

Contents

$$\begin{aligned} 1 \quad & \langle \text{declarations } 1 \rangle \equiv & (23a) \quad 2 \triangleright \\ & \text{typedef map<GRCNode *, int> CFGmap;} \\ & \text{typedef map<STNode *, int> STmap;} \end{aligned}$$

1 The generateC function

2 $\langle \textit{declarations} \rangle + \equiv$ (23a) $\langle 1 \ 8 \rangle$
void generateC(std::ostream &o, Module &, string, bool);

```

3  <definitions 3>≡ (23b) 9>
    CFGmap cfgmap; // FIXME: for debugging

    void generateC(std::ostream &o, Module &m, string basename, bool ansi)
    {
        CPrinter::Printer p(o, m);

        GRCgraph *g = dynamic_cast<AST::GRCgraph*>(m.body);
        if (!g) throw IR::Error("Module is not in GRC format");

        o << "/* Generated by CEC/GRCC2";
        if (ansi) o << " in ANSI mode ";
        else o << " using the GCC computed-goto extension ";
        o << "*/\n";

        // CFGmap cfgmap;
        STmap stmap;
        g->enumerate(cfgmap, stmap);

        EnterGRC *eg = dynamic_cast<EnterGRC*>(g->control_flow_graph);
        assert(eg); // The top of the control-flow graph should be an EnterGRC
        assert(eg->successors.size() == 2); // It should have two successors
        GRCNode *firstNode = eg->successors.back();

        // Perform minor restructuring on the control-flow graph

        for ( CFGmap::iterator i = cfgmap.begin() ; i != cfgmap.end() ; i++ )
            fixGRCNode( (*i).first );

        // Check that the generated graph is acyclic

        checkAcyclic(firstNode);

        // Cluster the nodes in the graph

        vector<Cluster*> clusters;
        map<GRCNode*, Cluster*> clusterOf;
#ifdef SIMPLE_CLUSTER
        // Schedule the nodes in the control-flow graph

        vector<GRCNode*> schedule;
        calculateSchedule(firstNode, schedule);

        o << "/* Schedule:\n";
        for ( vector<GRCNode*>::iterator i = schedule.begin() ; i != schedule.end() ;
              i++ )
            o << cfgmap[*i] << ' ';
        o << "*/\n";
        cluster(schedule, clusters, clusterOf);
#else

```

```

    greedyCluster(firstNode, clusters, clusterOf);
#endif

#ifdef CLUSTER_DOT_OUTPUT
    o << "/* Clusters:\n";
    for ( vector<Cluster*>::iterator i = clusters.begin() ;
          i != clusters.end() ; i++ ) {
        o << "subgraph cluster" << i - clusters.begin()
          << " { style=filled color=lightgrey\n ";
        for ( vector<GRCCNode*>::iterator j = (*i)->nodes.begin() ;
              j != (*i)->nodes.end() ; j++ )
            o << 'n' << cfmmap[*j] << ' ';
        o << "}\n";
    }
    o << "*/\n";
#endif

    vector<Level*> levels;
    levelize(clusters, levels);

    // The top level should contain exactly one cluster that starts everything.
    assert(levels.front()->clusters.size() == 1);
    // The first level should be the first cluster
    assert(levels.front()->clusters.front() == clusters.front());

#ifdef LEVEL_DOT_OUTPUT
    o << "/* Levels:\n";
    for ( vector<Level*>::iterator i = levels.begin() ;
          i != levels.end() ; i++ ) {
        o << i - levels.begin() << ": ";
        for ( vector<Cluster*>::iterator j = (*i)->clusters.begin() ;
              j != (*i)->clusters.end() ; j++ ) {
            o << '(';
            for ( vector<GRCCNode*>::iterator k = (*j)->nodes.begin() ;
                  k != (*j)->nodes.end() ; k++ )
                o << cfmmap[*k] << ' ';
            o << ')';
        }
        o << '\n';
    }
    o << "*/\n";
#endif

    p.printDeclarations(basename);
    p.ioDefinitions();

    // Split apart the CFGs for each cluster

    for ( vector<Level*>::iterator i = levels.begin() ;
          i != levels.end() ; i++ )

```

```

    for ( vector<Cluster*>::iterator j = (*i)->clusters.begin() ;
          j != (*i)->clusters.end() ; j++ )
        split(*j, clusterOf, p.labelFor);

// Generate definitions for the code to schedule each cluster

for ( vector<Level*>::iterator i = levels.begin() ;
      i != levels.end() ; i++ )
    for ( vector<Cluster*>::iterator j = (*i)->clusters.begin() ;
          j != (*i)->clusters.end() ; j++ ) {
        Cluster *cluster = *j;
        for ( vector<GRNode*>::iterator k = cluster->entries.begin() ;
              k != cluster->entries.end() ; k++ ) {
            GRNode *node = *k;
            o << "#define _schedule_" << cfgmap[node]
              << " { _next_" << cluster->id << " = _level_"
              << cluster->level << "; _level_" << cluster->level << " = ";
            if (ansi) {
                o << cfgmap[node];
            } else {
                o << "&&" << p.labelFor[node];
            }
            o << "; }\n";
        }
    }

// Main "tick" function

o <<
  "\n"
  "int " << m.symbol->name << "(void)\n"
  "{\n"
  ;

if (ansi) o << "  unsigned int _next;\n";

for ( unsigned int i = 1 ; i < clusters.size() ; i++ ) {
    if (ansi) o << "  unsigned int ";
    else o << "  void *";
    o << "_next_" << i << ";\n";
}
o << '\n';
for ( unsigned int i = 1 ; i < levels.size() ; i++ ) {
    if (ansi) o << "  unsigned int ";
    else o << "  void *";
    o << "_level_" << i << " = ";
    if (ansi) o << '0';
    else o << "&&_LEVEL_" << i << "_END";
    o << ";\n";
}

```

```

o << '\n';

// For each level, for each cluster, print code
for ( unsigned int i = 0 ; i < levels.size() ; i++ ) {

    Level &level = *(levels[i]);

    if ( i > 0 ) {
        if (ansi) {
            o <<
                "_next = _level_" << i << ";\n"
                "\n"
                "_LEVEL_" << i << "_START:\n"
                " switch (_next) {\n";
            for ( vector<Cluster*>::iterator j = level.clusters.begin() ;
                j != level.clusters.end() ; j++ ) {
                Cluster *cluster = *j;
                for ( vector<GRCCNode*>::iterator k = cluster->entries.begin() ;
                    k != cluster->entries.end() ; k++ ) {
                    GRCCNode *node = *k;
                    o << " case " << cfmname[node]
                        << ": goto " << p.labelFor[node] << ";\n";
                }
            }
            o <<
                " default: goto _LEVEL_" << i << "_END;\n"
                " }\n";
        } else
            o << " goto *_level_" << i << ";\n\n";
    }

    for ( unsigned int j = 0 ; j < level.clusters.size() ; j++ ) {
        Cluster *cluster = level.clusters[j];
        assert(cluster);
        unsigned int id = cluster->id;

        // Generate code for the body of the cluster

        assert(cluster->nodes.back()->successors.size() == 0);
        assert(cluster->nodes.back()->predecessors.size() > 0);
        p.printStructuredCode(cluster->nodes.back(), 1);

        if ( i > 0 ) {
            if (ansi) o <<
                " _next = _next_" << id << ";\n"
                " goto _LEVEL_" << i << "_START;\n"
                "\n";
            else o <<
                " goto *_next_" << id << ";\n"

```

```

        "\n";
    }
}

    if ( i > 0 ) o <<
        " _LEVEL_" << i << "_END:\n";
}

o << '\n';

p.outputFunctions();
p.resetInputs();

#ifdef DEBUG
// Print each of the state variables
for ( STmap::const_iterator i = stmap.begin() ; i != stmap.end() ; i++ ) {
    STexcl *e = dynamic_cast<STexcl*>((*i).first);
    if (e) {
        o << "  printf(\"";
        p.stateVar(e);
        o << " = %d\\n\\n", ";
        p.stateVar(e);
        o << ");\n";
    }
}
#endif

STexcl *excl = dynamic_cast<STexcl*>(g->selection_tree);
assert(excl);
assert(!excl->children.empty());

STleaf *terminal_leaf = dynamic_cast<STleaf*>(excl->children.front());

if (terminal_leaf && terminal_leaf->isfinal()) {
    o << "  return " << p.stateVar[excl] << " != 0;\n";
} else {
    o << "  return 1;\n";
}

o << "}" "\n";

// Reset function

o <<
    "\n"
    "int " << m.symbol->name << "_reset(void)\n"
    "{\n";

// Reset the topmost state variable
o << "  " << p.stateVar[excl];

```

```

o << " = " << (excl->children.size() - 1) << ";\n";

p.resetInputs();

o <<
    "    return 0;"    "\n"
    "}"              "\n";
}

```

2 fixGRCnode

This remove control-flow successors from Terminate nodes that lead to Sync nodes and adds a control-flow successor to from each Fork to its Sync. This is done because in the control-flow graph, only Sync nodes ever have more than one active incoming control arc. The scheduling code assumes that each node is scheduled at most once.

It also remove successors from any EnterGRC node and predecessors from any ExitGRC node.

```

8  <declarations 1>+≡ (23a) <2 10a>
    void fixGRCnode(GRCNode *);

```



```

9  <definitions 3>+≡ (23b) <3 10b>
void fixGRCNode(GRCNode *n)
{
    Terminate *t = dynamic_cast<Terminate *>(n);
    if (t) {
        if ( t->successors.size() == 1) {
            Sync *s = dynamic_cast<Sync*>(t->successors.front());
            if (s) {
                // Remove the Terminate from the sync node's predecessors
                for ( vector<GRCNode*>::iterator i = s->predecessors.begin() ;
                    i != s->predecessors.end() ; i++ )
                    if ( (*i) == t ) {
                        s->predecessors.erase(i);
                        break;
                    }
                // Remove the Terminate's successors
                t->successors.clear();
            }
        }
    }

    Fork *f = dynamic_cast<Fork *>(n);
    if (f && f->sync) {
        // Add the sync node as a successor to this Fork
        (*f) >> f->sync;
        // std::cerr << "Added " << cfgmap[f->sync] << " to fork node " << cfgmap[f] << std::endl;
    }

    if (dynamic_cast<EnterGRC*>(n)) {
        for ( vector<GRCNode*>::iterator j = n->successors.begin() ;
            j != n->successors.end() ; j++ )
            for ( vector<GRCNode*>::iterator k = (*j)->predecessors.begin() ;
                k != (*j)->predecessors.end() ; k++ )
                if (*k == n) {
                    (*j)->predecessors.erase(k);
                    break;
                }
        n->successors.clear();
    }

    if (dynamic_cast<ExitGRC*>(n)) {
        for ( vector<GRCNode*>::iterator j = n->predecessors.begin() ;
            j != n->predecessors.end() ; j++ )
            for ( vector<GRCNode*>::iterator k = (*j)->successors.begin() ;
                k != (*j)->successors.end() ; k++ )
                if (*k == n) {
                    (*j)->successors.erase(k);
                    break;
                }
        n->predecessors.clear();
    }
}

```

```
    }
}
```

3 Check Acyclic

This uses a simple DFS to verify that the given control-flow graph is acyclic.

```
10a  <declarations 1>+≡ (23a) <8 10c>
      void checkAcyclic(GRCNode *);

10b  <definitions 3>+≡ (23b) <9 11a>
      void checkAcyclic(GRCNode *n) {
          AcyclicChecker checker(n);
      }

10c  <declarations 1>+≡ (23a) <10a 11b>
      class AcyclicChecker {
          std::map<GRCNode*, bool> completed;
          bool visit(GRCNode *);
      public:
          AcyclicChecker(GRCNode* n) {
              if (visit(n)) {
                  std::cerr << std::endl;
                  throw IR::Error("CFG is cyclic");
              }
          }
      };
};
```

The DFS procedure `visit` returns true if a cycle was found.

```

11a  <definitions 3>+≡ (23b) <10b 11c>
      bool AcyclicChecker::visit(GRCNode *n)
      {
        if ( n == NULL ||
            (completed.find(n) != completed.end() && completed[n]) ) return false;

        if (completed.find(n) != completed.end() && !completed[n]) {
          std::cerr << "Cycle found, includes nodes " << cfgmap[n];
          return true;
        }

        completed[n] = false;

        for (vector<GRCNode*>::iterator i = n->successors.begin() ;
              i != n->successors.end() ; i++)
          if ( visit(*i) ) {
            std::cerr << ' ' << cfgmap[n];
            return true;
          }

        for (vector<GRCNode*>::iterator i = n->dataSuccessors.begin() ;
              i != n->dataSuccessors.end() ; i++)
          if ( visit(*i) ) {
            std::cerr << ' ' << cfgmap[n];
            return true;
          }

        completed[n] = true;

        return false;
      }

```

4 Scheduling

This computes a schedule for the reachable nodes in the control-flow graph.

This is a simple topological sort.

```

11b  <declarations 1>+≡ (23a) <10c 12a>
      void calculateSchedule(GRCNode *, vector<GRCNode*> &);

11c  <definitions 3>+≡ (23b) <11a 12b>
      void calculateSchedule(GRCNode *n, vector<GRCNode*> &s) {
        Scheduler scheduler(n, s);
      }

```

12a $\langle \text{declarations } 1 \rangle + \equiv$ (23a) $\langle 11b \ 12c \rangle$

```

class Scheduler {
    std::set<GRCNode*> visited;
    std::vector<GRCNode*> &schedule;
    void visit(GRCNode*);
public:
    Scheduler(GRCNode *n, vector<GRCNode*> &schedule) : schedule(schedule) {
        visit(n);
    }
};

```

12b $\langle \text{definitions } 3 \rangle + \equiv$ (23b) $\langle 11c \ 13 \rangle$

```

void Scheduler::visit(GRCNode *n)
{
    if (n == NULL || visited.find(n) != visited.end()) return;

    visited.insert(n);

    for (vector<GRCNode*>::iterator i = n->successors.begin() ;
        i != n->successors.end() ; i++)
        visit(*i);

    for (vector<GRCNode*>::iterator i = n->dataSuccessors.begin() ;
        i != n->dataSuccessors.end() ; i++)
        visit(*i);

    schedule.insert(schedule.begin(), n);
}

```

5 Simple Clustering

This algorithm constructs clusters: a sequence of nodes in the schedule that do not have control or data predecessors from outside the cluster.

12c $\langle \text{declarations } 1 \rangle + \equiv$ (23a) $\langle 12a \ 12d \rangle$

```

struct Cluster {
    unsigned int id;
    unsigned int level;
    vector<GRCNode*> nodes;
    std::set<Cluster*> successors;
    vector<GRCNode*> entries;
    Cluster(int id) : id(id) {}
};

```

12d $\langle \text{declarations } 1 \rangle + \equiv$ (23a) $\langle 12c \ 14 \rangle$

```

void cluster(vector<GRCNode*> &, vector<Cluster*> &, map<GRCNode*, Cluster*> &);

```

```

13  <definitions 3>+≡ (23b) <12b 15>
    void cluster(vector<GRCCNode*> &s, vector<Cluster*> &c, map<GRCCNode*, Cluster*> &m)
    {
        set<GRCCNode*> nodes;
        Cluster *cluster = NULL;
        unsigned int id = 0;

        for ( vector<GRCCNode*>::const_iterator i = s.begin(); i != s.end() ; i++ ) {

            // Decide whether to start a new cluster

            bool startNew = (cluster == NULL);
            if (!startNew)
                for ( vector<GRCCNode*>::const_iterator j = (*i)->predecessors.begin() ;
                    j != (*i)->predecessors.end() ; j++ )
                    if ( nodes.find(*j) == nodes.end() || dynamic_cast<Fork*>(*j) ) {
                        startNew = true;
                        break;
                    }
            if (!startNew)
                for ( vector<GRCCNode*>::const_iterator j = (*i)->dataPredecessors.begin() ;
                    j != (*i)->dataPredecessors.end() ; j++ )
                    if ( nodes.find(*j) == nodes.end() ) {
                        startNew = true;
                        break;
                    }

            if (startNew) {
                // Start a new cluster: add a new vector, clear the set
                cluster = new Cluster(id++);
                c.push_back(cluster);
                nodes.clear();
            }

            nodes.insert(*i);
            cluster->nodes.push_back(*i);
            m[*i] = cluster;
        }
    }

```

6 Greedy Clustering

The clustering algorithm. This takes a control-flow graph with information about control and data predecessors and successors and produces a set of clusters, each of which is a set of nodes that can be executed without interruption. Unlike the other clustering algorithm, this does not rely on a schedule; instead it effectively creates its own schedule by greedily trying to add nodes to a cluster until no more are possible.

```
14  <declarations 1>+≡ (23a) <12d 17a>
    void greedyCluster(GRCNode *, vector<Cluster*> &, map<GRCNode*, Cluster*> &);
```

```

15  <definitions 3>+≡ (23b) <13 18>
void greedyCluster(GRCNode *root, vector<Cluster*> &clusters,
                  map<GRCNode *, Cluster*> &clusterMap)
{
    // std::cerr << "greedyCluster()\n";

    // Set of nodes that have predecessors in some cluster but are not in a cluster
    set<GRCNode*> frontier;

    frontier.insert(root);

    unsigned int clusterId = 0;

    while (!frontier.empty()) {
        // Select a node from the frontier at random
        // and consider it as a seed

        set<GRCNode*>::const_iterator seedi = frontier.begin();

        GRCNode *seed = *seedi;
        assert(seed);

        frontier.erase(seed);

        // std::cerr << "Seed is " << cfgmap[seed] << std::endl;

        Cluster *cluster = 0;

        set<GRCNode*> pending; // Nodes to be considered
        pending.insert(seed);

        while (!pending.empty()) {
            set<GRCNode*>::const_iterator candidatei = pending.begin();

            GRCNode *candidate = *candidatei;
            assert(candidate);

            // std::cerr << "Candidate is " << cfgmap[candidate] << std::endl;

            pending.erase(candidatei);

            bool addToCluster = clusterMap.find(candidate) == clusterMap.end();
            for ( vector<GRCNode*>::const_iterator i =
                  candidate->predecessors.begin() ;
                  i != candidate->predecessors.end() ; i++ )
                if ( clusterMap.find(*i) == clusterMap.end() ) {
                    addToCluster = false;
                    break;
                }
            if (addToCluster)

```

```

    for ( vector<GRCNode*>::const_iterator i =
            candidate->dataPredecessors.begin() ;
          i != candidate->dataPredecessors.end() ; i++ )
        if ( clusterMap.find(*i) == clusterMap.end() ) {
            addToCluster = false;
            break;
        }
    // std::cerr << addToCluster << std::endl;
    if (addToCluster) {

        if (!cluster) {
            cluster = new Cluster(clusterId++);
            clusters.push_back(cluster);
        }

        cluster->nodes.push_back(candidate);
        clusterMap[candidate] = cluster;
        // std::cerr << "Added " << cfgmap[candidate] << " to " << clusters.size() << std::endl;

        if (dynamic_cast<Fork*>(candidate) == NULL) {
            // Not a fork: add all its non-null successors
            for ( vector<GRCNode*>::const_iterator i =
                    candidate->successors.begin() ;
                  i != candidate->successors.end() ; i++ )
                if (*i) pending.insert(*i);
        } else {
            // A fork node: only add its first successor
            assert(!candidate->successors.empty());
            assert(candidate->successors.front());
            pending.insert(candidate->successors.front());
        }

        // Add both control and data successors to the frontier
        for ( vector<GRCNode*>::const_iterator i =
                candidate->successors.begin() ;
              i != candidate->successors.end() ; i++ )
            if (*i) {
                frontier.insert(*i);
                // std::cerr << "Added " << cfgmap[*i] << " to frontier" << std::endl;
            }

        for ( vector<GRCNode*>::const_iterator i =
                candidate->dataSuccessors.begin() ;
              i != candidate->dataSuccessors.end() ; i++ ) {
            frontier.insert(*i);
            // std::cerr << "Added " << cfgmap[*i] << " to frontier" << std::endl;
        }

        set<GRCNode*>::iterator candi = frontier.find(candidate);
        if (candi != frontier.end()) frontier.erase(candi);
    }

```



```

    }
  }
}
// std::cerr << "Done with greedy clusters: " << clusterId << std::endl;
}

```

7 Levelizing

The clusters are divided into levels. Nodes within the clusters within a level do not communicate.

```

17a  <declarations 1>+≡ (23a) <14 17b>
      struct Level {
        vector<Cluster *> clusters;
      };

17b  <declarations 1>+≡ (23a) <17a 19>
      void levelize(vector<Cluster*> &, vector<Level*> &);

```

```

18  <definitions 3>+≡ (23b) <15 20>
void levelize(vector<Cluster*> &b, vector<Level*> &levels)
{
    assert(!b.empty()); // Need at least one cluster

    // Construct inter-cluster dependencies

    map<GRCNode*, Cluster*> clusterOfNode;
    for ( vector<Cluster*>::const_iterator i = b.begin() ; i != b.end() ; i++ ) {
        for ( vector<GRCNode*>::const_iterator j = (*i)->nodes.begin() ;
              j != (*i)->nodes.end() ; j++ ) {
            clusterOfNode[*j] = *i;
            for ( vector<GRCNode*>::const_iterator k = (*j)->predecessors.begin() ;
                  k != (*j)->predecessors.end() ; k++ ) {
                if (clusterOfNode.find(*k) != clusterOfNode.end() && clusterOfNode[*k] != *i)
                    clusterOfNode[*k]->successors.insert(*i);
            }
            for ( vector<GRCNode*>::const_iterator k = (*j)->dataPredecessors.begin() ;
                  k != (*j)->dataPredecessors.end() ; k++ ) {
                if (clusterOfNode.find(*k) != clusterOfNode.end() && clusterOfNode[*k] != *i)
                    clusterOfNode[*k]->successors.insert(*i);
            }
        }
    }

    // Calculate the level of each cluster through relaxation

    map<Cluster*, unsigned int> level;
    for ( vector<Cluster*>::const_iterator i = b.begin() ; i != b.end() ; i++ )
        level[*i] = 0;

    set<Cluster*> unvisited;
    unvisited.insert(b.front());

    unsigned maxlevel = 0;

    while (!unvisited.empty()) {
        Cluster *vb = *(unvisited.begin());
        assert(vb);
        unvisited.erase(unvisited.begin());

        assert(level.find(vb) != level.end());
        unsigned int nextlevel = level[vb] + 1;
        for ( set<Cluster*>::const_iterator i = vb->successors.begin() ;
              i != vb->successors.end() ; i++ )
            if ( level[*i] < nextlevel ) {
                level[*i] = nextlevel;
                if (nextlevel > maxlevel) maxlevel = nextlevel;
                unvisited.insert(*i);
            }
    }
}

```

```

    }

    // Create the levels

    for (unsigned int i = 0 ; i <= maxlevel ; i++)
        levels.push_back(new Level());

    // Insert clusters in the levels

    for ( map<Cluster *, unsigned int>::const_iterator i = level.begin() ;
          i != level.end() ; i++ ) {
        Cluster *cluster = (*i).first;
        unsigned int level = (*i).second;
        levels[level]->clusters.push_back(cluster);
        cluster->level = level;
    }
}

```

8 Split cluster nodes

The C generator wants a self-contained CFG; this breaks the control dependencies among nodes in different clusters to ensure this.

19 $\langle \text{declarations } 1 \rangle + \equiv$ (23a) $\triangleleft 17b$
 void split(Cluster *, map<GRCNode*, Cluster*> &, map<GRCNode*, string> &);

```

20  <definitions 3>+≡ (23b) <18
    void split(Cluster *cluster, map<GRCNode*, Cluster*> &clusterOf,
               map<GRCNode*, string> &labelFor)
    {
        assert(cluster);
        // std::cerr << "Splitting cluster " << cluster->id << '\n';
        ExitGRC *exitNode = new ExitGRC();

        for ( vector<GRCNode*>::iterator i = cluster->nodes.begin() ;
              i != cluster->nodes.end() ; i++ ) {
            GRCNode *node = *i;
            assert(node);
            // std::cerr << "Examining a node \n";

            if ( dynamic_cast<Fork*>(node) != NULL ) {

                // A fork node: convert its successors to a sequence of
                // schedule statements
                // that branch to the exitNode of the cluster.

                GRCNode *nopchain = exitNode;

                // If there is exactly one successor in this same cluster,
                // make it the successor of the nopchain
                for ( vector<GRCNode*>::iterator j = node->successors.begin() ;
                      j != node->successors.end() ; j++ ) {
                    assert(*j);
                    // The successor should have been put in some cluster
                    if (clusterOf.find(*j) == clusterOf.end()) std::cerr << "node " << cfgmap[*j] << " not
                    assert(clusterOf.find(*j) != clusterOf.end());
                    if (clusterOf[*j] == cluster) {
                        // Should not have already found a successor in the same cluster
                        assert(nopchain == exitNode);
                        nopchain = *j;
                    }
                }

                // Build a chain of "Nop" nodes that schedule the successors of the
                // fork that are in other clusters

                for ( vector<GRCNode*>::iterator j = node->successors.begin() ;
                      j != node->successors.end() ; j++ ) {
                    assert(*j);
                    assert(clusterOf.find(*j) != clusterOf.end());
                    if ( clusterOf[*j] != cluster ) {
                        Nop *nop = new Nop();
                        char buf[30];
                        sprintf(buf, "_schedule_%d", cfgmap[*j]);
                        nop->body = buf;
                        *nop >> nopchain;
                    }
                }
            }
        }
    }

```

```

        nopchain = nop;
        if (labelFor.find(*j) == labelFor.end()) {
            // Not yet marked as an entry point.
            char buf[30];
            sprintf(buf, "L%d", cfgmap[*j]);
            labelFor[*j] = buf;
            clusterOf[*j]->entries.push_back(*j);
        }
    }
}

// Disconnect the fork's successors
for ( vector<GRCCNode*>::iterator j = node->successors.begin() ;
      j != node->successors.end() ; j++ ) {
    for ( vector<GRCCNode*>::iterator k = (*j)->predecessors.begin() ;
          k != (*j)->predecessors.end() ; k++ )
        if (*k == node) {
            (*j)->predecessors.erase(k);
            break;
        }
}
node->successors.clear();

// Connect the fork to the beginning of the chain
*node >> nopchain;

} else {

    // A normal node

    for ( vector<GRCCNode*>::iterator j = node->successors.begin() ;
          j != node->successors.end() ; j++ )
        if ( *j ) {
            // The successor should have been put in some cluster
            if (clusterOf.find(*j) == clusterOf.end()) std::cerr << "node " << cfgmap[*j] << " not in any cluster\n";
            assert(clusterOf.find(*j) != clusterOf.end());
            if (clusterOf[*j] != cluster) {

                // std::cerr << "Fixing a node that branches to outside this cluster\n";

                // Control flows to a different cluster: change this successor to
                // a Nop node that schedules the cluster and branches to the exitNode

                // Delete the link back to us
                for ( vector<GRCCNode*>::iterator k = (*j)->predecessors.begin() ;
                      k != (*j)->predecessors.end() ; k++ )
                    if (*k == node) {
                        (*j)->predecessors.erase(k);
                    }
            }
        }
}

```

```

        break;
    }

    if (labelFor.find(*j) == labelFor.end()) {
        // Not yet marked as an entry point.
        char buf[30];
        sprintf(buf, "L%d", cfgmap[*j]);
        labelFor[*j] = buf;
        clusterOf[*j]->entries.push_back(*j);
    }

    Nop *nop = new Nop();
    char buf[30];
    sprintf(buf, "_schedule_%d", cfgmap[*j]);
    nop->body = buf;
    *j = nop;
    nop->predecessors.push_back(node);
    *nop >> exitNode;
}

// A node with no successors? Send it to the exit node
if (node->successors.empty())
    *node >> exitNode;
}

cluster->nodes.push_back(exitNode);
// Note: The list of nodes in the cluster does not include the Nop nodes
// Moreover, the clusterOf map does not include the Nops or the exit node

assert(exitNode->successors.size() == 0);
assert(exitNode->predecessors.size() > 0);
}

```

9 Top-Level Files

9.1 GRCC2.hpp

```
23a  <GRCC2.hpp 23a>≡
      #ifndef _GRCC2_HPP
      #  define _GRCC2_HPP

      #  include "AST.hpp"
      #  include "CPrinter.hpp"

      namespace GRCC2 {
        using namespace AST;
        <declarations 1>
      }

      #endif
```

9.2 GRCC2.cpp

```
23b  <GRCC2.cpp 23b>≡
      #include "GRCC2.hpp"
      #include <set>
      #include <vector>
      #include <cstdio>

      namespace GRCC2 {
        using std::set;
        using std::vector;

        <definitions 3>
      }
```

9.3 cec-grcc2.cpp

```

24  <cec-grcc2.cpp 24>≡
    #include "AST.hpp"
    #include "GRCC2.hpp"
    #include <iostream>
    #include <cassert>
    #include <string>
    #include <string.h>

    struct Usage {};

    int main(int argc, char *argv[])
    {
        try {

            std::string basename;
            bool ansi = false;

            argc--, argv++; // Skip program name

            while (argc > 0 && argv[0][0] == '-') {
                switch (argv[0][1]) {
                    case 'a':
                        ansi = true;
                        break;
                    case 'B':
                        argc--, argv++;
                        if (argc == 0) throw Usage();
                        basename = argv[0];
                        break;
                    case 'h':
                    default:
                        throw Usage();
                        break;
                }
                argc--, argv++;
            }

            if ( argc > 0 ) throw Usage();

            IR::XMLListream r(std::cin);
            IR::Node *n;
            r >> n;

            AST::Modules *mods = dynamic_cast<AST::Modules*>(n);
            if (!mods) throw IR::Error("Root node is not a Modules object");

            assert(mods->modules.size() > 0);
            AST::Module *m = mods->modules.front();

```



```
    assert(m);

    if (basename.empty()) basename = m->symbol->name;

    GRCC2::generateC(std::cout, *m, basename, ansi);

} catch (IR::Error &e) {
    std::cerr << e.s << std::endl;
    exit(-1);
} catch (Usage &) {
    std::cerr << "Usage: cec-grcc2 [-a] [-B basename]" << std::endl;
    exit(-1);
}
return 0;
}
```