Block Diagrams

5.1.1 Structure by Module



5.1.2 Structure by Toplevel Ocaml Function



5.2 Component Connective Interfaces

```
let get_data ast =
    let (which, builder) = if (Array.length Sys.argv <= 2)
        then ("Normal", KlassData.build_class_data)
        else ("Experimental", KlassData.build_class_data_test) in
    output_string (Format.sprintf " * Using %s KlassData Builder" which);
    match builder ast with
        | Left(data) -> data
        | Right(issue) -> Printf.fprintf stderr "%s\n" (KlassData.errstr issue); exit 1

let do_deanon klass_data sast = match Unanonymous.deanonymize klass_data sast with
    | Left(result) -> result
    | Right(issue) -> Printf.fprintf stderr "Error Deanonymizing:\n%s\n" (KlassData.
    errstr issue); exit 1

let source_cast _ =
    output_string " * Reading Tokens...";
    let tokens = with_file Inspector.from_channel Sys.argv.(1) in
    output_string " * Parsing Tokens...";
    let ast = Parser.cdecls (WhiteSpace.lextoks tokens) (Lexing.from_string "") in
    output_string " * Generating Global Data...";
    let klass_data = get_data ast in
```

```
    output_string " * Building Semantic AST...";
    let sast = BuildSast.ast_to_sast klass_data in
    output_string " * Deanonymizing Anonymous Classes.";
    let (klass_data, sast) = do_deanon klass_data sast in
    output_string " * Rebinding refinements.";
    let sast = BuildSast.update_refinements klass_data sast in
    output_string " * Generating C AST...";
    GenCast.sast_to_cast klass_data sast

let main _ =
    Printexc.record_backtrace true;
    output_string "/* Starting Build Process...";
    try
        let source = source_cast () in
        output_string " * Generating C...";
        output_string " */";
        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
```

Example 13: The Main Ray Compiler Ocaml (Trimmed)

The primary functionality of the compiler is collected into convenient ocaml modules. From the lexer to the C-AST to C conversion, the connections are the passing of data representations of the current step to the main function of the following module. We utilize as data representations three ASTs (basic, semantic, and C-oriented), a more searchable tabulation of class data, and, of course, a source string and a list of tokens. The presence of Anonymous classes complicates the building of the array of class data and the sast as can be seen by the functor `do_deanom`. Our testing experiences also lead to a more verbose form of AST generation for experimental features, hence `get_data`. In all other cases, the result of the previous step is simply stored in a variable by `let` and passed to the next step. The output of ray is a C file. The user must manually do the final step of compiling this file to bytecode using GCC.

5.3 Component Authorship

Each component was a combined effort. This is expressed somewhat in the project role section. However, for clarity, it will be reexpressed in terms of the module archetecture above:

- Inspector - Weiyuan/Arthy
- Parser - Ben/Arthy/Matthew
- KlassData - Matthew
- Unanonymous - Matthew
- BuildSast - Matthew/Weiyuan/Arthy
- GenCast - Matthew/Weiyuan/Ben/Arthy

- GenC - Matthew/Weiyuan/Ben/Arthy
- GCC - GNU

6 Test Plan

6.1 Examples Gamma Programs

6.1.1 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 14: "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[] = {
    "t_Boolean", "t_Float", "t_HelloWorld", "t_Integer", "t_Object", "t_Printer",
    "t_Scanner", "t_String", "t_System"
};


/*
 * Enums used to reference into ancestry meta-info strings.
 */
```

```
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(MAKE_NEW(
        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 15: "Hello World in Compiled C"

6.1.2 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.)

```
1  class IOTest:
2    public:
3      init():
4        super()
5
6      void interact():
7        Printer p := system.out
8        Integer i := promptInteger("Please enter an integer")
9        Float f := promptFloat("Please enter a float")
10       p.printString("Sum of integer + float = ")
11       p.printFloat(i.toF() + f)
12       p.printString("\n")
13
14   private:
15     void prompt(String msg):
16       system.out.printString(msg)
17       system.out.printString(": ")
18
19     Integer promptInteger(String msg):
20       prompt(msg)
21       return system.in.scanInteger()
22
23     Float promptFloat(String msg):
24       prompt(msg)
25       return system.in.scanFloat()
26
27   main(System system, String[] args):
28     IOTest test := new IOTest()
29     test.interact()
```

Example 16: "I/O in Gamma"

```
1 /* Starting Build Process...
2  * Reading Tokens...
3  * Parsing Tokens...
4  * Generating Global Data...
5  * 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.
 */
/* 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) */
/* Place-holder for struct t_Printer *printer_init(struct t_Printer *this, struct
    t_Boolean *v_stdout) */
/* Place-holder for void printer_print_float(struct t_Printer *this, struct t_Float *
    v_arg) */
/* Place-holder for void printer_print_integer(struct t_Printer *this, struct t_Integer *
    v_arg) */
/* Place-holder for void printer_print_string(struct t_Printer *this, struct t_String *
    v_arg) */
/* Place-holder for struct t_Scanner *scanner_init(struct t_Scanner *this) */
/* Place-holder for struct t_Float *scanner_scan_float(struct t_Scanner *this) */
/* Place-holder for struct t_Integer *scanner_scan_integer(struct t_Scanner *this) */
```

```
/* Place-holder for struct t_String *scanner_scan_string(struct t_Scanner *this) */
/* Place-holder for struct t_String *string_init(struct t_String *this) */
/* Place-holder for void system_exit(struct t_System *this, struct t_Integer *v_code) */
/* Place-holder for struct t_System *system_init(struct t_System *this) */

struct t_IOTest *f_00000001_init(struct t_IOTest *this)
{
    object_init((struct t_Object *)(this));
    return ( this );
}


void f_00000002_interact(struct t_IOTest *this)
{
    struct t_Printer *v_p = ((struct t_Printer *)(((this->Object).v_system)->System.v_out
    ));
    struct t_Integer *v_i = ((struct t_Integer *)(f_00000004_promptInteger(((struct
    t_IOTest *)(this)), LIT_STRING("Please enter an integer"))));
    struct t_Float *v_f = ((struct t_Float *)(f_00000005_promptFloat(((struct t_IOTest *)
    (this)), LIT_STRING("Please enter a float"))));
    ( printer_print_string(((struct t_Printer *)(v_p)), LIT_STRING("Sum of integer +
    float = ")) );
    ( printer_print_float(((struct t_Printer *)(v_p)), ADD_FLOAT_FLOAT( integer_to_f(((
    struct t_Integer *)(v_i))) , v_f )) );
    ( printer_print_string(((struct t_Printer *)(v_p)), LIT_STRING("\n")) );
}


void f_00000003_prompt(struct t_IOTest *this, struct t_String *v_msg)
{
    ( printer_print_string(((struct t_Printer *)(((this->Object).v_system)->System.v_out)
    ), v_msg) );
    ( printer_print_string(((struct t_Printer *)(((this->Object).v_system)->System.v_out)
    ), LIT_STRING(": ")) );
}


struct t_Integer *f_00000004_promptInteger(struct t_IOTest *this, struct t_String *v_msg)
{
    ( f_00000003_prompt(((struct t_IOTest *)(this)), v_msg) );
    return ( scanner_scan_integer(((struct t_Scanner *)(((this->Object).v_system)->System
    .v_in))) );
}


struct t_Float *f_00000005_promptFloat(struct t_IOTest *this, struct t_String *v_msg)
{
    ( f_00000003_prompt(((struct t_IOTest *)(this)), v_msg) );
    return ( scanner_scan_float(((struct t_Scanner *)(((this->Object).v_system)->System.
    v_in))) );
}


void f_00000006_main(struct t_System *v_system, struct t_String **v_args)
{
    struct t_IOTest *v_test = ((struct t_IOTest *)(f_00000001_init(MAKE_NEW(IOTest))));
    ( f_00000002_interact(((struct t_IOTest *)(v_test))) );
}



/*
 * Dispatch looks like this.
 */
```

```
187
188 /*
189  * Array allocators.
190  */
191
192
193 /*
194  * The main.
195  */
196 #define CASES "IOTest"
197
198 int main(int argc, char **argv) {
199     INIT_MAIN(CASES)
200     if (!strncmp(gmain, "IOTest", 7)) { f_00000006_main(&global_system, str_args); return
        0; }
201     FAIL_MAIN(CASES)
202     return 1;
203 }
```

Example 17: "I/O in Compiled C"

6.1.3 Argument Reading

This program prints out each argument passed to the program.

```
1  class Test:
2    public:
3      init():
4        super()
5
6    main(System sys, String[] args):
7      Integer i := 0
8      Printer p := sys.out
9
10     while (i < sys.argc):
11       p.printString("arg[")
12       p.printInteger(i)
13       p.printString("] = ")
14       p.printString(args[i])
15       p.printString("\n")
16       i += 1
```

Example 18: "Argument Reading in Gamma"

```
1  /* Starting Build Process...
2   * Reading Tokens...
3   * Parsing Tokens...
4   * Generating Global Data...
5   * Using Normal KlassData Builder
6   * Building Semantic AST...
7   * Deanonymizing Anonymous Classes.
8   * Rebinding refinements.
9   * Generating C AST...
10  * Generating C...
11  */
12
13
14 /*
15  * 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_Integer", "t_Object", "t_Printer", "t_Scanner",
    "t_String", "t_System", "t_Test"
};


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


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



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

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



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



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

    struct {
        struct t_System *v_system;
    } Object;

```

```
81      struct { BYTE empty_vars; } Test;
82  };
83
84
85
86
87  /*
88   * Header file containing information regarding built in functions.
89   */
90  #include "gamma-builtin-functions.h"
91
92
93
94  /*
95   * All of the function prototypes we need to do magic.
96   */
97  struct t_Test *f_00000001_init(struct t_Test *);
98  void f_00000002_main(struct t_System *, struct t_String **);
99
100
101 /*
102  * All the dispatching functions we need to continue the magic.
103  */
104
105
106 /*
107  * Array allocators also do magic.
108  */
109
110
111 /*
112  * All of the functions we need to run the program.
113  */
114 /* Place-holder for struct t_Boolean *boolean_init(struct t_Boolean *this) */
115 /* Place-holder for struct t_Float *float_init(struct t_Float *this) */
116 /* Place-holder for struct t_Integer *float_to_i(struct t_Float *this) */
117 /* Place-holder for struct t_Integer *integer_init(struct t_Integer *this) */
118 /* Place-holder for struct t_Float *integer_to_f(struct t_Integer *this) */
119 /* 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 19: "Argument Reading in Compiled C"

6.2 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.

6.2.1 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()
      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
    p.printString("Sum of integer = ")
    p.printFloat(ab.overview())
    p.printString("\n")
```

Test Source 3: "Binary Operations Between Incompatible Types"

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

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

    Integer badReturn():
      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.

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

    Integer badReturn():
      return
```

Test Source 5: "Empty Return Statement"

A return statement should return something.

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

    void badReturn():
      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)
      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 Parent
    Printer p := system.out
    p.printString("Sum of integer = ")
    p.printInteger(ab.overview())
    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.

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

Test Source 10: "unimplemented Refinement with Refinable"

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

6.2.2 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.

6.2.3 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
```

```
      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")
```

Test Source 15: "Add Floats"

These tests add numeric literal objects together.

```
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):
```

Test Source 16: "Multiplication"

```
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")
```

Test Source 17: "Divition"

These tests form products/quotions of Floats/Integers.

```
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")
```

Test Source 18: "Modulus"

This test forms the modulus of Integers.

```
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()
```

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")
```

```
13
14    main(System system, String[] args):
15      Test test := new Test()
16      test.interact()
```

Test Source 20: "Literal Casting and Subtraction"

```
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 21: "Literal Casting and Multiplication"

```
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("float/Integer = ")
11        p.printFloat(f/i.toF())
12        p.printString("\n")
13
14    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
```

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

Test Source 23: "Literal Casting and Exponentiation"

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

```
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()
```

Test Source 24: "Superclass Typing"

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

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

    void out(String msg):
      system.out.printString(msg)
      line()

  public:
    init():
      super()
      Integer a:=2
      Integer b:=3
      Integer c

      /* less and less and equal*/
      if (a<2)  { system.out.printString("1. a=2 a<2 shouldnot print\n"); }
      elsif (a<=2)  { system.out.printString("1. a=2 a<=2 success\n"); }
      else { system.out.printString("1. should never hit here\n"); }


      /* greater and greater than equal */
      if (b>3)  { system.out.printString("2. b=3 b>3 shouldnot print\n"); }
      else  { system.out.printString("2. b=3 b>=3 success\n"); }

      /*Equal and not equal*/
      if (a <> b)  { system.out.printString("3. a!=b success \n"); }
      a:=b
      if (a=b)  { system.out.printString("4. a=b success\n"); }

```

```
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"; }
```

```
      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()
```

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

    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")
```

Test Source 28: "Refinement"

This test checks that basic refinement works.

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

Test Source 29: "Refinable"

This test checks that the refinable keyword works.

```
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

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

  refinement:
    Integer update.setA():
      return 10
    Integer update.setB():
      return -5


class Test:
  protected:
    init():
      super()

  main(System sys, String[] args):
    Parent pop := new Parent("Father")
    Son son := new Son("Son")
    Daughter daughter := new Daughter("Daughter")

    pop.print()
    son.print()
    daughter.print()
    sys.out.printString("----------\n")
    pop.update()
    son.update()
    daughter.update()

    pop.print()
    son.print()
    daughter.print()
```

Test Source 30: "Refinements"

This test makes multiple trivial refinements.

6.2.4 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

      init():
          super()
          a := 1

  private:
      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()
```

Test Source 33: "Functions"

This test probes function scope.

6.2.5 A Complex Test

```
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()
```

Test Source 34: "Complex Scanning"

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

7 Lessions Learned

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.

8 Appendix

```
Int    addInt.gamma
Float  addFloat.gamma
Bool
String

Binop

arith
Add    addInt.gamma addFloat.gamma addMix.gamma addMix.gamma_err
Sub    subMix.gamma
Prod   prodMix.gamma
Div    divMix.gamma
Mod    mod.gamma
Neg
Pow   powMix.gamma

numtest   ifeq.gamma ( will be renamed)
Eq      pass
Neq     pass
Less    pass
Grtr    pass
Leq     pass
Geq     pass
And     pass
Or      pass
Nand    pass
Nor     pass
Xor     pass
Not     pass
nested conditions  not tested

This          ANY
Null
Id            ANY
NewObj        MANY
Anonymous
Literal       ANY
Assign        ANY
Deref
Field         ANY
Invoc         ANY
Unop

refinement
Refine         refine_refinable.gamma  refine_unrefinable.gamma
Refinable      refinable.gamma refinable.gamma_err

Decl           addInt.gamma
If             ifeq.gamma    nested-if-tobetested
While
Expr
Return        ANY
Super

private
public
protect
main
extends     refinement testcase
```

Source 1: "compiler-tests/testcaseregistry"

```
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 2: "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(": ")
```

```
18
19      Integer promptInteger(String msg):
20        prompt(msg)
21        return system.in.scanInteger()
22
23      Float promptFloat(String msg):
24        prompt(msg)
25        return system.in.scanFloat()
26
27    main(System system, String[] args):
28      IOTest test := new IOTest()
29      test.interact()
```

Source 3: "compiler-tests/programs/io.gamma"

```
1   class HelloWorld:
2     public:
3       String greeting
4       init():
5         super()
6         greeting := "Hello World!"
7
8     main(System system, String[] args):
9       HelloWorld hw := new HelloWorld()
10      system.out.printString(hw.greeting)
11      system.out.printString("\n")
```

Source 4: "compiler-tests/programs/helloworld.gamma"

```
1   class Test:
2     public:
3       init():
4         super()
5
6     main(System sys, String[] args):
7       Integer i := 0
8       Printer p := sys.out
9
10      while (i < sys.argc):
11        p.printString("arg[")
12        p.printInteger(i)
13        p.printString("] = ")
14        p.printString(args[i])
15        p.printString("\n")
16        i += 1
```

Source 5: "compiler-tests/programs/args.gamma"

```
1   class Parent:
2     public:
3       init():
4         super()
5
6   class Child extends Parent:
7     public:
8       init():
9         super()
10
```

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

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

Source 6: "compiler-tests/bad/super-assign.gamma"

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

Source 7: "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
    p.printString("Sum of integer = ")
    p.printFloat(ab.overview())
    p.printString("\n")
```

Source 8: "compiler-tests/bad/addMix.gamma"

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

    Integer badReturn():
      return "Hey There"
```

Source 9: "compiler-tests/bad/return1.gamma"

```
class BadAssign:
  public:
    init():
```

```
      super()
      Integer a
      a := 3.4
```

Source 10: "compiler-tests/bad/assign.gamma"

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

Source 11: "compiler-tests/bad/static.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 Parent
    Printer p := system.out
```

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

Source 12: "compiler-tests/bad/refine_refinable.gamma"

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

    Integer badReturn():
      return
```

Source 13: "compiler-tests/bad/return2.gamma"

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

    void badReturn():
      return "Hey There"
```

Source 14: "compiler-tests/bad/return3.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
```

```
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 15: "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 16: "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 17: "compiler-tests/stmts/while.gamma"

```
1   class IfTest:
2     private:
3       void line():
4         system.out.printString("\n")
5
```

```
    void out(String msg):
      system.out.printString(msg)
      line()

    void yes():
      out("This should print.")
    void no():
      out("This should not print.")

  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 18: "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 19: "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 20: "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 21: "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 22: "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 23: "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 24: "compiler-tests/exprs/addMix.gamma"

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

    void out(String msg):
      system.out.printString(msg)
      line()

  public:
    init():
      super()
      Integer a:=2
      Integer b:=3
      Integer c

      /* 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()
```

Source 25: "compiler-tests/exprs/ifeq.gamma"

```
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")
```

Source 26: "compiler-tests/exprs/mod.gamma"

```
```

Source 27: "compiler-tests/exprs/anonymous.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()
```

```
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/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 29: "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

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

  refinement:
    Integer update.setA():
      return 10
    Integer update.setB():
      return -5


class Test:
  protected:
    init():
      super()

  main(System sys, String[] args):
    Parent pop := new Parent("Father")
    Son son := new Son("Son")
    Daughter daughter := new Daughter("Daughter")

    pop.print()
    son.print()
    daughter.print()
    sys.out.printString("-----------\n")
    pop.update()
    son.update()
    daughter.update()

    pop.print()
    son.print()
    daughter.print()
```

Source 30: `"compiler-tests/exprs/simple-refine.gamma"`

```
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()
```

Source 31: "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 32: "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
```

```
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")
```

Source 33: "compiler-tests/exprs/div.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 Child()
44      Printer p := system.out
45      p.printString("Sum of integer = ")
46      p.printInteger(ab.overview())
47      p.printString("\n")
```

Source 34: "compiler-tests/exprs/refine_refinable.gamma"

```
1   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
    p.printString("Sum of integer = ")
    p.printInteger(ab.overview())
    p.printString("\n")
```

Source 35: "compiler-tests/exprs/refinable.gamma"

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

Source 36: "compiler-tests/structure/main.gamma"

```
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):
```

Source 37: "compiler-tests/structure/no-bodies.gamma"

```
class FuncTest:
  public:
      Integer a

      init():
          super()
          a := 1

  private:
      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 38: "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 39: "Debug.ml"

```
open Printf
open Util

let output_string whatever =
    print_string whatever;
    print_newline()

let load_file filename =
    if Sys.file_exists filename
        then open_in filename
        else raise(Failure("Could not find file " ^ filename ^ "."))

let with_file f file =
    let input = load_file file in
    let result = f input in
    close_in input;
    result

let get_data ast =
    let (which, builder) = if (Array.length Sys.argv <= 2)
        then ("Normal", KlassData.build_class_data)
        else ("Experimental", KlassData.build_class_data_test) in
    output_string (Format.sprintf " * Using %s KlassData Builder" which);
    match builder ast with
        | Left(data) -> data
        | Right(issue) -> Printf.fprintf stderr "%s\n" (KlassData.errstr issue); exit 1

let do_deanon klass_data sast = match Unanonymous.deanonymize klass_data sast with
    | Left(result) -> result
    | Right(issue) -> Printf.fprintf stderr "Error Deanonymizing:\n%s\n" (KlassData.
    errstr issue); exit 1

let source_cast _ =
    output_string " * Reading Tokens...";
    let tokens = with_file Inspector.from_channel Sys.argv.(1) in
    output_string " * Parsing Tokens...";
    let ast = Parser.cdecls (WhiteSpace.lextoks tokens) (Lexing.from_string "") in
    output_string " * Generating Global Data...";
    let klass_data = get_data ast in
    output_string " * Building Semantic AST...";
    let sast = BuildSast.ast_to_sast klass_data in
    output_string " * Deanonymizing Anonymous Classes.";
    let (klass_data, sast) = do_deanon klass_data sast in
    output_string " * Rebinding refinements.";
    let sast = BuildSast.update_refinements klass_data sast in
    output_string " * Generating C AST...";
```

```
    GenCast.sast_to_cast klass_data sast

let main _ =
    Printexc.record_backtrace true;
    output_string "/* Starting Build Process...";
    try
        let source = source_cast () in
        output_string " * Generating C...";
        output_string " */";
        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 40: `"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];;
StringMap.iter spitmap cnameMap;;

print_newline
```

Source 41: "unittest/bkup.ml"

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



type var_def = string * string;;
type func_def = {
  returns : string option;
  host    : string option;
  name    : string;
  static  : bool;
  formals : var_def list;
  (*body    : stmt list;*)
};;
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;*)
};;

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

let sdef1 = {
 privates = [VarMem("int","a"); VarMem("int","b");];
 protects = [VarMem("int","c"); VarMem("int","d");];
 publics  = [VarMem("int","e"); VarMem("int","f");];
};;

let sdef2 = {
 privates = [ VarMem("int","g"); VarMem("int","h");];
 protects = [ VarMem("int","j"); VarMem("int","i");];
 publics = [ VarMem("int","k"); VarMem("int","l");];
};;

let sdef3 = {
 privates = [ VarMem("int","m"); VarMem("int","n");];
 protects = [ VarMem("int","p"); VarMem("int","o");];
 publics = [ VarMem("int","q"); VarMem("int","r");];
};;

let sdef4 = {
 privates = [VarMem("int","x"); VarMem("int","s");];
 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

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

let rec spitmap fst snd = print_string fst; print_string "->";
        match snd with
          Some str ->  print_string str;print_string "\n"
        | None -> print_string "Object's parent is none\n";
in
StringMap.iter spitmap s2bmap;;

print_newline;;


print_string "getclassdef test\n\n";;
let rec getclassdef cname clist =
    match clist with
    [] -> None
    | hd::tl -> if hd.klass = cname then Some(hd) else getclassdef cname tl;;

```

```
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
```

```
            getfield basename vname cdeflist
    |    Some (cdef) -> lookupfield cdef vname;;

let field = getfield "myname3" "a" [d1;d2;d3;d4]
in
match field with
None -> print_string "field not found\n";
| Some tup -> print_string (fstoffour(tup));;
```

Source 42: `"unittest/sast.ml"`

```
%{
open Ast

(** Parser that reads from the scanner and produces an AST. *)

(** Set a single function to belong to a certain section *)
let set_func_section_to sect f = { f with section = sect }
(** Set a list of functions to belong to a certain section *)
let set_func_section sect = List.map (set_func_section_to sect)

(** Set a single member to belong to a certain subset of class memory.
    This is necessary as a complicated function because init and main
    can live in one of the several access levels. *)
let set_mem_section_to sect = function
  | VarMem(v) -> VarMem(v)
  | InitMem(func) -> InitMem({ func with section = sect })
  | MethodMem(func) -> MethodMem({ func with section = sect })

(** Set a list of members to belong to a certain subset of class memory *)
let set_mem_section sect = List.map (set_mem_section_to sect)


(** Set the klass of a func_def *)
let set_func_klass aklass func = { func with inklass = aklass }

(** Set the klass of a function member *)
let set_member_klass aklass = function
  | InitMem(func) -> InitMem(set_func_klass aklass func)
  | MethodMem(func) -> MethodMem(set_func_klass aklass func)
  | v -> v

(** Set the klass of all sections *)
let set_func_class aklass sections =
  let set_mems = List.map (set_member_klass aklass) in
  let set_funcs = List.map (set_func_klass aklass) in
  { privates = set_mems  sections.privates;
    publics  = set_mems  sections.publics;
    protects = set_mems  sections.protects;
    refines  = set_funcs sections.refines;
    mains    = set_funcs sections.mains }
%}

%token <int> SPACE
%token COLON NEWLINE
%token LPAREN RPAREN LBRACKET RBRACKET COMMA LBRACE RBRACE
%token PLUS MINUS TIMES DIVIDE MOD POWER
%token PLUSA MINUSA TIMESA DIVIDEA MODA POWERA
%token EQ NEQ GT LT GEQ LEQ AND OR NAND NOR XOR NOT
%token IF ELSE ELSIF WHILE
%token ASSIGN RETURN CLASS EXTEND SUPER INIT PRIVATE PROTECTED PUBLIC
%token NULL VOID THIS
%token NEW MAIN ARRAY
```

```
%token REFINABLE REFINE REFINES TO
%token SEMI COMMA DOT EOF

%token <string> TYPE
%token <int> ILIT
%token <float> FLIT
%token <bool> BLIT
%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 }
```

```
refinements:
  | /* Can be empty */       { [] }
  | refinements refinement   { $2 :: $1 }
refinement:
  | vartype ID DOT invocable  { { $4 with returns = Some($1); host = Some($2) } }
  | VOID ID DOT invocable     { { $4 with host = Some($2) } }

/* Private, protected, public members */
private_list:
  | PRIVATE member_list     { $2 }
protect_list:
  | PROTECTED member_list   { $2 }
public_list:
  | PUBLIC member_list      { $2 }

/* Members of such access groups */
member_list:
  | LBRACE members RBRACE   { $2 }
members:
  | { [] }
  | members member  { $2 :: $1 }
member:
  | vdecl semi   { VarMem($1)    }
  | mdecl        { MethodMem($1) }
  | init         { InitMem($1)   }

/* Methods */
mdecl:
  | vartype invocable  { { $2 with returns = Some($1) } }
  | VOID invocable     { $2 }

/* Constructors */
init:
  | INIT callable  { { $2 with name = "init" } }

/* Each class has an optional main */
main_method:
  | MAIN callable  { { $2 with name = "main"; static = true } }

/* Anything that is callable has these forms */
invocable:
  | ID callable  { { $2 with name = $1 } }
callable:
  | formals stmt_block
    { { returns = None;
        host    = None;
        name    = "";
        static  = false;
        formals = $1;
        body    = $2;
        section = Privates;
        inklass = "";
        uid     = UID.uid_counter ();
        builtin = false } }

/* Statements */
stmt_block:
  | LBRACE stmt_list RBRACE  { List.rev $2 }
stmt_list:
  | /* nada */      { [] }
  | stmt_list stmt  { $2 :: $1 }
stmt:
  | vdecl semi              { Decl($1, None) }
  | vdecl ASSIGN expr semi  { Decl($1, Some($3)) }
  | 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 43: "parser.mly"

```
open Ast
open Util
open StringModules
open GlobalData

(** Approximates a class *)
(**
    From a class get the parent
    @param aklass is a class_def to get the parent of
    @return The name of the parent object
  *)
let klass_to_parent aklass = match aklass with
    | { klass = "Object" } -> raise(Invalid_argument("Cannot get parent of the root"))
    | { parent = None; _ } -> "Object"
    | { parent = Some(aklass); _ } -> aklass

(**
    Utility function -- place variables in left, methods (including init) in right
    @param mem A member_def value (VarMem, MethodMem, InitMem)
    @return Places the values held by VarMem in Left, values held by MethodMem or InitMem
     in Right
  *)
let member_split mem = match mem with
    | VarMem(v) -> Left(v)
    | MethodMem(m) -> Right(m)
    | InitMem(i) -> Right(i)

(**
    Stringify a section to be printed
    @param section A class_section value (Privates, Protects, Publics, Refines, or Mains)
    @return The stringification of the section for printing
  *)
let section_string section = match section with
    | Privates -> "private"
    | Protects -> "protected"
    | Publics -> "public"
    | Refines -> "refinement"
    | Mains -> "main"

(**
    Return the variables of the class
    @param aklass The class to explore
    @return A list of ordered pairs representing different sections,
    the first item of each pair is the type of the section, the second
    is a list of the variables defs (type, name). Note that this only
    returns pairs for Publics, Protects, and Privates as the others
    cannot have variables
  *)
let klass_to_variables aklass =
    let vars members = fst (either_split (List.map member_split members)) in
    let s = aklass.sections in
    [(Publics, vars s.publics); (Protects, vars s.protects); (Privates, vars s.privates)]

(**
    Return the methods of the class
    @param aklass The class to explore
    @return A list of ordered pairs representing different sections,
    the first item of each pair is the type of the section, the second
    is a list of the methods. Note that this only returns the methods
```

```
    in Publics, Protects, or Privates as the other sections don't have
    'normal' methods in them
  *)
let klass_to_methods aklass =
    let funcs members = snd (either_split (List.map member_split members)) in
    let s = aklass.sections in
    [(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 =
```

```
121     match map_lookup klass_name data.variables with
122         | Some(var_map) -> map_lookup var_name var_map
123         | _ -> None
124
125 (**
126     Given a class_data record, a class_name, and a variable name, lookup the class in the
        hierarchy
127     that provides access to that variable from within that class (i.e. private in that
        class or
128     public / protected in an ancestor).
129     @param data A class_data record.
130     @param klass_name The name of a class (string)
131     @param var_name The name of a variable (string).
132     @return (class (string), type (string), class_section) option (None if not found).
133   *)
134 let class_field_lookup data klass_name var_name =
135     let var_lookup klass = class_var_lookup data klass var_name in
136     let rec lookup klass sections = match var_lookup klass, klass with
137         | Some((sect, vtype)), _ when List.mem sect sections -> Some((klass, vtype, sect)
        )
138         | _, "Object" -> None
139         | _, _ -> lookup (StringMap.find klass data.parents) [Publics; Protects] in
140     lookup klass_name [Publics; Protects; Privates]
141
142 (**
143     Given a class_data record, a class name, a var_name, and whether the receiver of the
        field lookup
144     is this, return the lookup of the field in the ancestry of the object. Note that this
        restricts
145     things that should be kept protected (thus this thusly passed)
146     @param data A class_data record
147     @param klass_name The name of a class (string)
148     @param var_name The name of a variable (string)
149     @return Either the left of a triple (class found, type, section) or a Right of a
        boolean, which
150     is true if the item was found but inaccessible and false otherwise.
151   *)
152 let class_field_far_lookup data klass_name var_name this =
153     match class_field_lookup data klass_name var_name with
154         | 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
```

```
    (* Organize by inklass *)
    let to_class map f = add_map_list f.inklass f map in
    let by_class = List.fold_left to_class StringMap.empty compat in

    (* Now make a map of only the best *)
    let best funcs = match best_matching_signature data actuals funcs with
        | [func] -> func
        | _ -> raise(Failure("Compiler error finding a unique best refinement.")) in
    let to_best klass funcs map = StringMap.add klass (best funcs) map in
    let best_map = StringMap.fold to_best by_class StringMap.empty in

    (* Now just return the bindings from the best *)
    List.map snd (StringMap.bindings best_map)

(**
    Get the names of the classes in level order (i.e. from root down).
    @param data A class_data record
    @return The list of known classes, from the root down.
  *)
let get_class_names data =
    let kids aklass = map_lookup_list aklass data.children in
    let rec append found = function
        | [] -> List.rev found
        | items -> let next = List.flatten (List.map kids items) in
            append (items@found) next in
    append [] ["Object"]


(**
    Get leaf classes
    @param data A class_data record
    @return A list of leaf classes
  *)
let get_leaves data =
    let is_leaf f = match map_lookup_list f data.children with
        | [] -> true
        | _ -> false in
    let leaves = StringSet.filter is_leaf data.known in
    StringSet.elements leaves
```

Source 44: `"Klass.ml"`

```
all: compile _tools _ray _doc

compile:
    #Generate the lexer and parser
    ocamllex scanner.mll
    ocamlyacc parser.mly

    ocamlc -c -g Ast.mli
    ocamlc -c -g UID.ml

    ocamlc -c -g parser.mli
    ocamlc -c -g scanner.ml
    ocamlc -c -g parser.ml

    ocamlc -c -g WhiteSpace.ml
    ocamlc -c -g Inspector.mli
    ocamlc -c -g Inspector.ml
    ocamlc -c -g Pretty.ml

    ocamlc -c -g Util.ml
    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"
```

```
    ocamldoc -hide-warnings -load $(docgen) -dot -dot-types -o "./doc/ray-types.dot"

bleach:
    rm *.cmi *.cmo parser.ml parser.mli scanner.ml
    rm -r ./doc

clean:
    rm *.cmi *.cmo parser.ml parser.mli scanner.ml

cleantools:
    rm tools/{prettify,inspect,streams,canonical,freevars,classinfo}
```

Source 45: `"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 46: `"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 47: "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 48: "demo/helloworld.gamma"

```
class Bank:
```

```
2     public:
3       init():
4         super()
5         id_counter := 0
6         accounts := new Account[](100)
7
8         /* Anonymous instantiation can 'get around' protected constructors */
9         Account president := (new Account(id_counter, "Bank President") {
10          Float apply_interest.rate() { return 0.10; }
11        })
12        accounts[id_counter] := president
13        id_counter += 1
14
15      Integer open_checking(String client_name):
16        Account new_account := new Checking(id_counter, client_name)
17        accounts[id_counter] := new_account
18        id_counter += 1
19        return id_counter-1
20
21      Integer open_savings(String client_name):
22        Account new_account := new Savings(id_counter, client_name)
23        accounts[id_counter] := new_account
24        id_counter += 1
25        return id_counter-1
26
27      Integer apply_interest(Integer id):
28        if(id > id_counter or id < 0):
29          return 1
30        accounts[id].apply_interest()
31        return 0
32
33      Float get_balance(Integer id):
34        if(id > id_counter):
35          system.out.printString("Invalid account number.\n")
36          return -1.0
37        return accounts[id].get_balance()
38
39      Integer deposit(Integer id, Float amount):
40        if(id > id_counter):
41          system.out.printString("Invalid account number.\n")
42          return 1
43
44        accounts[id].deposit(amount)
45        return 0
46
47      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 49: "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,
```

```
    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
    @param program A program as a list of tokens
    @return A program without superfluous indentation
  *)
let trim_lines program =
    let rec lines_trim tokens rtokens =
        match tokens with
            | [] -> List.rev rtokens
            | SPACE(_)::NEWLINE::rest -> lines_trim rest (NEWLINE::rtokens)
            | SPACE(_)::COLON::rest -> lines_trim rest (COLON::rtokens)
            | token::rest -> lines_trim rest (token::rtokens) in
    lines_trim program []

(**
    Remove consecutive newlines
    @param program A program as a list of tokens
    @return A program without consecutive newlines
  *)
let squeeze_lines program =
    let rec lines_squeeze tokens rtokens =
        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
```

```
  *)
let rec needs_semi = function
    | [] -> true              (* General base case *)
    | RBRACE::[] -> false     (* The end of bodies do not require semicolons *)
    | SEMI::[] -> false       (* A properly terminated line does not require an
    additional semicolon *)
    | _::rest -> needs_semi rest (* Go through *)

(**
    Build a block. Consecutive lines of the same indentation with only the last ending
    in a colon are a 'block'. Blocks are just 'lines' merged together but joined with
    a semi colon when necessary.
    @param lines The full set of lines
    @return A list of blocks
  *)
let block_merge lines =
    let add_semi = function
        | (n, toks, true) -> (n, toks, true, false)
        | (n, toks, false) -> (n, toks, false, needs_semi toks) in
    let lines = List.map add_semi lines in
    let rec merge_blocks rblocks = function
        | (n1, line1, false, s1)::(n2, line2, colon, s2)::rest when n1 = n2 ->
            let newline = line1 @ (if s1 then [SEMI] else []) @ line2 in
            merge_blocks rblocks ((n1, newline, colon, s2)::rest)
        | (n, line, colon, _)::rest -> merge_blocks ((n, line, colon)::rblocks) rest
        | [] -> List.rev rblocks in
    merge_blocks [] lines

(** Make sure every line is terminated with a semi-colon when necessary *)
let terminate_blocks blocks =
    let rec block_terminate rblocks = function
        | (n, toks, false)::rest ->
            let terminated = if (needs_semi toks) then toks@[SEMI] else toks in
            block_terminate ((n, terminated, false)::rblocks) rest
        | other::rest ->
            block_terminate (other::rblocks) rest
        | [] -> List.rev rblocks in
    block_terminate [] blocks

(** Pops the stack and adds rbraces when necessary *)
let rec arrange n stack rtokens =
    match stack with
        | top::rest when n <= top -> arrange n rest (RBRACE::rtokens)
        | _ -> (stack, rtokens)

(**
     Take results of pipeline and finally adds braces. If blocks are merged
    then either consecutive lines differ in scope or there are colons.
    so now everything should be easy peasy (lemon squeezy).
  *)
let space_to_brace = function
    | [] -> []
    | linelist -> let rec despace_enbrace stack rtokens = function
        | [] -> List.rev ((List.map (function _ -> RBRACE) stack) @ rtokens)
        | (n, line, colon)::rest ->
            let (stack, rtokens) = arrange n stack rtokens in
            let (lbrace, stack) = if colon then ([LBRACE], n::stack) else ([], stack) in
            despace_enbrace stack (lbrace@(List.rev line)@rtokens) rest
        in despace_enbrace [] [] linelist

(** Drop the EOF from a stream of tokens, failing if not possible *)
let drop_eof program =
    let rec eof_drop rtokens = function
        | EOF::[] -> List.rev rtokens
        | EOF::rest -> raise(Failure("Misplaced EOF"))
```

```
        | [] -> raise(Failure("No EOF available."))
        | tk::tks -> eof_drop (tk::rtokens) tks in
    eof_drop [] program

(** Append an eof token to a program *)
let append_eof program =
    let rec eof_add rtokens = function
        | [] -> List.rev (EOF::rtokens)
        | tk::tks -> eof_add (tk::rtokens) tks in
    eof_add [] program

(** Run the entire pipeline *)
let convert program =
    (* Get rid of the end of file *)
    let noeof = drop_eof program in
    (* Indent in response to blocks *)
    let indented = indenting_space noeof in
    (* Collapse whitespace around braces *)
    let despaced = despace_brace indented in
    (* Get rid of trailing whitespace *)
    let trimmed = trim_lines despaced in
    (* Remove consequetive newlines *)
    let squeezed = squeeze_lines trimmed in
    (* Turn tokens into semantics *)
    let lines = tokens_to_lines squeezed in
    (* Consolidate those semantics *)
    let merged = merge_lines lines in
    (* Turn the semantics into blocks *)
    let blocks = block_merge merged in
    (* Put in the semicolons *)
    let terminated = terminate_blocks blocks in
    (* Turn the blocks into braces *)
    let converted = space_to_brace terminated in
    (* Put the eof on *)
    append_eof converted

(** A function to act like a lexfun *)
let lextoks toks =
    let tokens = ref (convert toks) in
    function _ ->
        match !tokens with
            | [] -> raise(Failure("Not even EOF given."))
            | tk::tks -> tokens := tks; tk
```

Source 50: "WhiteSpace.ml"

```
open Cast
open StringModules

let c_indent = "  "

let dispatches = ref []
let dispatchon = ref []
let dispatcharr = ref []

let matches type1 type2 = String.trim (GenCast.get_tname type1) = String.trim type2

let lit_to_str lit = match lit with
    | Ast.Int(i) -> "LIT_INT("^(string_of_int i)^")"
    | Ast.Float(f) -> "LIT_FLOAT("^(string_of_float f)^")"
    | Ast.String(s) -> "LIT_STRING(\"" ^ s ^ "\")"  (* escapes were escaped during lexing
    *)
    | 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
171 and collect_dispatch_arr arrtype fname args =
172     dispatcharr := (arrtype, fname, args)::(!dispatcharr)
173
174 (**
175     Takes an element from the dispatchon list and generates the test function for
    refinable.
176     @param  klasses - list of klasses in which the refinable method is defined for the
    method
177             fuid - unique function name for the test function.
178     @return true or false
179     Checks if the object on which refinable was invoked has an associated refinable
    method
180     dispatched via this function that's being generated in one of the classes.
181 **)
182
183
184 let generate_testsw (klass, klasses, fuid) =
185     let test klass = Format.sprintf "\tif ( IS_CLASS(this, \"%s\") ) return LIT_BOOL(1);"
     (String.trim klass) in
186     let cases = String.concat "\n" (List.map test klasses) in
187     let body = Format.sprintf "%s\n\treturn LIT_BOOL(0);" cases in
188     Format.sprintf "struct t_Boolean *%s( struct %s*this )\n{\n%s\n}\n\n" fuid klass body
189
190 (**
191      Takes a dispatch element of the global dispatches list
192      And generates the dispatch function - dispatcher which dispatches
193      calls to refinable methods based on the RTTI of the this.
```

```
194         @param ret - return type of the function
195                args - arguments to the dispatcher and the dispatched method
196                dispatch_uid - unique function name for the dispatcher
197                cases - list of classes and their corresponding uid of the invokable
        refinable methods.
198     **)
199
200     let generate_refinesw (klass, ret, args, dispatchuid, cases) =
201         let rettype = match ret with
202             | None -> "void "
203             | Some(atype) -> Format.sprintf "struct %s*" atype in
204         let this = (Format.sprintf "struct %s*" klass, "this") in
205         let formals = List.mapi (fun i t -> (Format.sprintf "struct %s*" t, Format.sprintf "
        varg_%d" i)) args in
206         let signature = String.concat ", " (List.map (fun (t, v) -> t ^ v) (this::formals))
        in
207         let actuals = List.map snd formals in
208         let withthis kname = String.concat ", " ((Format.sprintf "(struct %s*) this" kname)::
        actuals) in
209         let invoc fuid kname = Format.sprintf "%s(%s)" fuid (withthis kname) in
210         let execute fuid kname = match ret with
211             | 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.";
```

```
    List.iter (fun d -> out (generate_testsw d)) (!dispatchon);
    List.iter (fun d -> out (generate_refinesw d)) (!dispatches);

    comment "Array allocators.";
    List.iter (fun d -> out (generate_arrayalloc d)) (!dispatcharr);

    comment "The main.";
    out (cast_to_c_main mains);
```

Source 51: `"GenC.ml"`

```
open Ast
open Variables
open StringModules

let rec get_vars_formals = function
    | [] -> StringSet.empty
    | [(_,var)] -> StringSet.singleton var
    | (_,var)::tl -> StringSet.add var (get_vars_formals tl)

let _ =
    let func = List.hd (Debug.get_example_longest_body "Multi" "Collection") in
    let stmts = func.body in
    let prebound = get_vars_formals func.formals in
    let free_variables = free_vars prebound stmts in
    StringSet.iter (Printf.printf "%s\n") free_variables
```

Source 52: `"freevars.ml"`

```
let debug_print tokens =
    let ptoken header tokens =
        Inspector.pprint_token_list header tokens;
        print_newline () in
    let plines header lines =
        Inspector.pprint_token_lines header lines;
        print_newline () in
    begin
        ptoken "Input:      " tokens;
        let tokens = WhiteSpace.drop_eof tokens in
        ptoken "No EOF      " tokens;
        let tokens = WhiteSpace.indenting_space tokens in
        ptoken "Indented:   " tokens;
        let tokens = WhiteSpace.despace_brace tokens in
        ptoken "In-Brace:   " tokens;
        let tokens = WhiteSpace.trim_lines tokens in
        ptoken "Trimmed:    " tokens;
        let tokens = WhiteSpace.squeeze_lines tokens in
        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 53: "streams.ml"

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

Source 54: "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 55: "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 *)
    refinable : (func_def list) lookup_table (** class -> host -> refinements (in
    subclasses) *)
}

(**
    All the different types of non-compiler errors that can occur (programmer errors)
  *)
type class_data_error
    = HierarchyIssue of string
    | DuplicateClasses of string list
    | DuplicateVariables of (string * string list) list
    | DuplicateFields of (string * (string * string) list) list
    | UnknownTypes of (string * (string * string) list) list
    | ConflictingMethods of (string * (string * string list) list) list
    | ConflictingInherited of (string * (string * string list) list) list
    | PoorlyTypedSigs of (string * (string * string option * (string * string) list) list
    ) list
    | Uninstantiable of string list
    | ConflictingRefinements of (string * (string * string list) list) list
    | MultipleMains of string list
```

Source 56: "GlobalData.mli"

```
{
  open Parser

  (** The general lexographic scanner for Gamma *)

  (**
      Build a string from a list of characters
      from: http://caml.inria.fr/mantis/view.php?id=5367
      @param l The list to be glued
      @return A string of the characters in the list glued together
  *)
```

```
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 *)
78  let vspace = ['\n' '\r' '\011' '\012']
79
80
81  rule token = parse
82    (* Handling whitespace mode *)
83    | hspace+ as s                  { SPACE(spacecount s) }
84    | ':' hspace* (vspace+ as v)    { count_lines v; COLON }
85    | vspace+ as v                  { count_lines v; NEWLINE }
86
87    (* Comments *)
88    | "/*"                          { comment 0 lexbuf }
89
90    (* Boolean Tests & Values *)
91    | "refinable"                   { REFINABLE }
92    | "and"                         { AND }
93    | "or"                          { OR }
94    | "xor"                         { XOR }
95    | "nand"                        { NAND }
96    | "nor"                         { NOR }
97    | "not"                         { NOT }
98    | "true"                        { BLIT(true) }
99    | "false"                       { BLIT(false) }
100   | "="                           { EQ }
101   | "<>"                          { NEQ }
102   | "=/="                         { NEQ }
103   | '<'                           { LT }
104   | "<="                          { LEQ }
105   | ">"                           { GT }
106   | ">="                          { GEQ }
107
108   (* Grouping [args, arrays, code, etc] *)
109   | "[]"                          { ARRAY }
110   | '['                           { LBRACKET }
111   | ']'                           { RBRACKET }
112   | '('                           { LPAREN }
113   | ')'                           { RPAREN }
114   | '{'                           { LBRACE }
115   | '}'                           { RBRACE }
116
117   (* Punctuation for the sytnax *)
118   | ';'                           { SEMI }
119   | ','                           { COMMA }
120
121   (* Arithmetic operations *)
122   | '+'                           { PLUS }
123   | '-'                           { MINUS }
124   | '*'                           { TIMES }
125   | '/'                           { DIVIDE }
126   | '%'                           { MOD }
127   | '^'                           { POWER }
128
129   (* Arithmetic assignment *)
130   | "+="                          { PLUSA }
131   | "-="                          { MINUSA }
132   | "*="                          { TIMESA }
133   | "/="                          { 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 57: "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)
23  let add_ivars klass env level =
24      let sects = match level with
25          | Publics -> [Publics]
26          | Protects -> [Publics; Protects]
27          | Privates -> [Publics; Protects; Privates]
28          | _ -> raise(Failure("Inappropriate class section - access level."))  in
29      let filter (s, _) = List.mem s sects in
30      let vars = Klass.klass_to_variables klass in
31      let eligible = List.flatten (List.map snd (List.filter filter vars)) in
32      env_updates (Instance(klass.klass)) env eligible
33
34  (** Marker for being in the current class -- ADT next time *)
35  let current_class = "_CurrentClassMarker_"
36
37  (** Marker for the null type -- ADT next time *)
38  let null_class = "_Null_"
39
40  (** Empty environment *)
41  let empty_environment = StringMap.empty
42
43  (** Return whether an expression is a valid lvalue or not *)
44  let is_lvalue (expr : Ast.expr) = match expr with
45      | Ast.Id(_) -> true
46      | Ast.Field(_, _) -> true
47      | Ast.Deref(_, _) -> true
48      | _ -> false
49
50  (**
51      Map a literal value to its type
52      @param litparam a literal
53      @return A string representing the type.
54    *)
55  let getLiteralType litparam = match litparam with
56      | Ast.Int(i) -> "Integer"
```

```
57      | Ast.Float(f) -> "Float"
58      | Ast.String(s) -> "String"
59      | Ast.Bool(b) -> "Boolean"
60
61  (**
62      Map a return type string option to a return type string
63      @param ret_type The return type.
64      @return The return type -- Void or its listed type.
65    *)
66  let getRetType ret_type = match ret_type with
67      | Some(retval) -> retval
68      | None -> "Void"
69
70  (**
71      Update a refinement switch based on updated data.
72    *)
73  let rec update_refinements_stmts klass_data kname mname = List.map (
        update_refinements_stmt klass_data kname mname)
74  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 *)

(**
    Given a class_data record, the name of the current class, a list of AST statements,
    and an initial environment, enumerate the statements and attach the environment at
    each step to that statement, yielding Sast statements. Note that when there is an
    issue the function will raise Failure.
    @param klass_data A class_data record
    @param kname The name of the class that is the current context.
    @param stmts A list of Ast statements
    @param initial_env An initial environment
    @return A list of Sast statements
  *)
let rec attach_bindings klass_data kname mname meth_ret isstatic stmts initial_env =
    (* Calls that go easy on the eyes *)
    let eval' = eval klass_data kname mname isstatic in
    let attach' = attach_bindings klass_data kname mname meth_ret isstatic in
    let eval_exprlist env elist = List.map (eval' env) elist in

    let rec get_superinit kname arglist =
        let parent = StringMap.find kname klass_data.parents in
        let argtypes = List.map fst arglist in
        match best_method klass_data parent "init" argtypes [Ast.Publics; Ast.Protects]
    with
            | None       -> raise(Failure "Cannot find super init")
            | Some(fdef) -> fdef in

    (* Helper function for building a predicate expression *)
    let build_predicate pred_env exp = match eval' pred_env exp with
        | ("Boolean", _) as evaled -> evaled
        | _ -> raise (Failure "Predicates must be boolean") in

    (* Helper function for building an optional expression *)
    let opt_eval opt_expr opt_env = match opt_expr with
        | None -> None
        | Some(exp) -> Some(eval' opt_env exp) in

    (* For each kind of statement, build the associated Sast statment *)
    let build_ifstmt iflist if_env =
        let build_block if_env (exp, slist) =
            let exprtyp = match exp with
                | None -> None
                | Some exp -> Some(build_predicate if_env exp) in
            (exprtyp, attach' slist if_env) in
        Sast.If(List.map (build_block if_env) iflist, if_env) in

    let build_whilestmt expr slist while_env =
        let exprtyp = build_predicate while_env expr in
        let stmts = attach' slist while_env in
        Sast.While(exprtyp, stmts, while_env) in

    let build_declstmt ((vtype, vname) as vdef) opt_expr decl_env =
        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))
        else match opt_eval opt_expr decl_env with
            | Some((atype, _)) as evaled -> if not (Klass.is_subtype klass_data atype
    vtype)
                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))
                else Sast.Decl(vdef, evaled, decl_env)
            | None -> Sast.Decl(vdef, None, decl_env) in

    let check_ret_type ret_type = match ret_type, meth_ret with
        | 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.
```

```
    @param klass_data A class_data record value
    @param ast_klass A class to transform
    @return The transformed class.
  *)
let ast_to_sast_klass klass_data (ast_klass : Ast.class_def) =
    let s : Ast.class_sections_def = ast_klass.sections in
    let rec update_env env sect (klass : Ast.class_def) =
        let env = add_ivars klass env sect in
        match klass.klass with
            | "Object" -> env
            | _ -> let parent = Klass.klass_to_parent klass in
                   let pclass = StringMap.find parent klass_data.classes in
                   update_env env Protects pclass in
    let env = update_env empty_environment Privates ast_klass in

    let mems = List.map (fun m -> ast_mem_to_sast_mem klass_data m env) in
    let funs = List.map (fun f -> ast_func_to_sast_func klass_data f env false) in

    let sections : Sast.class_sections_def =
        {   publics = mems s.publics;
            protects = mems s.protects;
            privates = mems s.privates;
            refines = funs s.refines;
            mains = funs (List.map check_main s.mains) } in

    let sast_klass : Sast.class_def =
        {   klass = ast_klass.klass;
            parent = ast_klass.parent;
            sections = sections } in

    if init_calls_super sast_klass then sast_klass
    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))

(**
    @param ast An ast program
    @return A sast program
*)
let ast_to_sast klass_data =
    let klasses = StringMap.bindings klass_data.classes in
    let to_sast (_, klass) = ast_to_sast_klass klass_data klass in
    List.map to_sast klasses
```

Source 58: "BuildSast.ml"

```
(**
    The abstract syntax tree for Gamma
*)

(**
    The four literal classes of Gamma:
    - Int - Integer
    - Float - Floating-point number
    - String - A sequence of characters
    - Bool - a boolean value of either true or false
*)
type lit =
    Int of int
  | Float of float
  | String of string
  | Bool of bool

(** 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. *)
61 and func_def = {
62   returns : string option;  (** A return type (method/refine) *)
63   host    : string option;  (** A host class (refine) *)
64   name    : string;         (** The function name (all) *)
65   static  : bool;           (** If the function is static (main) *)
66   formals : var_def list;   (** A list of all formal parameters of the function (all) *)
67   body    : stmt list;      (** A list of statements that form the function body (all) *)
68   section : class_section;  (** A sementic tag of the class section in which the function
       lives (all) *)
69   inklass : string;         (** A semantic tag of the class in which the function lives (
       all) *)
70   uid     : string;         (** A string for referencing this -- should be maintained in
       transformations to later ASTs *)
71   builtin : bool;           (** Whether or not the function is built in (uid should have
       _ in it then) *)
72 }
73
74 (** A member is either a variable or some sort of function *)
75 type member_def = VarMem of var_def | MethodMem of func_def | InitMem of func_def
76
77 (** 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 59: "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 60: "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 61: "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 *);
```

```
25 struct t_String *scanner_scan_string(struct t_Scanner *);
26 void printer_print_float(struct t_Printer *, struct t_Float *);
27 void printer_print_integer(struct t_Printer *, struct t_Integer *);
28 void printer_print_string(struct t_Printer *, struct t_String *);
29 struct t_String **get_gamma_args(char **argv, int argc);
30
31
32 char *stack_overflow_getline(FILE *);
33
34 /* Functions! */
35
36 /* Magic allocator. DO NOT INVOKE THIS, USE MAKE_NEW(TYPE)
37  * where type is not prefixed (i.e. MAKE_NEW(Integer) not
38  * MAKE_NEW(t_Integer))
39  */
40 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)
```

```
{
    object_init((struct t_Object *)(this));
    this->Scanner.source = stdin;
}

struct t_Integer *float_to_i(struct t_Float *this){
    return integer_value((int)(this->Float.value));
}

struct t_Float *integer_to_f(struct t_Integer *this){
    return float_value((double)(this->Integer.value));
}

void toendl(FILE *in) {
    int c = 0;
    while (1) {
      c = fgetc(in);
      if (c == '\n' || c == '\r' || c == EOF) break;
    }
}

struct t_Float *scanner_scan_float(struct t_Scanner *this)
{
    double dval;
    fscanf(this->Scanner.source, "%lf", &dval);
    toendl(this->Scanner.source);

    return float_value(dval);
}

struct t_Integer *scanner_scan_integer(struct t_Scanner *this)
{
    int ival;
    fscanf(this->Scanner.source, "%d", &ival);
    toendl(this->Scanner.source);
    return integer_value(ival);
}

struct t_String *scanner_scan_string(struct t_Scanner *this)
{
    char *inpstr = NULL;
    struct t_String *astring = NULL;

    inpstr = stack_overflow_getline(this->Scanner.source);
    astring = string_value(inpstr);

    free(inpstr);
    return astring;
}

void printer_print_float(struct t_Printer *this, struct t_Float *v_arg)
{
    fprintf(this->Printer.target, "%lf", v_arg->Float.value);
}

void printer_print_integer(struct t_Printer *this, struct t_Integer *v_arg)
{
    fprintf(this->Printer.target, "%d", v_arg->Integer.value);
}

void printer_print_string(struct t_Printer *this, struct t_String *v_arg)
{
    fprintf(this->Printer.target, "%s", v_arg->String.value);
}

```

```
void system_exit(struct t_System *this, struct t_Integer *v_code) {
    exit(INTEGER_OF(v_code));
}


struct t_String **get_gamma_args(char **argv, int argc) {
    struct t_String **args = NULL;
    int i = 0;

    if (!argc) return NULL;
    args = ONE_DIM_ALLOC(struct t_String *, argc);
    for (i = 0; i < argc; ++i)
        args[i] = string_value(argv[i]);
    args[i] = NULL;

    return args;
}



char *stack_overflow_getline(FILE *in) {
    char * line = malloc(100), * linep = line;
    size_t lenmax = 100, len = lenmax;
    int c;

    if(line == NULL)
        return NULL;

    for(;;) {
        c = fgetc(in);
        if(c == EOF)
            break;

        if(--len == 0) {
            len = lenmax;
            char * linen = realloc(linep, lenmax *= 2);

            if(linen == NULL) {
                free(linep);
                return NULL;
            }
            line = linen + (line - linep);
            linep = linen;
        }

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

Source 62: "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];
        va_end(objtypes);
}


void init_built_in_infos() {
    class_info_init(&M_Boolean, 2, m_classes[T_OBJECT], m_classes[T_BOOLEAN]);
    class_info_init(&M_Float, 2, m_classes[T_OBJECT], m_classes[T_FLOAT]);
    class_info_init(&M_Integer, 2, m_classes[T_OBJECT], m_classes[T_INTEGER]);
    class_info_init(&M_Object, 1, m_classes[T_OBJECT]);
    class_info_init(&M_Printer, 2, m_classes[T_OBJECT], m_classes[T_PRINTER]);
    class_info_init(&M_Scanner, 2, m_classes[T_OBJECT], m_classes[T_SCANNER]);
    class_info_init(&M_String, 2, m_classes[T_OBJECT], m_classes[T_STRING]);
    class_info_init(&M_System, 2, m_classes[T_OBJECT], m_classes[T_SYSTEM]);
}
```

Source 63: "headers/gamma-builtin-meta.h"

```

/*
 * Structures for each of the objects.
 */
struct t_Boolean;
struct t_Float;
struct t_Integer;
struct t_Object;
struct t_Printer;
struct t_Scanner;
struct t_String;
struct t_System;

```

```
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 64: "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))
    ))
```

```
#define POW_FLOAT_FLOAT(l, r)   PROMOTE_FLOAT( pow(FLOAT_OF(l), FLOAT_OF(r)) )

#define MAKE_NEW2(type, meta) ((struct type *)(allocate_for(sizeof(struct type), &meta)))
#define MAKE_NEW(t_name) MAKE_NEW2(t_##t_name, M_##t_name)

#define CAST(type, v) ( (struct t_##type *)(v) )
#define VAL_OF(type, v) ( CAST(type, v)->type.value )
#define BOOL_OF(b)    VAL_OF(Boolean, b)
#define FLOAT_OF(f)   VAL_OF(Float, f)
#define INTEGER_OF(i) VAL_OF(Integer, i)
#define STRING_OF(s)  VAL_OF(String, s)

#define NEG_INTEGER(i)            PROMOTE_INTEGER(-INTEGER_OF(i))
#define NEG_FLOAT(f)              PROMOTE_FLOAT(-FLOAT_OF(f))
#define NOT_BOOLEAN(b)            PROMOTE_BOOL(!BOOL_OF(b))

#define BINOP(type, op, l, r)     ( VAL_OF(type, l) op VAL_OF(type, r) )
#define PBINOP(type, op, l, r)    PROMOTE_BOOL(BINOP(type, op, l, r))
#define IBINOP(op, l, r)          PBINOP(Integer, op, l, r)
#define FBINOP(op, l, r)          PBINOP(Float, op, l, r)
#define BBINOP(op, l, r)          PBINOP(Boolean, op, l, r)

#define NTEST_EQ_INT_INT(l, r)    IBINOP(==, l, r)
#define NTEST_NEQ_INT_INT(l, r)   IBINOP(!=, l, r)
#define NTEST_LESS_INT_INT(l, r)  IBINOP(<, l, r)
#define NTEST_GRTR_INT_INT(l, r)  IBINOP(>, l, r)
#define NTEST_LEQ_INT_INT(l, r)   IBINOP(<=, l, r)
#define NTEST_GEQ_INT_INT(l, r)   IBINOP(>=, l, r)

#define NTEST_EQ_FLOAT_FLOAT(l, r)    FBINOP(==, l, r)
#define NTEST_NEQ_FLOAT_FLOAT(l, r)   FBINOP(!=, l, r)
#define NTEST_LESS_FLOAT_FLOAT(l, r)  FBINOP(<, l, r)
#define NTEST_GRTR_FLOAT_FLOAT(l, r)  FBINOP(>, l, r)
#define NTEST_LEQ_FLOAT_FLOAT(l, r)   FBINOP(<=, l, r)
#define NTEST_GEQ_FLOAT_FLOAT(l, r)   FBINOP(>=, l, r)

#define CTEST_AND_BOOL_BOOL(l, r)   BBINOP(&&, l, r)
#define CTEST_OR_BOOL_BOOL(l, r)    BBINOP(||, l, r)
#define CTEST_NAND_BOOL_BOOL(l, r)  PROMOTE_BOOL(( !(BOOL_OF(l) && BOOL_OF(r)) ))
#define CTEST_NOR_BOOL_BOOL(l, r)   PROMOTE_BOOL(( !(BOOL_OF(l) || BOOL_OF(r)) ))
#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 65: "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

(** An expression value -- like in AST *)
type expr_detail =
    | This
    | Null
    | Id of string
    | NewObj of string * expr list * funcid
    | Anonymous of string * expr list * Ast.func_def list (* Evaluation is delayed *)
    | Literal of Ast.lit
    | Assign of expr * expr  (* memory := data -- whether memory is good is a semantic issue *)
    | Deref of expr * expr (* road[pavement] *)
    | Field of expr * string (* road.pavement *)
    | Invoc of expr * string * expr list * funcid (* receiver.method(args) * bestmethod_uid  *)
    | Unop of Ast.op * expr (* !x *)
    | Binop of expr * Ast.op * expr (* x + y *)
    | Refine of string * expr list * string option * refine_switch (* refinement, arg list, opt ret type, switch *)
    | Refinable of string * refine_switch (* desired refinement, list of classes supporting refinement *)

(** An expression with a type tag *)
and expr = string * expr_detail

(** A statement tagged with an environment *)
and sstmt =
    | Decl of Ast.var_def * expr option * environment
    | If of (expr option * sstmt list) list * environment
    | While of expr * sstmt list * environment
    | Expr of expr * environment
    | Return of expr option * environment
    | Super of expr list * string * string * environment (**arglist, uidof super init, superclass, env**)

(** A function definition *)
and func_def = {
    returns : string option;
```

```
    host     : string option;
    name     : string;
    static   : bool;
    formals  : Ast.var_def list;
    body     : sstmt list;
    section  : Ast.class_section;  (* Makes things easier later *)
    inklass  : string;
    uid      : string;
    builtin  : bool;
}

(* A member is either a variable or some sort of function *)
type member_def = VarMem of Ast.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? *)
type class_def = {
    klass    : string;
    parent   : string option;
    sections : class_sections_def;
}

type program = class_def list
```

Source 66: `"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

(* A c func is a simplified function (no host, etc) *)
and cfunc = {
    returns : string option;
    name    : string;  (* Combine uid and name into this *)
    formals : Ast.var_def list;
    body    : cstmt list;
    builtin : bool;
    inklass : string; (* needed for THIS *)
    static  : bool;
}

(* The bare minimum for a struct represention *)
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 *)

(* A main is a class name and a function name for that main *)
type main_func = (string * string)

(* We actually need all the ancestry information, cause we're gonna do it the right way [
    lists should go from object down] *)
type ancestry_info = (string list) lookup_map

(* 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 *)
type program = class_struct lookup_map * cfunc list * main_func list * ancestry_info
```

Source 67: "Cast.mli"

```
#!/bin/bash

function errwith {
  echo "$1" >&2
  exit 1
}

function run_file {
  test "$#" -lt 1 && errwith "Please give a file to test"
  file=$1

  test -e "$file" || errwith "File $file does not exist."
  test -f "$file" || errwith "File $file is not a file."

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

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

Source 68: "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 69: `"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"
```

```
24      | LEQ -> "LEQ"
25      | GT -> "GT"
26      | GEQ -> "GEQ"
27      | LBRACKET -> "LBRACKET"
28      | RBRACKET -> "RBRACKET"
29      | LPAREN -> "LPAREN"
30      | RPAREN -> "RPAREN"
31      | LBRACE -> "LBRACE"
32      | RBRACE -> "RBRACE"
33      | SEMI -> "SEMI"
34      | 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)
195     @return Only returns a unit
196   *)
197 let pprint_token_lines header lines =
198     let spaces = String.make (String.length header) ' ' in
199     let rec lines_printer prefix = function
200         | line::rest ->
201             print_string prefix;
202             print_token_line line;
203             print_newline ();
204             lines_printer spaces rest
205         | [] -> () in
206     lines_printer header lines
207
208 (** The majority of the following functions are relatively direct AST to string
    operations *)
209
210 (* Useful for both sAST and AST *)
211 let _id x = x
212 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"

let inspect_ast_op (op : Ast.op) = match op with
    | Arithmetic(an_op) -> Printf.sprintf "Arithmetic(%s)" (inspect_ast_arith an_op)
    | NumTest(an_op)    -> Printf.sprintf "NumTest(%s)" (inspect_ast_numtest an_op)
    | CombTest(an_op)   -> Printf.sprintf "CombTest(%s)" (inspect_ast_combtest an_op)

let rec inspect_ast_expr (expr : Ast.expr) = match expr with
    | Id(id) -> Printf.sprintf "Id(%s)" id
    | This -> "This"
    | Null -> "Null"
    | NewObj(the_type, args) -> Printf.sprintf("NewObj(%s, %s)") the_type (
    inspect_str_list inspect_ast_expr args)
    | 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
    )
    | Literal(l) -> Printf.sprintf "Literal(%s)" (inspect_ast_lit l)
    | Invoc(receiver, meth, args) -> Printf.sprintf "Invocation(%s, %s, %s)" (
    inspect_ast_expr receiver) meth (inspect_str_list inspect_ast_expr args)
    | Field(receiver, field) -> Printf.sprintf "Field(%s, %s)" (inspect_ast_expr receiver
    ) field
    | Deref(var, index) -> Printf.sprintf "Deref(%s, %s)" (inspect_ast_expr var) (
    inspect_ast_expr var)
    | Unop(an_op, exp) -> Printf.sprintf "Unop(%s, %s)" (inspect_ast_op an_op) (
    inspect_ast_expr exp)
    | Binop(left, an_op, right) -> Printf.sprintf "Binop(%s, %s, %s)" (inspect_ast_op
    an_op) (inspect_ast_expr left) (inspect_ast_expr right)
    | Refine(fname, args, totype) -> Printf.sprintf "Refine(%s,%s,%s)" fname (
    inspect_str_list inspect_ast_expr args) (inspect_opt _id totype)
    | 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) =
    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 70: `"Inspector.ml"`

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

```
5
6   (** A place for StringSet and StringMap to live. *)
7
8   (**
9       Convenience type to make reading table types easier. A lookup_table
10      is a primary key -> second key -> value map (i.e. the values of the
11      first StringMap are themselves StringMap maps...
12    *)
13  type 'a lookup_table = 'a StringMap.t StringMap.t
14
15  (**
16      Convenience type to make reading string maps easier. A lookup_map
17      is just a StringMap map.
18    *)
19  type 'a lookup_map = 'a StringMap.t
20
21
22  (** Print the contents of a lookup_map *)
23  let print_lookup_map map stringer =
24      let print_item (secondary, item) =
25          print_string (stringer secondary item) in
26      List.iter print_item (StringMap.bindings map)
27
28  (** Print the contents of a lookup_table *)
29  let print_lookup_table table stringer =
30      let print_lookup_map (primary, table) =
31          print_lookup_map table (stringer primary) in
32      List.iter print_lookup_map (StringMap.bindings table)
33
34
35  (**
36      To put it into symbols, we have builder : (StringMap, errorList) -> item -> (
        StringMap', errorList')
37      @param builder A function that accepts a StringMap/(error list) pair and a new item
38      and returns a new pair with either and updated map or updated error list
39      @param alist The list of data to build the map out of.
40    *)
41  let build_map_track_errors builder alist =
42      match List.fold_left builder (StringMap.empty, []) alist with
43          | (value, []) -> Left(value)
44          | (_, errors) -> Right(errors)
45
46  (**
47      Look a value up in a map
48      @param key The key to look up
49      @param map The map to search in
50      @return Some(value) or None
51    *)
52  let map_lookup key map = if StringMap.mem key map
53      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
```

```
    StringMap.add key (value::old) map

(** Updating a string map that has a list of possible values with a bunch of new values
    *)
let concat_map_list key values map =
    let old = map_lookup_list key map in
    StringMap.add key (values@old) map

(** Update a map but keep track of collisions *)
let add_map_unique key value (map, collisions) =
    if StringMap.mem key map
        then (map, key::collisions)
        else (StringMap.add key value map, collisions)
```

Source 71: "StringModules.ml"

```
val token_to_string : Parser.token -> string
val descan : Parser.token -> string
val token_list : (Lexing.lexbuf -> Parser.token) -> Lexing.lexbuf -> Parser.token list
val from_channel : Pervasives.in_channel -> Parser.token list
val pprint_token_list : string -> Parser.token list -> unit
val pprint_token_lines : string -> (int * Parser.token list * bool) list -> unit
val inspect_ast_lit : Ast.lit -> string
val inspect_ast_arith : Ast.arith -> string
val inspect_ast_numtest : Ast.numtest -> string
val inspect_ast_combtest : Ast.combtest -> string
val inspect_ast_op : Ast.op -> string
val inspect_ast_expr : Ast.expr -> string
val inspect_ast_var_def : Ast.var_def -> string
val inspect_ast_stmt : Ast.stmt -> string
val inspect_ast_clause : Ast.expr option * Ast.stmt list -> string
val inspect_ast_class_section : Ast.class_section -> string
val inspect_ast_func_def : Ast.func_def -> string
val inspect_ast_member_def : Ast.member_def -> string
val inspect_ast_class_sections : Ast.class_sections_def -> string
val inspect_ast_class_def : Ast.class_def -> string
```

Source 72: "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 73: "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
```

```
12
13  let pp_lit = function
14      | Int(i)    -> Printf.sprintf "Int(%d)" i
15      | Float(f)  -> Printf.sprintf "Float(%f)" f
16      | String(s) -> Printf.sprintf "String(%s)" s
17      | Bool(b)   -> Printf.sprintf "Bool(%B)" b
18
19  let pp_arith = function
20      | Add  -> "Add"
21      | Sub  -> "Sub"
22      | Prod -> "Prod"
23      | Div  -> "Div"
24      | Mod  -> "Mod"
25      | Neg  -> "Neg"
26      | Pow  -> "Pow"
27
28  let pp_numtest = function
29      | Eq   -> "Eq"
30      | Neq  -> "Neq"
31      | Less -> "Less"
32      | Grtr -> "Grtr"
33      | Leq  -> "Leq"
34      | Geq  -> "Geq"
35
36  let pp_combtest = function
37      | 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*)
110      Format.sprintf "\n%sInitMem(%s)@]"
111      (indent depth) (pp_func_def (depth+1) imem)
112      (*Format.sprintf fmt
113      (pp_func_def (depth+1) imem)*)
114
115 let pp_class_sections sections depth =
116  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 74: "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 75: "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 76: `"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 77: `"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
```

```
14  let get_rname (f : Sast.func_def) = match f.host with
15      | None -> raise(Failure("Generating refine name for non-refinement " ^ f.name ^ " in
        class " ^ f.inklass ^ "."))
16      | Some(host) -> to_rname f.uid host f.name
17  let get_vname vname = "v_" ^ vname
18  let get_pointer typ = ("t_"^(Str.global_replace (Str.regexp "\\[\\]") "*" typ));;
19
20  let get_tname tname =
21      let fixtypes str = try
22          let splitter n = (String.sub str 0 n, String.sub str n (String.length str - n))
        in
23          let (before, after) = splitter (String.index str '*') in (String.trim before) ^ "
         " ^ (String.trim after)
24      with Not_found -> str ^ " " in
25  fixtypes (get_pointer tname)
26
27
28  let from_tname tname = String.sub tname 2 (String.length tname - 3)
29  let opt_tname = function
30      | None -> None
31      | Some(atype) -> Some(get_tname atype)
32  let get_vdef (vtype, vname) = (get_tname vtype, get_vname vname)
33
34  let cast_switch meth refine =
35      let update_klass klass = get_tname klass in
36      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)
    | Sast.Binop(e1, op, e2)                    -> Cast.Binop(sast_to_castexpr mname
    env e1, op, sast_to_castexpr mname env e2)
    | Sast.Refine(name, args, rtype, switch)    -> Cast.Refine(sast_to_castexprlist
    mname env args, opt_tname rtype, cast_switch mname name switch)
    | 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;
        formals = List.map get_vdef func.formals;
        body = cstmtlist func.name func.body;
        builtin = func.builtin;
        inklass = func.inklass;
        static  = func.static;
    }

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 78: "GenCast.ml"

```
open Util

val klass_to_parent : Ast.class_def -> string
val section_string : Ast.class_section -> string
val klass_to_variables : Ast.class_def -> (Ast.class_section * Ast.var_def list) list
val klass_to_methods : Ast.class_def -> (Ast.class_section * Ast.func_def list) list
val klass_to_functions : Ast.class_def -> (Ast.class_section * Ast.func_def list) list
val conflicting_signatures : Ast.func_def -> Ast.func_def -> bool
val signature_string : Ast.func_def -> string
val full_signature_string : Ast.func_def -> string
val class_var_lookup : GlobalData.class_data -> string -> string -> (Ast.class_section *
    string) option
val class_field_lookup : GlobalData.class_data -> string -> string -> (string * string *
    Ast.class_section) option
val class_field_far_lookup : GlobalData.class_data -> string -> string -> bool -> ((
    string * string * Ast.class_section), bool) either
val class_method_lookup : GlobalData.class_data -> string -> string -> Ast.func_def list
val class_ancestor_method_lookup : GlobalData.class_data -> string -> string -> bool ->
    Ast.func_def list
val refine_lookup : GlobalData.class_data -> string -> string -> string -> Ast.func_def
    list
val refinable_lookup : GlobalData.class_data -> string -> string -> string -> Ast.
    func_def list
val get_distance : GlobalData.class_data -> string -> string -> int option
val is_type : GlobalData.class_data -> string -> bool
val is_subtype : GlobalData.class_data -> string -> string -> bool
val is_proper_subtype : GlobalData.class_data -> string -> string -> bool
val compatible_formals : GlobalData.class_data -> string list -> string list -> bool
val compatible_function : GlobalData.class_data -> string list -> Ast.func_def -> bool
val compatible_return : GlobalData.class_data -> string option -> Ast.func_def -> bool
val compatible_signature : GlobalData.class_data -> string option -> string list -> Ast.
    func_def -> bool
val best_matching_signature : GlobalData.class_data -> string list -> Ast.func_def list
    -> Ast.func_def list
val best_method : GlobalData.class_data -> string -> string -> string list -> Ast.
    class_section list -> Ast.func_def option
val best_inherited_method : GlobalData.class_data -> string -> string -> string list ->
    bool -> Ast.func_def option
val refine_on : GlobalData.class_data -> string -> string -> string -> string list ->
    string option -> Ast.func_def list
val get_class_names : GlobalData.class_data -> string list
val get_leaves : GlobalData.class_data -> string list
```

Source 79: "Klass.mli"

```
open Ast
open Str

(** Built in classes *)

let built_in cname : Ast.func_def = match Str.split (regexp "_") cname with
    | [] -> raise(Failure "Bad cname -- empty.")
    | [klass] -> raise(Failure("Bad cname -- just class: " ^ klass))
    | klass::func ->
        let methname = match func with
            | [] -> raise(Failure("Impossible!"))
            | func::rest -> func ^ (String.concat "" (List.map String.capitalize rest))
```

```
    in
        { returns = None;
          host = None;
          name = methname;
          static = false;
          formals = [];
          body = [];
          section = Publics;
          inklass = String.capitalize klass;
          uid = cname;
          builtin = true }
let breturns cname atype = { (built_in cname) with returns = Some(atype) }
let btakes cname formals = { (built_in cname) with formals = formals }

let sections : Ast.class_sections_def =
    { publics = [];
      protects = [];
      privates = [];
      refines = [];
      mains = [] }

let func f = if f.name = "init" then InitMem(f) else MethodMem(f)
let var v = VarMem(v)
let variables = List.map var
let functions = List.map func
let members f v = (functions f) @ (variables v)

let class_object : Ast.class_def =
    let name = "Object" in

    let init_obj : Ast.func_def = { (built_in "object_init") with section = Protects } in
    let system = ("System", "system") in

    let sections : Ast.class_sections_def =
        { sections with
          publics = [];
          protects = [func init_obj; var system] } in

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

let class_scanner : Ast.class_def =
    let name = "Scanner" in

    let scan_line : Ast.func_def = breturns "scanner_scan_string" "String" in
    let scan_int : Ast.func_def = breturns "scanner_scan_integer" "Integer" in
    let scan_float : Ast.func_def = breturns "scanner_scan_float" "Float" in
    let scan_init : Ast.func_def = built_in "scanner_init" in

    let sections : Ast.class_sections_def =
        { sections with
          publics = functions [scan_line; scan_int; scan_float; scan_init] } in

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

let class_printer : Ast.class_def =
    let name = "Printer" in

    let print_string : Ast.func_def = btakes "printer_print_string" [("String", "arg")]
    in
    let print_int : Ast.func_def = btakes "printer_print_integer" [("Integer", "arg")] in
    let print_float : Ast.func_def = btakes "printer_print_float" [("Float", "arg")] in
    let print_init : Ast.func_def = btakes "printer_init" [("Boolean", "stdout")] in

    let sections : Ast.class_sections_def =
        { 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
114     { klass = name; parent = None; sections = sections }
115
116 let class_float : Ast.class_def =
117     let name = "Float" in
118
119     let float_init : Ast.func_def = built_in "float_init" in
120     let float_integer : Ast.func_def = breturns "float_to_i" "Integer" in
121
122     let sections : Ast.class_sections_def =
123         { sections with
124           publics = [func float_integer];
125           protects = [func float_init] } in
126
127     { klass = name; parent = None; sections = sections }
128
129 let class_system : Ast.class_def =
130     let name = "System" in
131
132     let system_init : Ast.func_def = built_in "system_init" in
133     let system_exit : Ast.func_def = btakes "system_exit" [("Integer", "code")] in
134
135     let system_out = ("Printer", "out") in
136     let system_err = ("Printer", "err") in
137     let system_in = ("Scanner", "in") in
138     let system_argc = ("Integer", "argc") in
139
140     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 80: "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 81: "Variables.ml"

```
gcc -g -I ../headers -lm -o a.out test.c
```

Source 82: "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 83: `"classinfo.ml"`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "inspect" "expect-parser" "$@"
```

Source 84: `"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 85: `"test/README"`

```
#!/bin/bash

program="$( basename "$1" )"
scriptdir="$( dirname "$1" )"
exe="./tools/$2"
old="$3"
shift 3

# Arguments
justrun=
save=
verbose=
pattern=*
folderpattern=*

# Calculated values change in each iteration
current=
results=

# Don't change per iteration
tmpfile="test/check"
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.
```

```
for current in "${files[@]}" ; do
  len=`echo "$current" | wc -c`
  test $len -gt $maxlength && maxlength="$len"
done
maxlength=$(( maxlength + 5 ))

for afolder in "${folders[@]}" ; do
  echo "${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 86: `"test/.testdrive"`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "prettify" "expect-ast-pretty" "$@"
```

Source 87: `"test/ast-pretty"`

```
#!/bin/bash

testdir="$( dirname "$0" )"
testprogram=".testdrive"

"$testdir/$testprogram" "$0" "streams" "expect-scanner" "$@"
```

Source 88: `"test/scanner"`

```
class List {
}
```

Source 89: "test/tests/Brace/Empty/Class"

```
class List {
  public {
    init() {
    }
    void noop() {
    }
  }
}
```

Source 90: "test/tests/Brace/Empty/InitMethod"

```
class List {
  refinement {
  }
}
```

Source 91: "test/tests/Brace/Empty/Refinements"

```
class List {
  public {
    void noop() {
    }
  }
}
```

Source 92: "test/tests/Brace/Empty/Method"

```
class List {
  private {
  }
}
```

Source 93: "test/tests/Brace/Empty/Private"

```
class List {
  public {
    void noop() {
      while(true) {
      }
    }
  }
}
```

Source 94: "test/tests/Brace/Empty/WhileMethod"

```
class List {
  public {
    init() {
```

```
    }
  }
}
```

Source 95: "test/tests/Brace/Empty/Init"

```
class List {
  public {
  }
}
```

Source 96: "test/tests/Brace/Empty/Public"

```
class List {
  protected {
  }
}
```

Source 97: "test/tests/Brace/Empty/Protected"

```
class List {
  public {
    void noop() {
      if(true) {
      }
    }
  }
}
```

Source 98: "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 99: `"test/tests/Brace/Multi/Collection"`

```
class List extends Node {
  public {
    init() {
      Int c;
      c := 1234;
    }
  }
}
```

Source 100: `"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 101: "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 102: "test/tests/Brace/Simple/Rectangle"

```
class List:
```

Source 103: "test/tests/Mixed1/Empty/Class"

```
class List:
  public:
    init():
    void noop() {
    }
```

Source 104: "test/tests/Mixed1/Empty/InitMethod"

```
class List:
  refinement {
  }
```

Source 105: "test/tests/Mixed1/Empty/Refinements"

```
class List:
  public:
    void noop() {
    }
```

Source 106: "test/tests/Mixed1/Empty/Method"

```
class List:
```

```
  private {
  }
```

Source 107: "test/tests/Mixed1/Empty/Private"

```
class List:
  public:
    void noop():
      while(true){

      }
```

Source 108: "test/tests/Mixed1/Empty/WhileMethod"

```
class List:
  public:
    init() {
    }
```

Source 109: "test/tests/Mixed1/Empty/Init"

```
class List:
  public {
  }
```

Source 110: "test/tests/Mixed1/Empty/Public"

```
class List:
  protected {
  }
```

Source 111: "test/tests/Mixed1/Empty/Protected"

```
class List:
  public:
    void noop(){
      if(true){}
    }
```

Source 112: "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 113: "test/tests/Mixed1/Multi/Collection"

```
class List extends Node:
  public:
    init() {
      Int c;
      c := 1234;
    }
```

Source 114: "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 115: "test/tests/Mixed1/Simple/Rectangle"

```
class List:
```

Source 116: "test/tests/Space/Empty/Class"

```
class List:
  public:
    init():
    void noop():
```

Source 117: "test/tests/Space/Empty/InitMethod"

```
class List:
  refinement:
```

Source 118: "test/tests/Space/Empty/Refinements"

```
class List:
  public:
    void noop():
```

Source 119: "test/tests/Space/Empty/Method"

```
class List:
  private:
```

Source 120: "test/tests/Space/Empty/Private"

```
class List:
  public:
    void noop():
      while(true):
```

Source 121: "test/tests/Space/Empty/WhileMethod"

```
class List:
  public:
    init():
```

Source 122: "test/tests/Space/Empty/Init"

```
class List:
```

```
  public:
```

Source 123: "test/tests/Space/Empty/Public"

```
class List:
  protected:
```

Source 124: "test/tests/Space/Empty/Protected"

```
class List:
  public:
    void noop():
      if(true):
```

Source 125: "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 126: "test/tests/Space/Multi/Collection"

```
class List extends Node:
  public:
    init():
      Int c;
      c := 1234;
```

Source 127: "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 128: "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 =
```

```
29      let get_label state klass =
30          let (n, labeler) = match map_lookup klass state.labeler with
31              | None -> (0, StringMap.add klass 0 state.labeler)
32              | Some(n) -> (n+1, StringMap.add klass (n+1) state.labeler) in
33          (Format.sprintf "anon_%s_%d" klass n, { state with labeler = labeler }) in
34
35      let get_var_type state env var_name =
36          match map_lookup var_name env with
37              | Some(vinfo) -> Some(fst vinfo)
38              | None -> match Klass.class_field_lookup state.data state.current var_name
    with
39                  | Some((_, vtype, _)) -> Some(vtype)
40                  | _ -> None in
41
42      let deanon_init args formals klass : Ast.func_def =
43          let givens = List.map (fun (t, _) -> (t, "Anon_v_" ^ UID.uid_counter ())) args in
44          let all_formals = givens @ formals in
45          let super = Ast.Super(List.map (fun (_, v) -> Ast.Id(v)) givens) in
46          let assigner (_, vname) = Ast.Expr(Ast.Assign(Ast.Field(Ast.This, vname), Ast.Id(
    vname))) in
47          {   returns = None;
48              host = None;
49              name = "init";
50              static = false;
51              formals = all_formals;
52              body = super::(List.map assigner formals);
53              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

    match expr_deets with
        | Sast.Anonymous(klass, args, refines) ->
            let (newklass, state) = get_label init_state klass in
            let freedefs = deanon_freedefs state env refines in
            let (init_id, ast_class) = deanon_klass args freedefs newklass klass refines
    in
            let freeargs = List.map (fun (t, v) -> (t, Sast.Id(v))) freedefs in
            let instance = Sast.NewObj(newklass, args @ freeargs, Sast.FuncId init_id) in
            let state = { state with deanon = ast_class::state.deanon } in
            (instance, state)
        | Sast.This -> (Sast.This, init_state)
        | Sast.Null -> (Sast.Null, init_state)
        | Sast.Id(id) -> (Sast.Id(id), init_state)
        | Sast.NewObj(klass, args, funcid) ->
            let (args, state) = deanon_exprs init_state env args in
            (Sast.NewObj(klass, args, funcid), state)
        | Sast.Literal(lit) -> (Sast.Literal(lit), init_state)
        | Sast.Assign(mem, data) ->
            let (mem, state) = deanon_expr init_state env mem in
            let (data, state) = deanon_expr state env data in
            (Sast.Assign(mem, data), state)
        | Sast.Deref(arr, idx) ->
            let (arr, state) = deanon_expr init_state env arr in
            let (idx, state) = deanon_expr state env idx in
            (Sast.Deref(arr, idx), state)
        | Sast.Field(expr, mbr) ->
            let (expr, state) = deanon_expr init_state env expr in
            (Sast.Field(expr, mbr), state)
        | Sast.Invoc(recvr, klass, args, funcid) ->
            let (recvr, state) = deanon_expr init_state env recvr in
            let (args, state) = deanon_exprs state env args in
            (Sast.Invoc(recvr, klass, args, funcid), state)
        | Sast.Unop(op, expr) ->
            let (expr, state) = deanon_expr init_state env expr in
            (Sast.Unop(op, expr), state)
        | Sast.Binop(l, op, r) ->
            let (l, state) = deanon_expr init_state env l in
            let (r, state) = deanon_expr state env r in
            (Sast.Binop(l, op, r), state)
        | Sast.Refine(refine, args, ret, switch) ->
            let (args, state) = deanon_exprs init_state env args in
            (Sast.Refine(refine, args, ret, switch), state)
        | Sast.Refinable(refine, switch) ->
            (Sast.Refinable(refine, switch), init_state)

(**
    Update an type-tagged sAST expression to be deanonymized.
    Returns the deanonymized expr and a possibly updated anon_state
    @param init_state anon_state value
    @param env an environment like those attached to stmts in the sAST
    @param t the type of the expr_detail exp
    @param exp an expression detail
    @return ((t, exp'), state') where exp' is exp but deanonymized and
    state' is an updated version of init_state
  *)
and deanon_expr init_state env (t, exp) =
    let (deets, state) = deanon_expr_detail init_state env exp in
    ((t, deets), state)

(**
    Deanonymize a list of expressions maintaining the state properly throughout.
    Returns the list of expressions (deanonymized) and the updated state.
    @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
```

```
        (* Every sAST has been deanonymized, even the deanonymized ones converted into sASTs
         * Every Ast has been sAST'd too. So we are done.
         *)
        | [], [] ->
            if is_empty init_state.deanon then Left((init_state.data, init_state.clean))
            else raise(Failure("Deanonymization somehow did not recurse properly."))

        | [], klass::rest ->
            let (asts, state) = deanon_class init_state klass in
            run_deanon state asts rest

        | klass::rest, _ -> match KlassData.append_leaf init_state.data klass with
            | Left(data) ->
                let sast_klass = BuildSast.ast_to_sast_klass data klass in
                let state = { init_state with data = data } in
                run_deanon state rest (sast_klass::sasts)
            | Right(issue) -> Right(issue) in

    run_deanon (empty_deanon_state klass_data) [] sast_klasses
```

Source 129: "Unanonymous.ml"

```
open StringModules
open Util

val fold_classes : GlobalData.class_data -> ('a -> Ast.class_def -> 'a) -> 'a -> 'a
val map_classes : GlobalData.class_data -> ('a StringMap.t -> Ast.class_def -> 'a StringMap.t) -> 'a StringMap.t
val dfs_errors : GlobalData.class_data -> (string -> 'a -> 'b -> ('a * 'b)) -> 'a -> 'b -> 'b

val build_class_data : Ast.class_def list -> (GlobalData.class_data, GlobalData.class_data_error) either
val build_class_data_test : Ast.class_def list -> (GlobalData.class_data, GlobalData.class_data_error) either

val append_leaf : GlobalData.class_data -> Ast.class_def -> (GlobalData.class_data, GlobalData.class_data_error) either
val append_leaf_test : GlobalData.class_data -> Ast.class_def -> (GlobalData.class_data, GlobalData.class_data_error) either

val print_class_data : GlobalData.class_data -> unit
val errstr : GlobalData.class_data_error -> string
```

Source 130: "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
    let (known, collisions) = List.fold_left build_known (StringSet.empty, StringSet.
    empty) klasses in
    let classes = List.fold_left build_classes StringMap.empty klasses in
    if StringSet.is_empty collisions
        then Left({ empty_data with known = known; classes = classes })
        else Right(collisions)

(**
    Given an initialized class_data record, build the children map
    from the classes that are stored within it.
    The map is from parent to children list.
    @param data A class_data record
    @return data but with the children.
  *)
let build_children_map data =
    let map_builder map aklass = match aklass.klass with
        | "Object" -> map
        | _ -> add_map_list (klass_to_parent aklass) aklass.klass map in
    let children_map = map_classes data map_builder in
    { data with children = children_map }

(**
    Given an initialized class_Data record, build the parent map
    from the classes that are stored within it.
    The map is from child to parent.
    @param data A class_data record
    @return data but with the parent map updated.
  *)
let build_parent_map data =
    let map_builder map aklass = match aklass.klass with
        | "Object" -> map
        | _ -> StringMap.add (aklass.klass) (klass_to_parent aklass) map in
    let parent_map = map_classes data map_builder in
    { data with parents = parent_map }

(**
    Validate that the parent map in a class_data record represents a tree rooted at
    object.
    @param data a class_data record
    @return An optional string (Some(string)) when there is an issue.
  *)
let is_tree_hierarchy data =
    let rec from_object klass checked =
        match map_lookup klass checked with
            | Some(true) -> Left(checked)
            | Some(false) -> Right("Cycle detected.")
            | _ -> match map_lookup klass data.parents with
                | None -> Right("Cannot find parent after building parent map: " ^ klass)
                | Some(parent) -> match from_object parent (StringMap.add klass false
    checked) with
                    | Left(updated) -> Left(StringMap.add klass true updated)
                    | issue -> issue in
```

```
141     let folder result aklass = match result with
142         | Left(checked) -> from_object aklass.klass checked
143         | issue -> issue in
144     let checked = StringMap.add "Object" true StringMap.empty in
145     match fold_classes data folder (Left(checked)) with
146         | Right(issue) -> Some(issue)
147         | _ -> None
148
149 (**
150     Add the class (class name - string) -> ancestors (list of ancestors - string list) map to a
151     class_data record. Note that the ancestors go from 'youngest' to 'oldest' and so should start
152     with the given class (hd) and end with Object (last item in the list).
153     @param data The class_data record to update
154     @return An updated class_data record with the ancestor map added.
155   *)
156 let build_ancestor_map data =
157     let rec ancestor_builder klass map =
158         if StringMap.mem klass map then map
159         else
160             let parent = StringMap.find klass data.parents in
161             let map = ancestor_builder parent map in
162             let ancestors = StringMap.find parent map in
163             StringMap.add klass (klass::ancestors) map in
164     let folder map aklass = ancestor_builder aklass.klass map in
165     let map = StringMap.add "Object" ["Object"] StringMap.empty in
166     let ancestor_map = fold_classes data folder map in
167     { data with ancestors = ancestor_map }
168
169 (**
170     For a given class, build a map of variable names to variable information.
171     If all instance variables are uniquely named, returns Left (map) where map
172     is  var name -> (class_section, type)  otherwise returns Right (collisions)
173     where collisions are the names of variables that are multiply declared.
174     @param aklass A parsed class
175     @return a map of instance variables in the class
176   *)
177 let build_var_map aklass =
178     let add_var section map (typeId, varId) = add_map_unique varId (section, typeId) map in
179     let map_builder map (section, members) = List.fold_left (add_var section) map members in
180     build_map_track_errors map_builder (klass_to_variables aklass)
181
182 (**
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))
269   *)
270 let type_check_signatures data =
271     let folder klass_name aklass bad = match type_check_class data aklass with
272         | Left(data) -> bad
273         | Right(issue) -> issue::bad in
274     match StringMap.fold folder data.classes [] with
275         | [] -> Left(data)
276         | bad -> Right(bad)
277
278 (**
279     Build a map of all the methods within a class, returing either a list of collisions
280     (in Right) when there are conflicting signatures or the map (in Left) when there
281     are not. Keys to the map are function names and the values are lists of func_def's.
282     @param aklass A klass to build a method map for
283     @return Either a list of collisions or a map of function names to func_def's.
284   *)
285 let build_method_map aklass =
286     let add_method (map, collisions) fdef =
287         if List.exists (conflicting_signatures fdef) (map_lookup_list fdef.name map)
288             then (map, fdef::collisions)
289             else (add_map_list fdef.name fdef map, collisions) in
290     let map_builder map funcs = List.fold_left add_method map funcs in
291     build_map_track_errors map_builder (List.map snd (klass_to_methods aklass))
292
293 (**
294     Add the class name (string) -> method name (string) -> methods  (func_def list)
295     methods table to a class_data record, given a list of classes. If there are no
296     collisions, the updated record is returned (in Left), otherwise the collision
297     list is returned (in Right).
298     @param data A class data record
299     @return Either a list of collisions (in Right) or the updated record (in Left).
300     Collisions are pairs (class name, colliding methods for that class). Methods collide
301     if they have conflicting signatures (ignoring return type).
302   *)
303 let build_class_method_map data =
304     let map_builder (klass_map, collision_list) (_, aklass) =
305         match build_method_map aklass with
306             | Left(method_map) -> (StringMap.add aklass.klass method_map klass_map,
    collision_list)
307             | Right(collisions) -> (klass_map, (build_collisions aklass.klass collisions
    false)::collision_list) in
308     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 *)
347
348 (**
349     Add a map of main functions, from class name (string) to main (func_def) to the
350     class_data record passed in. Returns a list of collisions if any class has more
351     than one main (in Right) or the updated record (in Left)
352     @param data A class_data record
353     @param klasses A list of parsed classes
354     @return Either the collisions (Right) or the updated record (Left)
355   *)
356 let build_main_map data =
357     let add_klass (map, collisions) (_, aklass) = match aklass.sections.mains with
358         | [] -> (map, collisions)
359         | [main] -> (StringMap.add aklass.klass main map, collisions)
360         | _ -> (map, aklass.klass :: collisions) in
361     match build_map_track_errors add_klass (StringMap.bindings data.classes) with
362         | Left(main_map) -> Left({ data with mains = main_map })
363         | Right(collisions) -> Right(collisions) (* Same value different types
    parametrically *)
364
365 (**
366     Given a class_data record, verify that there are no double declarations of instance
367     variables as you go up the tree. This means that no two classes along the same root
368     leaf path can have the same public / protected variables, and a private cannot be
369     a public/protected variable of an ancestor.
370     @param data A class_data record.
371     @return Left(data) if everything was okay or Right(collisions) where collisions is
372     a list of pairs of collision information - first item class, second item a list of
373     colliding variables for that class (name, ancestor where they collide)
374   *)
375 let check_field_collisions data =
376     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
            | (fields, []) -> (fields, collisions)
            | (fields, cols) -> (fields, (aklass, cols)::collisions) in

    match dfs_errors data dfs_explorer StringMap.empty [] with
        | [] -> Left(data)
        | collisions -> Right(collisions)

(**
    Check to make sure that we don't have conflicting signatures as we go down the class tree.
    @param data A class_data record value
    @return Left(data) if everything is okay, otherwise a list of (string
  *)
let check_ancestor_signatures data =
    let check_sigs meth_name funcs (methods, collisions) =
        let updater (known, collisions) func =
            if List.exists (conflicting_signatures func) known
                then (known, func::collisions)
                else (func::known, collisions) in
        let apriori = map_lookup_list meth_name methods in
        let (known, collisions) = List.fold_left updater (apriori, collisions) funcs in
        (StringMap.add meth_name known methods, collisions) in

    let skip_init meth_name funcs acc = match meth_name with
        | "init" -> acc
        | _ -> check_sigs meth_name funcs acc in

    let check_class_meths aklass parent_methods =
        let methods = StringMap.find aklass data.methods in
        StringMap.fold skip_init methods (parent_methods, []) in

    let dfs_explorer aklass methods collisions =
       match check_class_meths aklass methods with
            | (methods, []) -> (methods, collisions)
            | (methods, cols) -> (methods, (build_collisions aklass cols false)::collisions) in

    match dfs_errors data dfs_explorer StringMap.empty [] with
        | [] -> Left(data)
        | collisions -> Right(collisions)

(**
    Verifies that each class is able to be instantiated.
    @param data A class_data record
    @return Either the data is returned in Left or a list of uninstantiable classes in Right
  *)
let verify_instantiable data =
    let uninstantiable klass =
        let inits = class_method_lookup data klass "init" in
        not (List.exists (fun func -> func.section <> Privates) inits) in
    let klasses = StringSet.elements data.known in
    match List.filter uninstantiable klasses with
        | [] -> 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)
```

```
let append_parent data = Left(build_parent_map data)
let test_tree data = match is_tree_hierarchy data with
    | None -> Left(data)
    | Some(problem) -> Right(HierarchyIssue(problem))
let append_ancestor data = Left(build_ancestor_map data)
let append_distance data = Left(build_distance_map data)
let append_variables data = match build_class_var_map data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(DuplicateVariables(collisions))
let test_types data = match verify_typed data with
    | Left(data) -> Left(data)
    | Right(bad) -> Right(UnknownTypes(bad))
let test_fields data = match check_field_collisions data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(DuplicateFields(collisions))
let append_methods data = match build_class_method_map data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(ConflictingMethods(collisions))
let test_init data = match verify_instantiable data with
    | Left(data) -> Left(data)
    | Right(bad) -> Right(Uninstantiable(bad))
let test_inherited_methods data = match check_ancestor_signatures data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(ConflictingInherited(collisions))
let append_refines data = match build_class_refinement_map data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(ConflictingRefinements(collisions))
let test_signatures data = match type_check_signatures data with
    | Left(data) -> Left(data)
    | Right(bad) -> Right(PoorlyTypedSigs(bad))
let append_refinable data = Left(build_refinable_map data)
let append_mains data = match build_main_map data with
    | Left(data) -> Left(data)
    | Right(collisions) -> Right(MultipleMains(collisions))

let test_list =
    [ append_children ; append_parent ; test_tree ; append_ancestor ;
      append_distance ; append_variables ; test_fields ; test_types ;
      append_methods ; test_init ; test_inherited_methods ; append_refines ;
      test_signatures ; append_refinable ; append_mains ]

let production_list =
    [ append_children ; append_parent ; test_tree ; append_ancestor ;
      append_distance ; append_variables ; test_fields ; append_methods ;
      test_init ; append_refines ; append_mains ]

let build_class_data klasses = seq (initial_data klasses) test_list (*production_list*)
let build_class_data_test klasses = seq (initial_data klasses) test_list

let append_leaf_known aklass data =
    let updated = StringSet.add aklass.klass data.known in
    if StringSet.mem aklass.klass data.known
        then Right(DuplicateClasses([aklass.klass]))
        else Left({ data with known = updated })
let append_leaf_classes aklass data =
    let updated = StringMap.add aklass.klass aklass data.classes in
    Left({ data with classes = updated })
let append_leaf_tree aklass data =
    (* If we assume data is valid and data has aklass's parent then we should be fine *)
    let parent = klass_to_parent aklass in
    if StringMap.mem parent data.classes
        then Left(data)
        else Right(HierarchyIssue("Appending a leaf without a known parent."))
let append_leaf_children aklass data =
    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 131: "KlassData.ml"