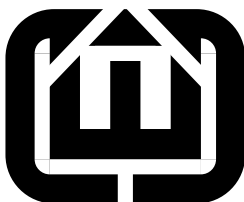


CEC Run Module Expander



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1 Overview

This performs macro expansion of Esterel's `run` statement, making a copy of each module. This module, which operates on the AST, should be run before the dismantler assigns completion codes, since completion code assignment is a global operation.

Berry, in the Esterel primer, writes

All data objects (types, functions, procedures, tasks) are global to an Esterel program. Therefore, the data declarations of the instantiated submodule are exported to the parent module. If some data objects were already declared in the parent, the parent and child declarations must be the same.

The notation x/y means “use x for y .”

Things that can be renamed:

- Types

The type in the module being instantiated is either new and is copied, the same and simply redirected, or renamed to an existing type.

- Constants

Can be new, the same, renamed to an existing constant, or replaced with an actual constant.

- Functions

Can be new, the same, renamed to an existing function, or replaced with a predefined function.

- Procedures

Can be new, the same, or renamed to an existing procedure.

- Tasks

Like procedures.

- Signals

Berry writes, “The signal interface declarations of the instantiated module are simply discarded, as well as the relation declarations. This means that

the interface signals of the instantiated submodule must exist in the parent module with the same type. Notice that a signal declared as input in the submodule is seen as global after instantiation.”

One of the first tasks is identifying the root modules. These are exactly those modules that are not instantiated by any others. This is easily checked in the IC file format: a linear search of the statements gives all the Run statements and the modules they call.

2 The Rewrite function

The rewrite function—the main entry point for the expander—does two things: determines which modules are root modules and copies each of these recursively, expanding run statements as necessary. It uses the FindRoots class to find modules that are run somewhere; those that aren’t are considered roots. Then, it uses the Copier class to recursively copy each of the root modules.

3a *⟨rewrite function declaration 3a⟩*≡ (34a)
`Modules *rewrite(Modules *);`

3b *⟨rewrite function definition 3b⟩*≡ (34b)
`Modules *rewrite(Modules *m)
{
 assert(m);
 FindRoots fr(m);
 const set<Module*> *roots = fr.find();
 if (roots->empty())
 throw IR::Error("No root nodes. Is there a cyclic module dependency?");

 // Copy each root module in the order in which it appeared
 // in the original list of modules (preserve order)
 Modules *result = new Modules();
 for (vector<Module*>::const_iterator i = m->modules.begin() ;
 i != m->modules.end() ; i++)
 if (roots->find(*i) != roots->end()) {
 Copier copier(m, result);
 result->add(copier.copyModule(*i));
 }

 return result;
}`

3 FindRoots

The FindRoots class determines which modules are root modules. These are those modules that are not “run” by any others. This is a simple depth-first search.

4a *<find roots class declaration 4a>*≡ (34a)

```
class FindRoots : public Visitor {
    Modules *modules;
public:
    set<Module*> roots;
    <find roots method declarations 4b>
};
```

4b *<find roots method declarations 4b>*≡ (4a) 4c>

```
FindRoots(Modules *m) {
    assert(m);
    modules = m;
}

virtual ~FindRoots() {}
```

The find method does most of the work: it initializes the root set and recursively walks every module, removing modules that are run in others.

4c *<find roots method declarations 4b>*+≡ (4a) <4b 4e>

```
const set<Module*> *find();
```

4d *<find roots method definitions 4d>*≡ (34b) 5b>

```
const set<Module*> *FindRoots::find()
{
    // Start the set of roots off as all modules
    for ( vector<Module*>::const_iterator i = modules->modules.begin() ;
          i != modules->modules.end() ; i++ ) {
        assert(*i);
        roots.insert(*i);
    }

    // Visit each of the modules and remove any run modules from the roots set

    for ( vector<Module*>::const_iterator i = modules->modules.begin() ;
          i != modules->modules.end() ; i++ )
        recurse(*i);

    return &roots;
}
```

The recurse method visits statements.

4e *<find roots method declarations 4b>*+≡ (4a) <4c 5a>

```
void recurse(ASTNode* n) { if (n) n->welcome(*this); }
```

3.1 The Run Statement

This statement is the only one that does anything productive: modules that are run are removed from the set of roots, since a module that is run is by definition not a root.

```

5a  <find roots method declarations 4b>+≡ (4a) <4e 5c>
      Status visit(Run &);

5b  <find roots method definitions 4d>+≡ (34b) <4d
      Status FindRoots::visit(Run &s)
      {
        if ( !(modules->module_symbols.contains(s.old_name)) )
          throw IR::Error("Attempt to run unknown module " + s.old_name);
        ModuleSymbol *ms =
          dynamic_cast<ModuleSymbol*>(modules->module_symbols.get(s.old_name));
        assert(ms);
        Module *m = ms->module;
        assert(m);
        roots.erase(m);
        return Status();
      }

```

3.2 Atomic Statements

These are very simple: they stop the recursion since they do not contain any other statements.

```

5c  <find roots method declarations 4b>+≡ (4a) <5a 6a>
      Status visit(Nothing &) { return Status(); }
      Status visit(Pause &) { return Status(); }
      Status visit(Halt &) { return Status(); }
      Status visit(Exit &) { return Status(); }
      Status visit(Emit &) { return Status(); }
      Status visit(Sustain &) { return Status(); }
      Status visit(Assign &) { return Status(); }
      Status visit(ProcedureCall &) { return Status(); }

```

3.3 Composite Statements

These all continue the recursion on each of their child statements.

Statements with a single body are simplest:

- 6a $\langle \text{find roots method declarations } 4b \rangle + \equiv$ (4a) $\langle 5c \ 6b \rangle$
- ```

Status visit(Module &m) { recurse(m.body); return Status(); }
Status visit(Loop &s) { recurse(s.body); return Status(); }
Status visit(Repeat &s) { recurse(s.body); return Status(); }
Status visit(Signal &s) { recurse(s.body); return Status(); }
Status visit(Var &s) { recurse(s.body); return Status(); }
Status visit(LoopEach &s) { recurse(s.body); return Status(); }
Status visit(Every &s) { recurse(s.body); return Status(); }
Status visit(Suspend &s) { recurse(s.body); return Status(); }
Status visit(DoUpto &s) { recurse(s.body); return Status(); }

```
- 6b  $\langle \text{find roots method declarations } 4b \rangle + \equiv$  (4a)  $\langle 6a \ 6c \rangle$
- ```

Status visit(DoWatching &s) {
    recurse(s.body);
    recurse(s.timeout);
    return Status();
}

```
- 6c $\langle \text{find roots method declarations } 4b \rangle + \equiv$ (4a) $\langle 6b \ 6d \rangle$
- ```

Status visit(Trap &s) {
 recurse(s.body);
 for (vector<PredicatedStatement*>::const_iterator i = s.handlers.begin() ;
 i != s.handlers.end() ; i++) {
 assert(*i);
 recurse((*i)->body);
 }
 return Status();
}

```
- Sequences iterate over each child.
- 6d  $\langle \text{find roots method declarations } 4b \rangle + \equiv$  (4a)  $\langle 6c \ 6e \rangle$
- ```

Status visit(StatementList &l) {
    for (vector<Statement*>::iterator i = l.statements.begin() ;
        i != l.statements.end() ; i++ )
        recurse(*i);
    return Status();
}

```
- 6e $\langle \text{find roots method declarations } 4b \rangle + \equiv$ (4a) $\langle 6d \ 7a \rangle$
- ```

Status visit(ParallelStatementList &l) {
 for (vector<Statement*>::iterator i = l.threads.begin() ;
 i != l.threads.end() ; i++)
 recurse(*i);
 return Status();
}

```

IfThenElse may have child statements.

7a  $\langle \text{find roots method declarations 4b} \rangle + \equiv$  (4a)  $\langle 6e \ 7b \rangle$   

```

Status visit(IfThenElse &s) {
 recurse(s.then_part);
 recurse(s.else_part);
 return Status();
}

```

7b  $\langle \text{find roots method declarations 4b} \rangle + \equiv$  (4a)  $\langle 7a \ 7c \rangle$   

```

Status visit(Exec &s) {
 for (vector<TaskCall*>::iterator i = s.calls.begin() ;
 i != s.calls.end() ; i++) {
 assert(*i);
 recurse((*i)->body);
 }
 return Status();
}

```

### 3.4 Case Statements

These consist of a collection of predicated statements plus an (optional) default.  
The following helper function handles most of them.

7c  $\langle \text{find roots method declarations 4b} \rangle + \equiv$  (4a)  $\langle 7b \ 7d \rangle$   

```

void visitCase(CaseStatement *s) {
 for (vector<PredicatedStatement*>::const_iterator i = s->cases.begin() ;
 i != s->cases.end() ; i++) {
 assert(*i);
 recurse((*i)->body);
 }
 recurse(s->default_stmt);
}

```

7d  $\langle \text{find roots method declarations 4b} \rangle + \equiv$  (4a)  $\langle 7c \ 7e \rangle$   

```

Status visit(Present &s) { visitCase((CaseStatement*) &s); return Status(); }
Status visit(If &s) { visitCase((CaseStatement*) &s); return Status(); }
Status visit(Await &s) { visitCase((CaseStatement*) &s); return Status(); }

```

7e  $\langle \text{find roots method declarations 4b} \rangle + \equiv$  (4a)  $\langle 7d \rangle$   

```

Status visit(Abort &s) {
 visitCase((CaseStatement*) &s);
 recurse(s.body);
 return Status();
}

```

## 4 Copier

The copier is the main workhorse: it does a recursive visit of a module, copying each AST node as it goes.

The `copiedSymbolMap` maps from symbols in the original module to symbols in the copied module. Copying a symbol typically fills this map.

The `copiedSymbolTableMap` maps from symbol tables in the original module to those in the copied module. This is used to set “parent” symbol table links.

A run statement can replace constants with expressions. The `newConstantExpression` map maps from variable symbols (i.e., constants) in the old module to an object that can generate a copy of the replacement expression in the new module. If a particular variable symbol doesn’t appear in this map, it should be in the `copiedSymbolMap`.

```

8a <copier class declaration 8a>≡ (34a)
 class Copier : public Visitor {
 map<const Symbol*, Symbol*> copiedSymbolMap;
 map<const SymbolTable*, SymbolTable*> copiedSymbolTableMap;
 map<const ConstantSymbol*, ExpressionCopier*> newConstantExpression;
 Modules *oldModules;
 Modules *newModules;
 Module *newModule;
 public:
 <copier method declarations 8b>
 };

8b <copier method declarations 8b>≡ (8a) 8c>
 Copier(Modules *om, Modules *nm)
 : oldModules(om), newModules(nm), newModule(0) {
 assert(nm);
 assert(om);
 }

 Copier(Copier *c) {
 assert(c);
 oldModules = c->oldModules;
 newModules = c->newModules;
 newModule = c->newModule;
 }

 virtual ~Copier() {}

 The copy method is the main one: it uses the visitor to make a copy of the
 node and then casts it back appropriately. Null pointers are simply returned.

8c <copier method declarations 8b>+≡ (8a) <8b 9a>
 template <class T> T* copy(T* n) {
 T* result = n ? dynamic_cast<T*>(n->welcome(*this).n) : 0;
 assert(result || !n);
 return result;
 }

```

The `newSymbol` method returns a pointer to the copy of the symbol stored in the `copiedSymbolMap` map. This assumes that a copy has been made; it's an error to ask for a symbol that hasn't been registered in the table. Note: the names of the new symbol may not match the old one because it may have been renamed.

```
9a <copier method declarations 8b>+≡ (8a) <8c 9b>
 template <class T> T* newSymbol(const T* s) {
 if (!s) return 0;
 // std::cerr << "newSymbol " << s->name << std::endl;
 map<const Symbol*, Symbol*>::const_iterator i = copiedSymbolMap.find(s);
 assert(i != copiedSymbolMap.end()); // Should be in the map
 assert((*i).second); // Should be non-NULL
 T* result = dynamic_cast<T*>((*i).second);
 assert(result); // Should be the same type
 return result;
 }
```

The `newSymbolTable` method returns the copy of an old symbol table. It assumes that a copy has been made.

```
9b <copier method declarations 8b>+≡ (8a) <9a 9c>
 SymbolTable *newSymbolTable(const SymbolTable *s) {
 assert(s);
 map<const SymbolTable*, SymbolTable*>::const_iterator i =
 copiedSymbolTableMap.find(s);
 assert(i != copiedSymbolTableMap.end());
 SymbolTable *result = (*i).second;
 assert(result);
 return result;
 }
```

## 4.1 Symbol Table Copier

This makes a copy of each of the symbols in the given symbol table and enters the duplicate in the `copiedSymbolMap`. It also fixes the parent pointer using `copiedSymbolTableMap` and enters the relationship between the two symbol tables in the map.

```
9c <copier method declarations 8b>+≡ (8a) <9b 10b>
 void copySymbolTable(const SymbolTable *, SymbolTable *);
```

```

10a <copier method definitions 10a>≡ (34b) 11a>
 void Copier::copySymbolTable(const SymbolTable *source, SymbolTable *dest)
 {
 assert(source);
 assert(dest);

 for (SymbolTable::const_iterator i = source->begin() ;
 i != source->end() ; i++) {
 assert(*i);
 Symbol *news = copy(*i);
 dest->enter(news);
 copiedSymbolMap.insert(std::make_pair(*i, news));
 // std::cout << "Copied " << news->name << std::endl;
 }

 if (source->parent)
 dest->parent = newSymbolTable(source->parent);

 copiedSymbolTableMap.insert(std::make_pair(source, dest));
 }

```

## 4.2 Method

The method copier is only used when copying a root module.

```

10b <copier method declarations 8b>+≡ (8a) <9c 11b>
 Module *copyModule(Module&);

```

The order in which the symbol tables is copied is important: signals must appear after variables since they have presence variables.

- 11a  $\langle \text{copier method definitions 10a} \rangle + \equiv$  (34b)  $\langle 10a \ 13 \rangle$
- ```

Module *Copier::copyModule(Module &m)
{
    assert(m.symbol);
    ModuleSymbol *ms = new ModuleSymbol(m.symbol->name);
    Module *result = new Module(ms);
    newModule = result;
    ms->module = result;

    // std::cout << "Copying " << m.symbol->name << std::endl;

    copySymbolTable(m.types, result->types);
    copySymbolTable(m.constants, result->constants);
    copySymbolTable(m.functions, result->functions);
    copySymbolTable(m.procedures, result->procedures);
    copySymbolTable(m.tasks, result->tasks);
    copySymbolTable(m.variables, result->variables);
    copySymbolTable(m.signals, result->signals);

    for ( vector<InputRelation*>::const_iterator i = m.relations.begin() ;
          i != m.relations.end() ; i++ ) {
        assert(*i);
        result->relations.push_back(copy(*i));
    }

    result->body = copy(m.body);
    return result;
}

```
- 11b $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 10b \ 11c \rangle$
- ```

Status visit(Exclusion &e) {
 Exclusion *result = new Exclusion();
 for (vector<SignalSymbol*>::const_iterator i = e.signals.begin() ;
 i != e.signals.end() ; i++) {
 assert(*i);
 result->signals.push_back(newSymbol(*i));
 }
 return result;
}

```
- 11c  $\langle \text{copier method declarations 8b} \rangle + \equiv$  (8a)  $\langle 11b \ 12 \rangle$
- ```

Status visit(Implication &e) {
    return new Implication(newSymbol(e.predicate), newSymbol(e.implication));
}

```

4.3 The Run Statement

This is the main challenge: When the copier hits a "run" statement, instead of simply copying the run statement, it makes a copy of the module itself with the appropriate renaming of signals and other interface objects.

12 $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 11c \ 25a \rangle$
 Status visit(Run &);

```

13  <copier method definitions 10a>+≡                                     (34b) <11a 25c>
    Status Copier::visit(Run &r)
    {
        assert(newModule);

        // std::cout << "run " << r.new_name << " / " << r.old_name << std::endl;

        // Locate the old module by its name
        assert(oldModules);
        if ( !(oldModules->module_symbols.contains(r.old_name)) )
            throw IR::Error("Attempt to run unknown module " + r.old_name);

        ModuleSymbol *ms =
            dynamic_cast<ModuleSymbol*>(oldModules->module_symbols.get(r.old_name));
        assert(ms);
        Module *moduleToCopy = ms->module;
        assert(moduleToCopy);

        Statement *body = dynamic_cast<Statement*>(moduleToCopy->body);
        assert(body);

        Copier newcopier(this);

        // Map the declaration symbol tables in the module being run to the
        // equivalent ones in the new module
        newcopier.copiedSymbolTableMap.insert(std::make_pair( moduleToCopy->constants,
                                                                newModule->constants));

        <renamed signal rules 14>
        <normal signal rules 15a>

        <renamed type rules 15b>
        <normal type rules 16>

        <renamed constant rules 17>
        <normal constant rules 18>

        <renamed function rules 19>
        <normal function rules 20>

        <renamed procedure rules 21>
        <normal procedure rules 22>

        <renamed task rules 23a>
        <normal task rules 23b>

        <variable rules 24>

        Statement *result = newcopier.copy(body);
        return result;

```

}

4.3.1 Signals

There are two cases for each signal in the run module: it is assigned to a new signal by renaming it at the run statement, or it matches the name of a signal in the scope where the run statement appeared.

This code handles renamed signals. The signal renaming object provides two things: the name of the signal in the module being run and a pointer to the symbol that will replace it. This code locates the signal in the run module by name, fetches its symbol, and adds a map of this symbol in the run module to the new copy of the new signal.

[illegible]

This code, run after renamed signals have been entered in the map, finds a matching signal for each in the interface of the run module. It looks for corresponding signals in the symbol table of signals attached to the run statement, which represents the scope in which the run statement appears. It skips any signal for which a mapping already exists; it has been renamed.

```

15a  <normal signal rules 15a>≡ (13)
      assert(r.signalScope); // Should have been put there during static semantics
      SymbolTable *newSignalTable = newSymbolTable(r.signalScope);
      newcopier.copiedSymbolTableMap.insert(std::make_pair(moduleToCopy->signals,
                                                             newSignalTable));

      for ( SymbolTable::const_iterator i = moduleToCopy->signals->begin() ;
            i != moduleToCopy->signals->end() ; i++ ) {
        SignalSymbol *oldSignal = dynamic_cast<SignalSymbol*>(*i);
        assert(oldSignal);
        if ( newcopier.copiedSymbolMap.find(oldSignal) ==
              newcopier.copiedSymbolMap.end() ) {
          if (!newSignalTable->contains(oldSignal->name))
            throw IR::Error("Could not find signal " + oldSignal->name +
                             " in enclosing scope");
          SignalSymbol *newSignal =
            dynamic_cast<SignalSymbol*>(newSignalTable->get(oldSignal->name));
          assert(newSignal);
          newcopier.copiedSymbolMap.insert( std::make_pair(oldSignal, newSignal) );
        }
      }

```

4.3.2 Types

There are three cases for each type in the run module: the type is new and is added to the running module, the type already exists in the running module, or the type has been renamed.

This code handles type renaming: for each renamed type, make sure its name is a type in the run module, then add a map from the old type symbol to the symbol in the running module.

```

15b  <renamed type rules 15b>≡ (13)
      for ( vector<TypeRenaming*>::const_iterator i = r.types.begin() ;
            i != r.types.end() ; i++ ) {
        TypeRenaming *tr = *i;
        assert(tr);
        if ( !(moduleToCopy->types->local_contains(tr->old_name)) )
          throw IR::Error("Attempting to rename unknown type " + tr->old_name);
        TypeSymbol *oldType =
          dynamic_cast<TypeSymbol*>(moduleToCopy->types->get(tr->old_name));
        assert(oldType);
        TypeSymbol *newType = newSymbol(tr->new_type);
        newcopier.copiedSymbolMap.insert(std::make_pair(oldType, newType));
      }

```

This code handles non-renamed types. For each type in the run module, it first checks to see that it hasn't already been renamed, then either uses an existing identically-named type or adds it to the running module.

```

16  <normal type rules 16>≡ (13)
    #if 0
        std::cout << "Start of symbol table" << std::endl;
        for ( SymbolTable::const_iterator i = newModule->types->begin() ;
              i != newModule->types->end() ; i++ ) {
            assert(*i);
            std::cout << "type " << (*i)->name << std::endl;
        }
        std::cout << "End of symbol table" << std::endl;
    #endif

    for ( SymbolTable::const_iterator i = moduleToCopy->types->begin() ;
          i != moduleToCopy->types->end() ; i++ ) {
        TypeSymbol *oldType = dynamic_cast<TypeSymbol*>(*i);
        assert(oldType);
        // std::cout << "copying type " << oldType->name << std::endl;

        if ( newcopier.copiedSymbolMap.find(oldType) ==
              newcopier.copiedSymbolMap.end() ) {

            TypeSymbol *newType;
            if ( newModule->types->local_contains(oldType->name) ) {
                // Use existing type
                newType = dynamic_cast<TypeSymbol*>(newModule->types->get(oldType->name));
                assert(newType);
            } else {
                // Copy type into running module
                newType = newcopier.copy(oldType);
                newModule->types->enter(newType);
            }

            assert(newType);
            newcopier.copiedSymbolMap.insert( std::make_pair(oldType, newType) );
        }
    }
}

```

4.3.3 Constants

Handle renamed constants: These are replaced with expressions by registering them in the newConstantExpression map

```

17  <renamed constant rules 17>≡ (13)
    for ( vector<ConstantRenaming*>::const_iterator i = r.constants.begin() ;
          i != r.constants.end() ; i++ ) {
        ConstantRenaming *cr = *i;
        assert(cr);
        if ( !(moduleToCopy->constants->local_contains(cr->old_name)) )
            throw IR::Error("Attempting to rename unknown constant " + cr->old_name);
        ConstantSymbol *oldConstant =
            dynamic_cast<ConstantSymbol*>(moduleToCopy->constants->get(cr->old_name));
        assert(oldConstant);
        ExpressionCopier *ec = new ExpressionCopier(cr->new_value, this);
        newcopier.newConstantExpression.insert(std::make_pair(oldConstant, ec));
    }

```

```

18  <normal constant rules 18>≡ (13)
    for ( SymbolTable::const_iterator i = moduleToCopy->constants->begin() ;
          i != moduleToCopy->constants->end() ; i++ ) {
        ConstantSymbol *oldConstant = dynamic_cast<ConstantSymbol*>(*i);
        assert(oldConstant);
        // Here, we have a constant in the instantiated module. It may be that
        // 1. The constant is new: add it to the module being built
        // 2. The constant already exists in the main module: use that one
        // 3. The constant has been renamed: do nothing; this was handled above

        if ( newcopier.newConstantExpression.find(oldConstant) ==
              newcopier.newConstantExpression.end() ) {

            // Haven't already renamed this constant

            ConstantSymbol *newConstant;

            if ( newModule->constants->local_contains(oldConstant->name) ) {
                // Found the constant: use the existing one
                newConstant =
                    dynamic_cast<ConstantSymbol*>(newModule->constants->get(oldConstant->name));
                /* FIXME: Should verify that the initial value of the two
                   constants is consistent

                   module Foo:
                       constant c = 10 : integer;
                       run Bar
                   end module

                   module Bar:
                       constant c = 20 : integer;
                       nothing
                   end module
                */

            } else {
                // Constant doesn't already exist in the new module: copy it
                // std::cout << "Making a new copy of " << oldConstant->name << std::endl;
                newConstant = newcopier.copy(oldConstant);
                newModule->constants->enter(newConstant);

                /* FIXME: This won't generate re-parsable code if the
                   constant's name was hidden by a local variable decalaration, e.g.,

                   module Foo:
                       var c : integer in
                           run Bar
                       end
                   end module
                */
            }
        }
    }

```

```

        module Bar:
        constant c : integer;
        nothing
        end module

        Berry's iclc doesn't worry about this because it simply numbers
        everything and stores the names separately.
    */
}

    assert(newConstant);
    newcopier.copiedSymbolMap.insert( std::make_pair(oldConstant, newConstant) );
}
}

```

4.3.4 Functions

19 *<renamed function rules 19>*≡ (13)

```

    /* FIXME: Renaming built-in functions, such as +, will generate
       strange output,

       e.g., c := +(a,b)
    */

    for ( vector<FunctionRenaming*>::const_iterator i = r.functions.begin() ;
          i != r.functions.end() ; i++ ) {
        FunctionRenaming *fr = *i;
        assert(fr);
        if ( !(moduleToCopy->functions->local_contains(fr->old_name)) )
            throw IR::Error("Attempting to rename unknown function " + fr->old_name);
        FunctionSymbol *oldFunction =
            dynamic_cast<FunctionSymbol*>(moduleToCopy->functions->get(fr->old_name));
        assert(oldFunction);
        FunctionSymbol *newFunction = newSymbol(fr->new_func);
        newcopier.copiedSymbolMap.insert(std::make_pair(oldFunction, newFunction));
    }

```

```

20  <normal function rules 20>≡ (13)
    for ( SymbolTable::const_iterator i = moduleToCopy->functions->begin() ;
          i != moduleToCopy->functions->end() ; i++ ) {
        FunctionSymbol *oldFunction = dynamic_cast<FunctionSymbol*>(*i);
        assert(oldFunction);
        // Here, we have a function in the instantiated module. It may be that
        // 1. The function is new: add it to the module being built
        // 2. The function already exists in the main module: use that one
        // 3. The function has been renamed: do nothing; this was handled above

        if ( newcopier.copiedSymbolMap.find(oldFunction) ==
              newcopier.copiedSymbolMap.end() ) {

            // Haven't already renamed this function

            FunctionSymbol *newFunction;

            if ( newModule->functions->local_contains(oldFunction->name) ) {
                // Found the function: use the existing one
                newFunction =
                    dynamic_cast<FunctionSymbol*>(newModule->functions->get(oldFunction->name));

                // FIXME: Should check that the parameter types are consistent

            } else {
                // Function doesn't already exist in the new module: copy it
                newFunction = newcopier.copy(oldFunction);
                newModule->functions->enter(newFunction);
            }

            assert(newFunction);
            newcopier.copiedSymbolMap.insert( std::make_pair(oldFunction, newFunction) );
        }
    }

```

4.3.5 Procedures

Renamed procedures are much like renamed constants or functions: map each old procedure symbol to the new one.

```

21  <renamed procedure rules 21>≡ (13)
    for ( vector<ProcedureRenaming*>::const_iterator i = r.procedures.begin() ;
          i != r.procedures.end() ; i++ ) {
        ProcedureRenaming *pr = *i;
        assert(pr);
        if ( !(moduleToCopy->procedures->local_contains(pr->old_name)) )
            throw IR::Error("Attempting to rename unknown procedure " + pr->old_name);
        ProcedureSymbol *oldProcedure =
            dynamic_cast<ProcedureSymbol*>(moduleToCopy->procedures->get(pr->old_name));
        assert(oldProcedure);
        ProcedureSymbol *newProcedure = newSymbol(pr->new_proc);
        newcopier.copiedSymbolMap.insert(std::make_pair(oldProcedure, newProcedure));
    }

```

Like functions, there are three cases for procedures that are not being renamed:

1. The procedure in the module being run is new; add it to the module being built
2. The procedure already exists in the main module; use it
3. The procedure is being renamed. This was handled above.

```

22  <normal procedure rules 22>≡ (13)
    for ( SymbolTable::const_iterator i = moduleToCopy->procedures->begin() ;
          i != moduleToCopy->procedures->end() ; i++ ) {
        ProcedureSymbol *oldProcedure = dynamic_cast<ProcedureSymbol*>(*i);
        assert(oldProcedure);

        if ( newcopier.copiedSymbolMap.find(oldProcedure) ==
              newcopier.copiedSymbolMap.end() ) {

            // Haven't already renamed this procedure
            ProcedureSymbol *newProcedure;

            if ( newModule->procedures->local_contains(oldProcedure->name) ) {
                // Found the procedure: use the existing one
                newProcedure =
                    dynamic_cast<ProcedureSymbol*>(newModule->procedures->get(oldProcedure->name));

                // FIXME: Verify the parameter count and types are consistent

            } else {
                // Procedure doesn't already exist in the new module: copy it
                newProcedure = newcopier.copy(oldProcedure);
                newModule->procedures->enter(newProcedure);
            }
            assert(newProcedure);
            newcopier.copiedSymbolMap.insert( std::make_pair(oldProcedure, newProcedure) );
        }
    }

```

4.3.6 Tasks

Tasks are essentially identical to procedures and handled similarly.

```

23a  <renamed task rules 23a>≡ (13)
      for ( vector<ProcedureRenaming*>::const_iterator i = r.tasks.begin() ;
            i != r.tasks.end() ; i++ ) {
        ProcedureRenaming *pr = *i;
        assert(pr);
        if ( !(moduleToCopy->tasks->local_contains(pr->old_name)) )
            throw IR::Error("Attempting to rename unknown task " + pr->old_name);
        TaskSymbol *oldTask =
            dynamic_cast<TaskSymbol*>(moduleToCopy->tasks->get(pr->old_name));
        assert(oldTask);
        TaskSymbol *newTaskSymbol = dynamic_cast<TaskSymbol*>(pr->new_proc);
        assert(newTaskSymbol);
        TaskSymbol *newTask = newSymbol(newTaskSymbol);
        newcopier.copiedSymbolMap.insert(std::make_pair(oldTask, newTask));
    }

23b  <normal task rules 23b>≡ (13)
      for ( SymbolTable::const_iterator i = moduleToCopy->tasks->begin() ;
            i != moduleToCopy->tasks->end() ; i++ ) {
        TaskSymbol *oldTask = dynamic_cast<TaskSymbol*>(*i);
        assert(oldTask);

        if ( newcopier.copiedSymbolMap.find(oldTask) ==
              newcopier.copiedSymbolMap.end() ) {

            // Haven't already renamed this task
            TaskSymbol *newTask;

            if ( newModule->tasks->local_contains(oldTask->name) ) {
                // Found the task: use the existing one
                newTask =
                    dynamic_cast<TaskSymbol*>(newModule->tasks->get(oldTask->name));

                // FIXME: Verify the parameter count and types are consistent

            } else {
                // Task doesn't already exist in the new module: copy it
                newTask = newcopier.copy(oldTask);
                newModule->tasks->enter(newTask);
            }
            assert(newTask);
            newcopier.copiedSymbolMap.insert( std::make_pair(oldTask, newTask) );
        }
    }

```

4.3.7 Variables

Although normal variables aren't visible in the run module, variables that are owned by the module (e.g., signal and trap presence and value variables) need to be copied. The main trick is ensuring the names don't collide: this is done by prepending the module's new name to the existing variable name and adding a suffix if necessary.

[illegible]

4.4 Symbols

These simply copy their names and data; the `copySymbolTable` method is responsible for entering them in the map.

```

25a  <copier method declarations 8b>+≡ (8a) <12 25b>
      Status visit(TypeSymbol &s) { return new TypeSymbol(s.name); }

      Status visit(BuiltinTypeSymbol &s) { return new BuiltinTypeSymbol(s.name); }

      Status visit(ConstantSymbol &s) {
        return new ConstantSymbol(s.name, newSymbol(s.type), copy(s.initializer));
      }

      Status visit(BuiltinConstantSymbol &s) {
        return new BuiltinConstantSymbol(s.name, newSymbol(s.type),
                                           copy(s.initializer));
      }

25b  <copier method declarations 8b>+≡ (8a) <25a 27a>
      Status visit(FunctionSymbol&);
      Status visit(BuiltinFunctionSymbol&);
      Status visit(ProcedureSymbol&);
      Status visit(TaskSymbol&);

25c  <copier method definitions 10a>+≡ (34b) <13 26>
      Status Copier::visit(FunctionSymbol &s)
      {
        FunctionSymbol *result = new FunctionSymbol(s.name);
        result->result = newSymbol(s.result);
        for ( vector<TypeSymbol*>::const_iterator i = s.arguments.begin() ;
              i != s.arguments.end() ; i++ ) {
          assert(*i);
          result->arguments.push_back(newSymbol(*i));
        }
        return result;
      }

      Status Copier::visit(BuiltinFunctionSymbol &s)
      {
        BuiltinFunctionSymbol *result = new BuiltinFunctionSymbol(s.name);
        result->result = newSymbol(s.result);
        for ( vector<TypeSymbol*>::const_iterator i = s.arguments.begin() ;
              i != s.arguments.end() ; i++ ) {
          assert(*i);
          result->arguments.push_back(newSymbol(*i));
        }
        return result;
      }

```

26 *<copier method definitions 10a>+≡* (34b) <25c 28b>

```

Status Copier::visit(ProcedureSymbol &s)
{
    ProcedureSymbol *result = new ProcedureSymbol(s.name);
    for ( vector<TypeSymbol*>::const_iterator i = s.reference_arguments.begin() ;
          i != s.reference_arguments.end() ; i++ ) {
        assert(*i);
        result->reference_arguments.push_back(newSymbol(*i));
    }
    for ( vector<TypeSymbol*>::const_iterator i = s.value_arguments.begin() ;
          i != s.value_arguments.end() ; i++ ) {
        assert(*i);
        result->value_arguments.push_back(newSymbol(*i));
    }
    return result;
}

Status Copier::visit(TaskSymbol &s)
{
    TaskSymbol *result = new TaskSymbol(s.name);
    for ( vector<TypeSymbol*>::const_iterator i = s.reference_arguments.begin() ;
          i != s.reference_arguments.end() ; i++ ) {
        assert(*i);
        result->reference_arguments.push_back(newSymbol(*i));
    }
    for ( vector<TypeSymbol*>::const_iterator i = s.value_arguments.begin() ;
          i != s.value_arguments.end() ; i++ ) {
        assert(*i);
        result->value_arguments.push_back(newSymbol(*i));
    }
    return result;
}

```

27a $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 25b \ 27b \triangleright$

```

Status visit(SignalSymbol &s)
{
    // std::cout << "Copy signal " << s.name << std::endl;
    return
        new SignalSymbol( s.name, newSymbol(s.type), (SignalSymbol::kinds) s.kind,
                          newSymbol(s.combine), copy(s.initializer),
                          newSymbol(s.presence), newSymbol(s.value) );
}

Status visit(BuiltinSignalSymbol &s)
{
    return
        new BuiltinSignalSymbol( s.name, newSymbol(s.type),
                                (SignalSymbol::kinds) s.kind,
                                newSymbol(s.combine), newSymbol(s.presence),
                                newSymbol(s.value) );
}

```

27b $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 27a \ 27c \triangleright$

```

Status visit(VariableSymbol &s) {
    return new VariableSymbol(s.name, newSymbol(s.type), copy(s.initializer));
}

```

4.5 Atomic Statements

These simply return a new copy of themselves.

27c $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 27b \ 27d \triangleright$

```

Status visit(Nothing &) { return new Nothing(); }
Status visit(Pause &) { return new Pause(); }
Status visit(Halt &) { return new Halt(); }

```

The emit and sustain statements have a signal and optional expression.

27d $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 27c \ 27e \triangleright$

```

Status visit(Emit &e) {
    return new Emit(newSymbol(e.signal), copy(e.value));
}

Status visit(Sustain &s) {
    return new Sustain(newSymbol(s.signal), copy(s.value));
}

```

The assign statement has a variable symbol and an expression.

27e $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 27d \ 27f \triangleright$

```

Status visit(Assign &a) {
    return new Assign(newSymbol(a.variable), copy(a.value));
}

```

27f $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\triangleleft 27e \ 28a \triangleright$

```

Status visit(Exit &e) { return new Exit(newSymbol(e.trap), copy(e.value)); }

```

28a \langle *copier method declarations* 8b $\rangle + \equiv$ (8a) \langle 27f 28c \rangle
`Status visit(ProcedureCall &c);`

28b \langle *copier method definitions* 10a $\rangle + \equiv$ (34b) \langle 26 28d \rangle
`Status Copier::visit(ProcedureCall &c)`
`{`
`ProcedureCall *result = new ProcedureCall(newSymbol(c.procedure));`
`for (vector<VariableSymbol*>::const_iterator i = c.reference_args.begin() ;`
`i != c.reference_args.end() ; i++) {`
`assert(*i);`
`result->reference_args.push_back(newSymbol(*i));`
`}`
`for (vector<Expression*>::const_iterator i = c.value_args.begin() ;`
`i != c.value_args.end() ; i++) {`
`assert(*i);`
`result->value_args.push_back(copy(*i));`
`}`
`return result;`
`}`

4.6 Statement Lists

These make copies of all statements under their control.

28c \langle *copier method declarations* 8b $\rangle + \equiv$ (8a) \langle 28a 29a \rangle
`Status visit(StatementList&);`
`Status visit(ParallelStatementList&);`

28d \langle *copier method definitions* 10a $\rangle + \equiv$ (34b) \langle 28b 30a \rangle
`Status Copier::visit(StatementList &l)`
`{`
`StatementList *result = new StatementList();`
`for (vector<Statement*>::iterator i = l.statements.begin() ;`
`i != l.statements.end() ; i++) {`
`*result << copy(*i);`
`}`
`return result;`
`}`

`Status Copier::visit(ParallelStatementList &l)`
`{`
`ParallelStatementList *result = new ParallelStatementList();`
`for (vector<Statement*>::iterator i = l.threads.begin() ;`
`i != l.threads.end() ; i++) {`
`result->threads.push_back(copy(*i));`
`}`
`return result;`
`}`

4.7 Composite Statements

- 29a $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 28c \ 29b \triangleright$
`Status visit(IfThenElse &s) {
 return new IfThenElse(copy(s.predicate), copy(s.then_part),
 copy(s.else_part));
}`
- 29b $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29a \ 29c \triangleright$
`Status visit(Loop &s) { return new Loop(copy(s.body)); }`
- 29c $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29b \ 29d \triangleright$
`Status visit(Repeat &s) {
 return new Repeat(copy(s.body), copy(s.count), s.is_positive);
}`
- 29d $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29c \ 29e \triangleright$
`Status visit(LoopEach &s) {
 return new LoopEach(copy(s.body), copy(s.predicate));
}`
- 29e $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29d \ 29f \triangleright$
`Status visit(Every &s) {
 return new Every(copy(s.body), copy(s.predicate));
}`
- 29f $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29e \ 29g \triangleright$
`Status visit(Suspend &s) {
 return new Suspend(copy(s.body), copy(s.predicate));
}`
- 29g $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29f \ 29h \triangleright$
`Status visit(DoWatching &s) {
 return new DoWatching(copy(s.body), copy(s.predicate), copy(s.timeout));
}`
- 29h $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29g \ 29i \triangleright$
`Status visit(DoUpto &s) {
 return new DoUpto(copy(s.body), copy(s.predicate));
}`
- 29i $\langle \text{copier method declarations } 8b \rangle + \equiv$ (8a) $\triangleleft 29h \ 30b \triangleright$
`Status visit(Exec &);`

30a \langle copier method definitions 10a $\rangle + \equiv$ (34b) \langle 28d 30c \rangle

```

Status Copier::visit(Exec &e)
{
    Exec *result = new Exec();
    for ( vector<TaskCall*>::const_iterator j = e.calls.begin() ;
          j != e.calls.end() ; j++ ) {
        TaskCall *c = *j;
        assert(c);
        TaskSymbol *ts = dynamic_cast<TaskSymbol*>(c->procedure);
        assert(ts);
        TaskCall *newCall = new TaskCall(newSymbol(ts));
        newCall->signal = newSymbol(c->signal);
        newCall->body = copy(c->body);
        for ( vector<VariableSymbol*>::const_iterator i = c->reference_args.begin() ;
              i != c->reference_args.end() ; i++ ) {
            assert(*i);
            newCall->reference_args.push_back(newSymbol(*i));
        }
        for ( vector<Expression*>::const_iterator i = c->value_args.begin() ;
              i != c->value_args.end() ; i++ ) {
            assert(*i);
            newCall->value_args.push_back(copy(*i));
        }
        result->calls.push_back(newCall);
    }
    return result;
}

```

4.8 Case Statements

30b \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 29i 31a \rangle

```

void copyCases(const CaseStatement &, CaseStatement *);

```

30c \langle copier method definitions 10a $\rangle + \equiv$ (34b) \langle 30a 33f \rangle

```

void Copier::copyCases(const CaseStatement &source, CaseStatement *dest)
{
    assert(dest);
    for ( vector<PredicatedStatement*>::const_iterator i = source.cases.begin() ;
          i != source.cases.end() ; i++ ) {
        assert(*i);
        dest->newCase(copy((*i)->body), copy((*i)->predicate));
    }

    dest->default_stmt = copy(source.default_stmt);
}

```

- 31a $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 30b \ 31b \rangle$

```

    Status visit(Abort &s) {
        Abort *result = new Abort(copy(s.body), s.is_weak);
        copyCases(s, result);
        return result;
    }

```

31b $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 31a \ 31c \rangle$

```

    Status visit(Await &s) {
        Await *result = new Await();
        copyCases(s, result);
        return result;
    }

```

31c $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 31b \ 31d \rangle$

```

    Status visit(Present &s) {
        Present *result = new Present();
        copyCases(s, result);
        return result;
    }

    Status visit(If &s) {
        If *result = new If();
        copyCases(s, result);
        return result;
    }

```

4.9 Scope Statements

- 31d $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 31c \ 31e \rangle$

```

    Status visit(Var &s) {
        Var *result = new Var();
        result->symbols = new SymbolTable();
        copySymbolTable(s.symbols, result->symbols);
        result->body = copy(s.body);
        return result;
    }

```

31e $\langle \text{copier method declarations 8b} \rangle + \equiv$ (8a) $\langle 31d \ 32a \rangle$

```

    Status visit(Signal &s) {
        Signal *result = new Signal();
        result->symbols = new SymbolTable();
        copySymbolTable(s.symbols, result->symbols);
        result->body = copy(s.body);
        return result;
    }

```

32a *<copier method declarations 8b>+≡* (8a) *<31e 32b>*

```

Status visit(Trap &s) {
    Trap *result = new Trap();
    result->symbols = new SymbolTable();
    copySymbolTable(s.symbols, result->symbols);
    result->body = copy(s.body);
    for ( vector<PredicatedStatement *>::const_iterator i = s.handlers.begin() ;
          i != s.handlers.end() ; i++ ) {
        assert(*i);
        result->newHandler( copy((*i)->predicate), copy((*i)->body) );
    }
    return result;
}

```

4.10 Expressions

These are all quite simple. The one trick is that the type associated with each expression is usually initialized from the expression's operands.

32b *<copier method declarations 8b>+≡* (8a) *<32a 33a>*

```

Status visit(Literal &l) { return new Literal(l.value, newSymbol(l.type)); }

```

When a module is run with a literal substituted for a constant, e.g., `run MyModule [constant 3.14 / pi]`, instances of constant references (actually, load variable expressions) need to be replaced with an appropriate copy of the expression. A `CopyExpression` object records the information for doing this.

32c *<expression copier class declaration 32c>≡* (34a)

```

class ExpressionCopier {
    Expression *theExpr;
    Copier *theCopier;
public:
    ExpressionCopier(Expression*, Copier*);
    Expression *copy();
};

```

32d *<expression copier method definitions 32d>≡* (34b)

```

ExpressionCopier::ExpressionCopier(Expression *e, Copier *c)
    : theExpr(e), theCopier(c) { assert(e); assert(c); }

Expression *ExpressionCopier::copy() { return theCopier->copy(theExpr); }

```

- 33a \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 32b 33b \rangle

```

Status visit(LoadVariableExpression &e) {
    ConstantSymbol *cs = dynamic_cast<ConstantSymbol*>(e.variable);
    if (cs) {
        map<const ConstantSymbol*, ExpressionCopier*>::iterator i =
            newConstantExpression.find(cs);
        if ( i != newConstantExpression.end() )
            return (*i).second->copy();
    }
    return new LoadVariableExpression(newSymbol(e.variable));
}

```
- 33b \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 33a 33c \rangle

```

Status visit(LoadSignalExpression &e) {
    return new LoadSignalExpression(e.type, newSymbol(e.signal));
}

Status visit(LoadSignalValueExpression &e) {
    return new LoadSignalValueExpression(newSymbol(e.signal));
}

```
- 33c \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 33b 33d \rangle

```

Status visit(Delay &d) {
    return new Delay(newSymbol(d.type), copy(d.predicate),
                    copy(d.count), d.is_immediate);
}

```
- 33d \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 33c 33e \rangle

```

Status visit(UnaryOp &o) {
    return new UnaryOp(newSymbol(o.type), o.op, copy(o.source));
}

Status visit(BinaryOp &o) {
    return new BinaryOp(newSymbol(o.type), o.op,
                        copy(o.source1), copy(o.source2));
}

```
- 33e \langle copier method declarations 8b $\rangle + \equiv$ (8a) \langle 33d \rangle

```

Status visit(FunctionCall &);

```
- 33f \langle copier method definitions 10a $\rangle + \equiv$ (34b) \langle 30c \rangle

```

Status Copier::visit(FunctionCall &c)
{
    FunctionCall *result = new FunctionCall(newSymbol(c.callee));
    for ( vector<Expression*>::const_iterator i = c.arguments.begin() ;
          i != c.arguments.end() ; i++ ) {
        assert(*i);
        result->arguments.push_back(copy(*i));
    }
    return result;
}

```

5 ExpandModules.hpp and .cpp

```

34a  <ExpandModules.hpp 34a>≡
      #ifndef _DISMANTLE_HPP
      #  define _DISMANTLE_HPP

      #  include "AST.hpp"
      #  include <assert.h>
      #  include <sstream>
      #  include <set>
      #  include <map>

      namespace ExpandModules {
        using namespace IR;
        using namespace AST;
        using std::set;
        using std::map;

        <find roots class declaration 4a>
        class Copier;
        <expression copier class declaration 32c>
        <copier class declaration 8a>
        <rewrite function declaration 3a>
      }
      #endif

34b  <ExpandModules.cpp 34b>≡
      #include "ExpandModules.hpp"

      namespace ExpandModules {
        using namespace IR;
        using namespace AST;
        <find roots method definitions 4d>
        <copier method definitions 10a>
        <expression copier method definitions 32d>
        <rewrite function definition 3b>
      }

```

6 Notes on V5's iclc

The Run statement has an interesting field in the renamings section defined as “the index of the last signal declared at the level of the instruction expanding the module’s code.”

An example:

```

module Test_Run3:
input A;          signals: 5
output B;         0: input: A 1 pure: bool: 0 0 previous: - %lc: 2 7 0%
                  1: output: B 2 pure: previous: 0 %lc: 3 8 0%
run Foo;          2: local: C pure: previous: 1 %lc: 6 8 0%
signal C,         3: local: D pure: previous: 2 %lc: 7 8 0%
    D,            4: local: E pure: previous: 3 %lc: 8 8 0%
    E in          end:
    pause;
    pause
end signal        statements: 7
                  0: Return: 0 %lc: 13 1 0%
                  1: Run: Foo [ 1] (2) <0> %lc: 5 1 0%
end module        2: Sigscope: [
                  2 %lc: 6 8 0%,
module Foo:       3 %lc: 7 8 0%,
                  4 %lc: 8 8 0%
nothing          ] {3} (4)
                  3: Endscope: [0] (0) <0> %lc: 6 1 0%
end module

```

The index is 1, since only A and B are in scope at the run Foo statement.

Signals above these aren’t visible to the module being run, but it isn’t a simple less-than relationship because of “holes” in the namespace.

```

module Test_Run4:
signal A, B, C in
    nothing
end signal;
signal D, E in
    run Foo
end signal;
signal F, G in
    pause
end signal
end module

module Foo:
inputoutput D;    6: Run: Foo [ 4] (7) <5> %lc: 10 3 0%
emit D
end module

```

The index here is 4 (corresponding to E), but 0-2 aren’t visible.

The Instance table in the IC file format is trivial for the IC format (each module has exactly one instance, itself), but describes the instantiation hierarchy in an LC file.

Constant renaming can replace constant names with (trivial) constant expressions. This substitution appears to replace every instance of the constant with the appropriate expression.