Data and Process Abstraction in PIPS Internal Representation

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PIPS Overview

project started in 1988, 23 years ago!

interprocedural analyses and transformations

linear algebra based analyses *preconditions, array regions*

par4all HPCProject initiative

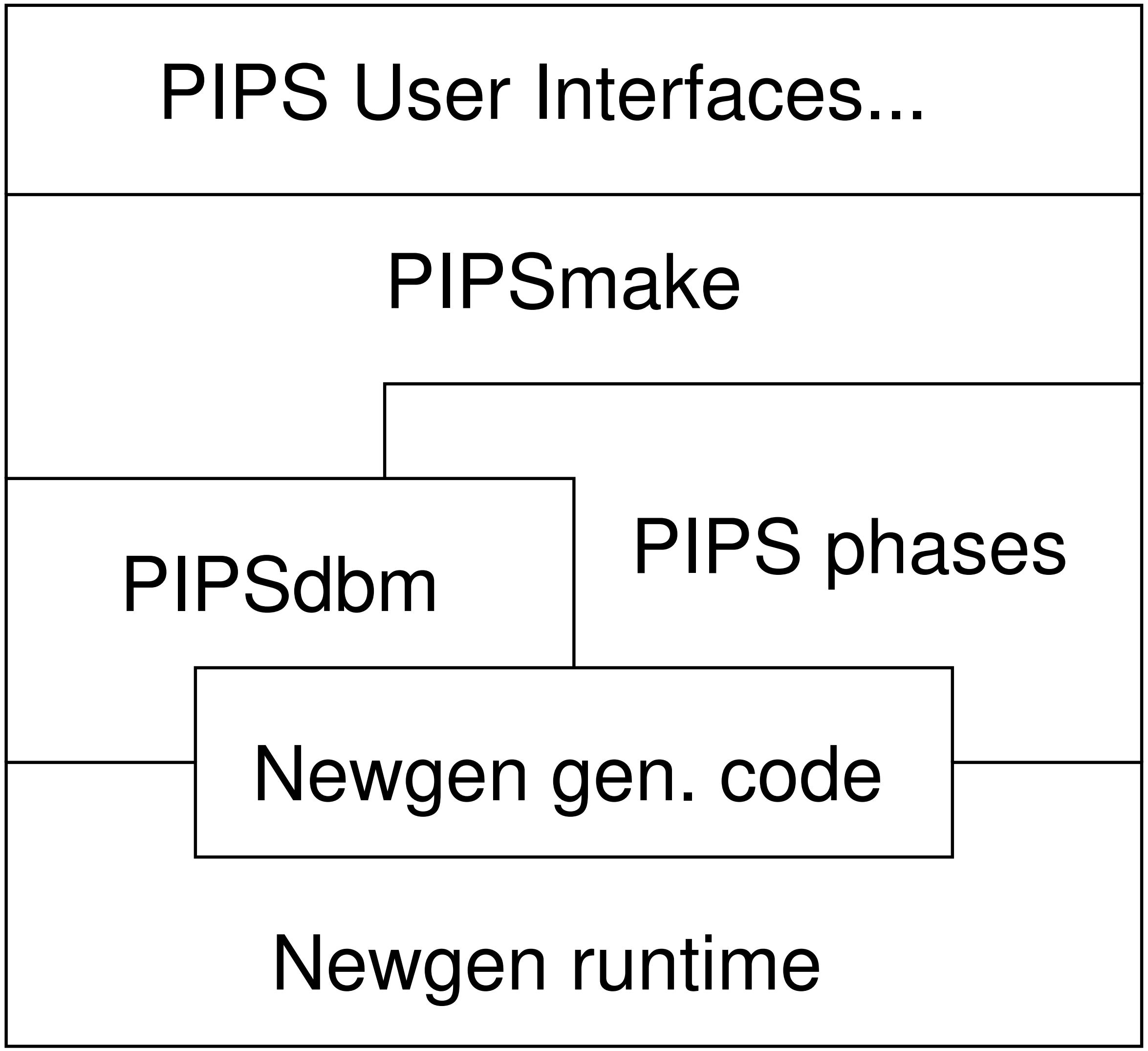
input Fortran 77, Fortran 95, C

output idem, source to source!

Newgen data structure generator, used for IR

PIPSmake on demand dependency handling *à la make*

PIPSdbm database layer for persistence


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

PIPSmake resource dependencies

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

```
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 Intermediate Representation

- **entity** global symbol table
- **statement** Hierarchical Control Flow Graph
- code **decorations** use functional mappings

PIPS Symbol Table

symbol anything with a name!

identifier, type, constant, label, field, parameter, memory location...

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`

global can be large, kept in memory!

necessary for interprocedural analyses

with type, storage, 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 semantical whenever possible

- only for really structured code!
- otherwise false loops are *desugarized*
- can be relied on for semantical analyses

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

- with `unstructured control` domains
- *prettyprint* regenerate 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 *hashtable*

```
statement_effects = persistant statement -> effects
```

- serialization: must rely on an absolute identifier

  statement number computed on the code

Newgen generic recursion engine

- 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
- can abort the recursion
- stack query: parent, parent of a given type...

Code examples

1. Index of a loop within a test?
2. (Simple) variable substitution
3. 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 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: before

```
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);
  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

HCFG representation for source to source

- extensions from Fortran 77 to C and Fortran 95

23 years later and still going strong!

- a lot of thesis work was capitalized

PAWS PIPS As a Web Service *new web interface*