Data and Process Abstraction in PIPS Internal Representation

Fabien Coelho, Pierre Jouvelot, Corinne Ancourt, François Irigoin

Centre de recherche en informatique

Mathématiques et systèmes

MINES ParisTech

Fontainebleau

Typeset with LaTeX, revision 415

PIPS Overview

Project started in 1988, 23 years ago!

Interprocedural analyses with summarizations, and transformations

Linear algebra based analyses and transformations, when possible:

preconditions, array regions, loop bounds, communications,. . .

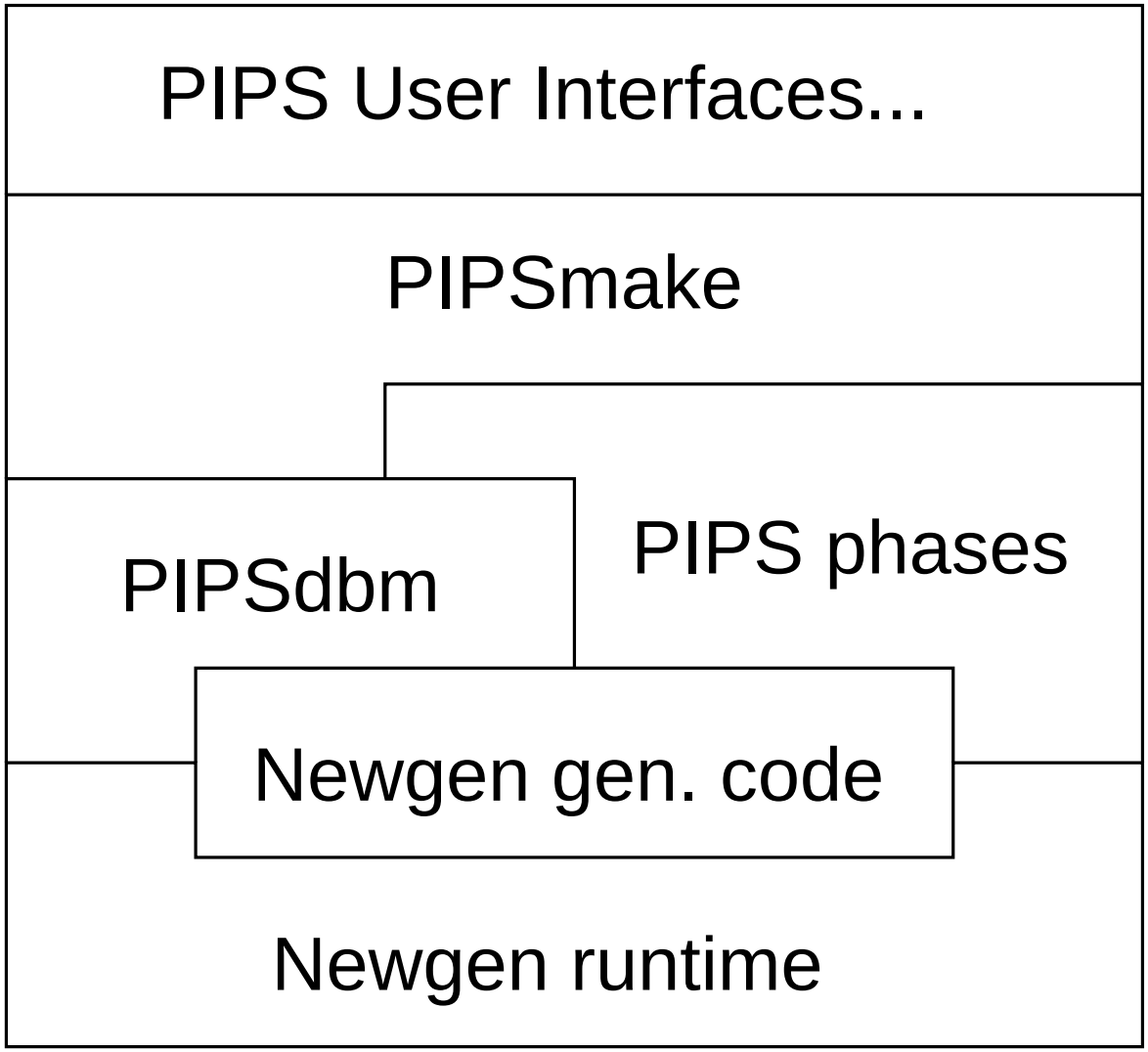
Input: Fortran 77, Fortran 95, C, C99

Output: Fortran 77, Fortran 95, C, C99, OpenMP, CUDA, MPI. . .

Newgen: data structure generator, used for IR

PIPSmake: on demand dependency handling *à la make*

PIPSdbm: database layer for persistence


PIPS User Interfaces...
PIPSmake
PIPSdbm
PIPS phases
Newgen gen. code
Newgen runtime

PIPSmake resource dependencies

- links usage, passes and production (interprocedural consistency)
- per PROGRAM or MODULE (fonction)
- transformations: use/produce `MODULE.code`, require, preserve

```
initializer > MODULE.user_file
            > MODULE.initial_file

filter_file > MODULE.source_file
    < MODULE.initial_file
    < MODULE.user_file

bootstrap   > PROGRAM.entities
```

```
parser       > MODULE.parsed_code
             > MODULE.callees
     < PROGRAM.entities
     < MODULE.source_file

controlizer > MODULE.code
     < PROGRAM.entities
     < MODULE.parsed_code

print_code  > MODULE.printed_file
     < PROGRAM.entities
     < MODULE.code
```

Newgen, a Data Description Language (DDL)

- **external** type defined outside of Newgen
- **int, bool, string** basic types, including enumerations
- **x +** cross product, alternative
- *** []** $\{\}$ list, array, set
- $->$ functional mapping

```
workshop = { WIR, ODES, IMPACT, ACCA };
date = year:int x month:int x day:int;
person = name:string x email:string;
attendee = workshop x person x date;
participants = attendees:attendee*;
```

Newgen code generation for C

- (opaque) data structure definition: both STATIC and DYNAMIC types!

```
#define date_domain 124
typedef struct {
  int type;                    // dynamic type tag
  int year, month, day;        // other fields
} * date;
```

- cons/des-tructor, clone `make/free/copy_date(...)`
- accessors `int date_year(date)`
- /de-serialization `write/read_date(FILE *...)`
- typed list constructor, data structure check. . .

PIPS Internal Representation

- **entity:** global symbol table
- **statement:** Hierarchical Control Flow Graph

  AST + CFG components
- code **decorations:** mappings from statement to. . .

- IR Navigator: http://pips4u.org/ir-navigator

PIPS Symbol Table

symbol: anything with a name!

variable, function, type, constant, symbolic constant, label, field, parameter, memory location, value...

tabulated: name is a unique key to retrieve an entity

storage in an underlying hashtable for quick retrieval

use prefixes for disambiguation

`main:0‘result`, `TOP-LEVEL:10`

global: can be large, kept in memory!

useful for interprocedural analyses

linked to: information about type, storage and initial value

```
tabulated entity = name:string x type x
  storage x initial:value;

type = statement:unit + area + variable +
  functional + varargs:type + unknown:unit +
  void:qualifier* + struct:entity* +
  union:entity* + enum:entity*;
variable = basic x dimensions:dimension* x
  qualifiers:qualifier*;
basic = int:int + float:int + logical:int +
  overloaded:unit + complex:int + string:value +
  bit:symbolic + pointer:type + derived:entity +
  typedef:entity;
dimension = lower:expression x upper:expression;
```

```
qualifier = const:unit + restrict:unit +
   volatile:unit + register:unit + auto:unit;
functional = parameters:parameter* x result:type;

storage = return:entity + ram + formal + rom:unit;

value = code + symbolic + constant +
  intrinsic:unit + unknown:unit + expression;
```

PIPS code: Hierarchical Control Flow Graph (HCFG)

language C or Fortran, but specific constructs...

AST whenever compatible with parallelization

sequence, one-exit loop and test

otherwise loops with exits are *desugarized*

can be relied on for equation-based semantic analyses

CFG handles goto, exit, continue, return...

with `unstructured control` domains

prettyprint regenerates necessary gotos

PIPS statement definition

```
statement = label:entity x number:int x
  ordering:int x comments:string x instruction x
  declarations:entity* x decls_text:string x
  extensions;

instruction = sequence + test + loop +
  whileloop + goto:statement + call +
  unstructured + multitest + forloop +
  expression;

sequence = statements:statement* ;
```

```
test = condition:expression x true:statement x
  false:statement;

loop = index:entity x range x body:statement x
  label:entity x execution x locals:entity*;

whileloop = condition:expression x
  body:statement x label:entity x evaluation;

call = function:entity x arguments:expression*;

unstructured = entry:control x exit:control;
control = statement x predecessors:control* x
  successors:control*;
```

```
forloop = initialization:expression x
  condition:expression x increment:expression x
  body:statement;

expression = syntax x normalized;
syntax = reference + range + call + cast +
  sizeofexpression + subscript + application +
  va_arg:sizeofexpression*;
reference = variable:entity x indices:expression*;
```

Code decorations

- use pointer to value mappings: *hash table*

  `statement_effects = persistant statement -> effects`

- piecewise serialization: must rely on an absolute identifier

  unique *statement position* computed on the HCFG

Newgen generic recursion engine: *visitor pattern*

- use dynamic typing tag to check/guide the recursion
- per-recursion context to pass data structures
- apply functions per newgen domain
- top-down: filter function tells whether to go on
- bottom-up: rewrite function applied if filter said true
- optimization: does not recurse if not needed because of types
- can abort the recursion, or stop on *persistant* keyword
- stack query: parent, parent of a given type. . .

Three code examples

1. Query: Is a variable v the index of a loop contained in a test?
2. Transformation: (Simple) variable name substitution
3. Instrumentation: Add control counters

Index of a loop within a test?

```
typedef struct {
   entity var;  bool is_index;
} ctx;

static bool loop_flt(loop l, ctx * c) {
   if (loop_index(l)==c->var &&
         gen_get_ancestor(test_domain, l)!=NULL) {
      c->is_index = true;
      gen_recurse_stop(NULL);
   }
   return true;
}
```

```
bool var_is_index_in_test(statement s, entity v)
{
  ctx cs = { v, false };
  gen_context_multi_recurse(s, &cs,
     loop_domain, loop_flt, gen_null,
     NULL);
  return cs.is_index;
}
```

(Simple) variable name substitution

```
typedef struct {
  entity from, to;
} ctx;

static void loop_rwt(loop l, ctx * c) {
  if (loop_index(l)==c->from)
    loop_index(l) = c->to;
}

static void ref_rwt(reference r, ctx * c) {
  if (reference_variable(r)==c->from)
    reference_variable(r) = c->to;
```

```
}

void subs_var(statement s, entity from, entity
to) {
  ctx cs = { from, to };
  gen_context_multi_recurse(s, &cs,
    loop_domain, gen_true, loop_rwt,
    reference_domain, gen_true, ref_rwt,
    NULL);
}
```

Control counters

```
int compute(int n) {
  int i = 1;
  while (i<n) {
    i<<=1;
    if (rand()) i++;
  }
  return i;
}
```

```
int compute(int n) {
  int i = 1;
  int if_then_0 = 0, if_else_0 = 0, while_0 = 0;
  while (i<n) {
    while_0 = while_0+1;
    i <<= 1;
    if (rand()) {
      if_then_0 = if_then_0+1;
      i++;
    } else
      if_else_0 = if_else_0+1;
  }
  return i;
}
```

```
// File "add_control_counter.c"
#include "..."

statement make_increment(entity var) {
  return make_assign_statement(...);
}

entity create_counter
  (entity module, string name) {
  return ...;
}

// Add Control Counter recursion context
typedef struct { entity module; } acc_ctx;
```

```
// add a new counter at entry of statement "s"
void add_counter
  (acc_ctx * c, string name, statement s)
{
  entity cnt = create_counter(c->module, name);
  insert_statement(s, make_increment(cnt), true);
}

void test_rwt(test t, acc_ctx * c) {
  add_counter(c, "if_then", test_true(t));
  add_counter(c, "if_else", test_false(t));
}
```

```
void loop_rwt(loop l, acc_ctx * c) {
  add_counter(c, "do", loop_body(l));
}

void whileloop_rwt(whileloop w, acc_ctx * c) {
  add_counter(c, "while", whileloop_body(w));
}

void forloop_rwt(forloop f, acc_ctx * c) {
  add_counter(c, "for", forloop_body(f));
}
```

```
// add control counter instrumentation
void add_cnt(entity module, statement root)
{
  acc_ctx c = { module };
  gen_context_multi_recurse
    (root, &c,
     test_domain, gen_true, test_rwt,
     loop_domain, gen_true, loop_rwt,
     whileloop_domain, gen_true, whileloop_rwt,
     forloop_domain, gen_true, forloop_rwt,
     NULL);
}
```

```
// PASS: instrument with control structure counters
bool add_control_counters(string name) {
  entity module = name_to_entity(name);
  statement stat = (statement)
    db_get_memory_resource(DBR_CODE, name, true);
  set_current_module_entity(module);
  set_current_module_statement(stat);
  add_cnt(module, stat);
  module_reorder(stat);
  DB_PUT_MEMORY_RESOURCE(DBR_CODE, name, stat);
  reset_current_module_entity();
  reset_current_module_statement();
  return true;
}
```

Conclusion

Newgen provides useful services

results in quite homogeneous code

powerful recursion engine based on visitor pattern

HCFG representation for source to source

extensions from Fortran 77 to C and Fortran 95

PIPSmake, PIPSdbm for consistency and persistance management

23 years later? A lot of PhD work has been and is being capitalized

Par4All compiler for OpenMP, CUDA, OpenCL, SCMP...

PyPS Programmable pass manager, compiler generation

PAWS PIPS As a Web Service, http://paws.pips4u.org, *soon to be*