LOOP FUSION

Experience feedback on ~~hacking~~implementation in PIPS

Mehdi AMINI – PIPS DAYS 25/10/2010

Idea : combine multiple loop nest into one

Ex :

```
for( i=0; i<N; i++) {
  A[i]  = ....;
}
for( i=0; i<N; i++) {
  ... = A[i] ....;
}
```


```
for( i=0; i<N; i++) {
  A[i]  = ....
  .... = A[i] + ....;
}
```

Pros :

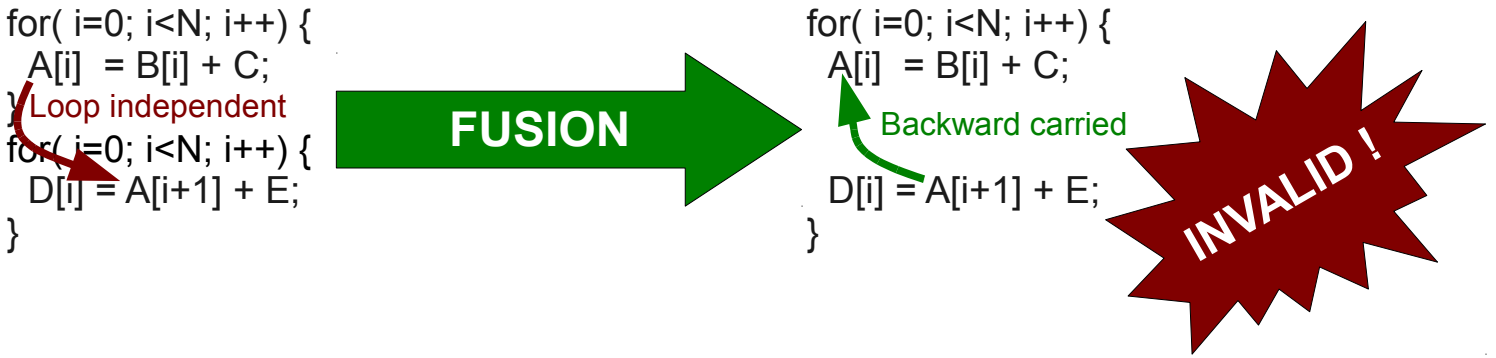
- May improve data locality
- Reduce loop overhead
- Reduce synchronizations in case of parallel loops
- Enables array contraction
- May enable better instruction scheduling

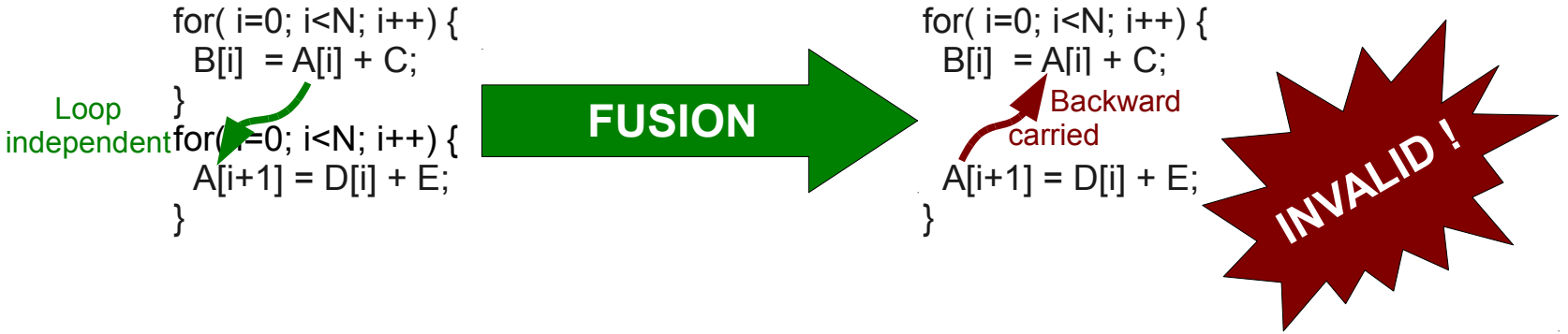
Cons :

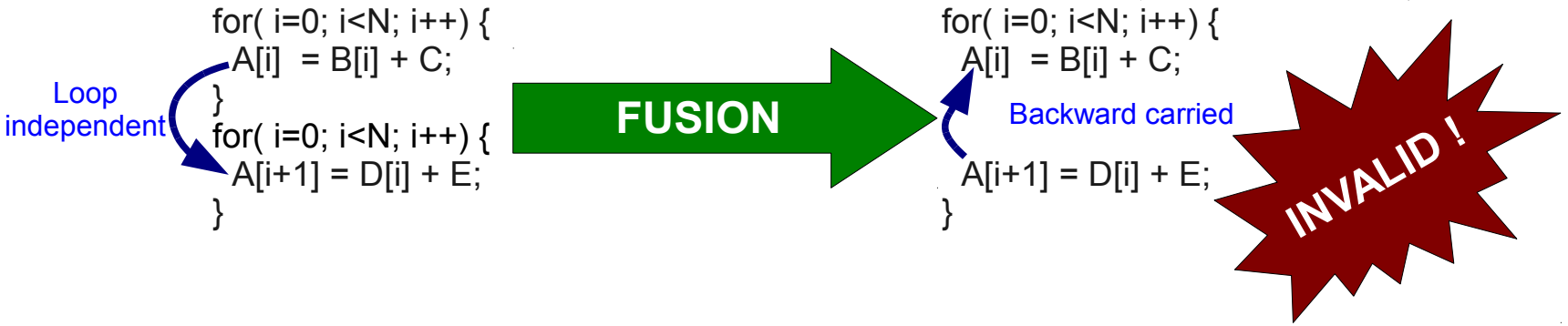
- May hurt data locality

What about the legality ?

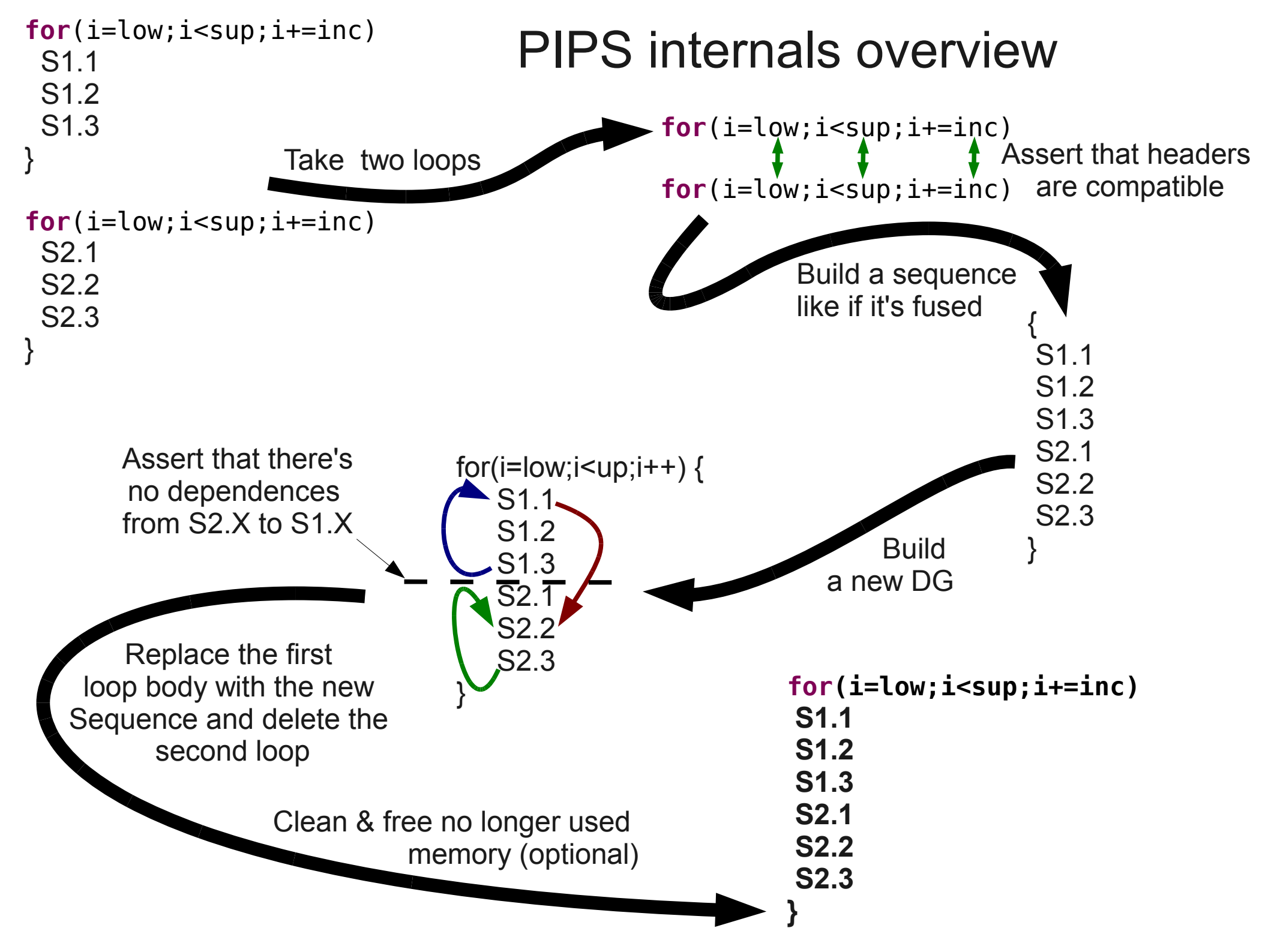
« A loop-independent dependence between statement in two different loops (i.e. From S1 to S2) is *fusion preventing* if fusing the two loops causes the dependence to be carried by the combined loop in the reverse direction (from S2 to S1). » Kennedy & McKinley.



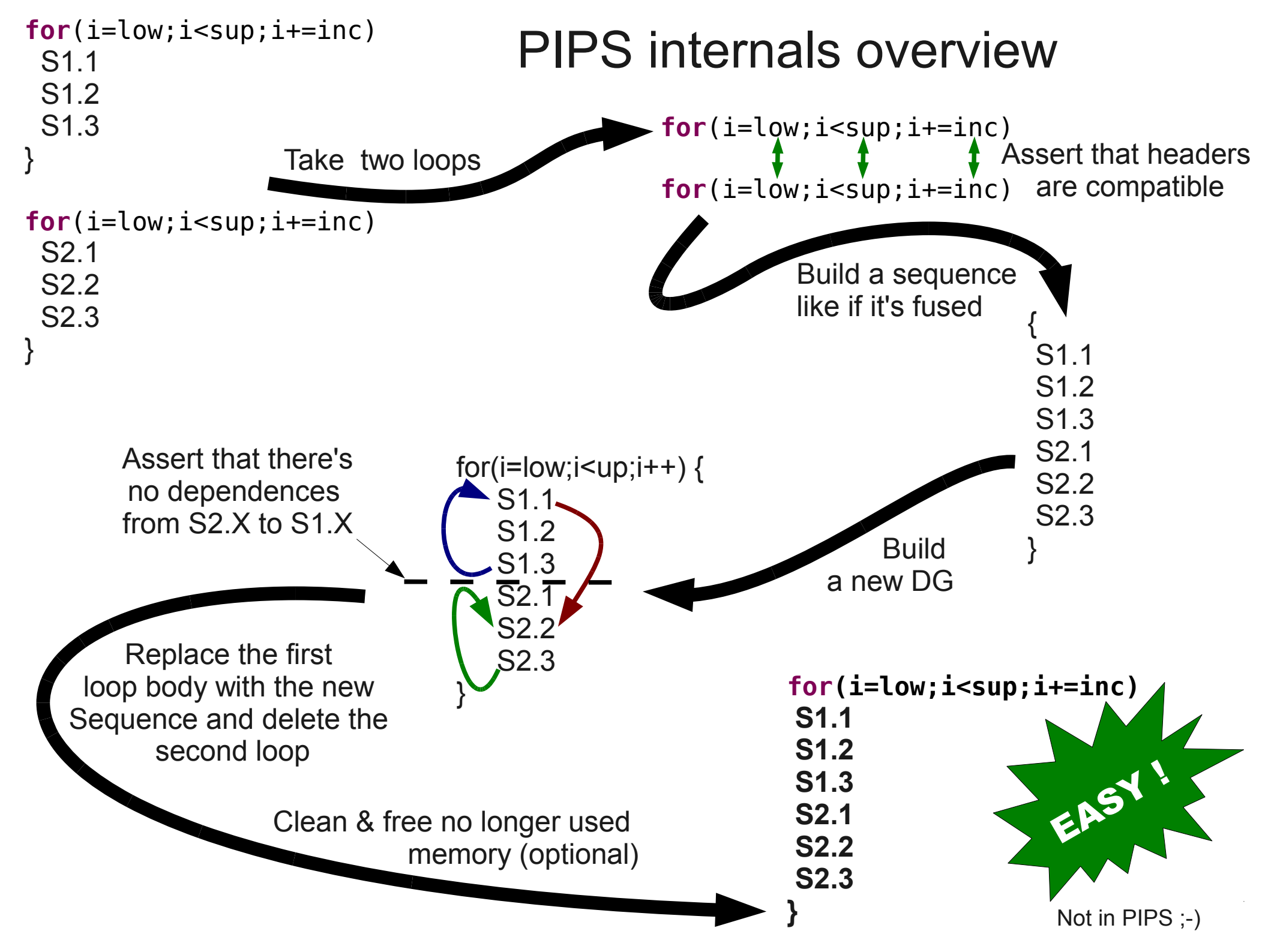




PIPS internals overview

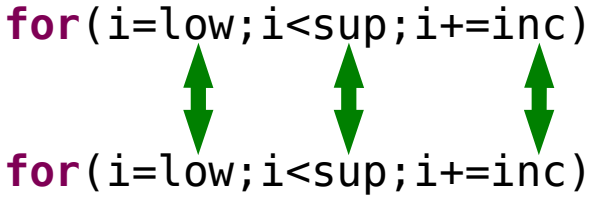


PIPS internals overview



Compatible header ?

aka “*easy part*”




```
/**
 * @brief Check that two loop statements have the same bounds
 */
static bool loops_have_same_bounds_p(loop loop1, loop loop2) {
  bool same_p = FALSE;

  range r1 = loop_range(loop1);
  range r2 = loop_range(loop2);

  same_p = range_equal_p(r1, r2);

  return same_p;
}

bool range_equal_p(range r1, range r2)
{
  return expression_equal_p(range_lower(r1), range_lower(r2))
    && expression_equal_p(range_upper(r1), range_upper(r2))
    && expression_equal_p(range_increment(r1), range_increment(r2));
}
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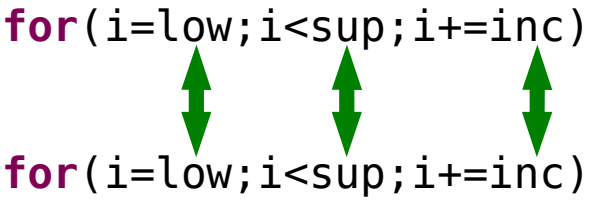


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    && expression_equal_p(range_increment(r1), range_increment(r2));
}
```

Hey ! But we are doing store dependent comparison !

```
int start = 0, sup = 10, inc = 1;

for (i = start; i < sup; i += inc) {
  ...
}
start = 2; sup = 20; inc=2;
for (i = start; i < sup; i += inc) {
  ...
}
```

Compatible header ?

aka “*easy part*”

```
for(i=low;i<sup;i+=inc)
for(i=low;i<sup;i+=inc)
```

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/**
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 */
static bool loops_have_same_bounds_p(loop loop1, loop loop2) {
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for (i = start; i < sup; i += inc) {
  ...
}
start = 2; sup = 20; inc=2;
for (i = start; i < sup; i += inc) {
  ...
}
```

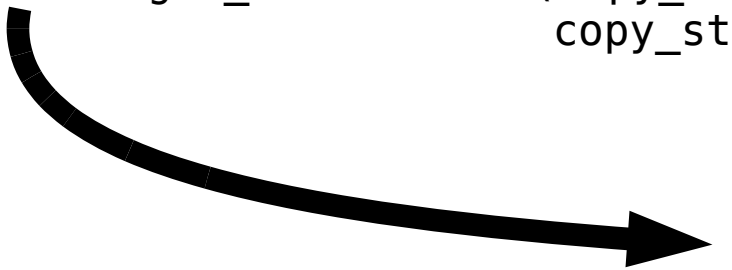
Hopefully dependences will prevent that we try to fuse these loops

Build&validate new candidate body

aka “*(might be) easy part...”*

```
for(i=low;i<sup;i+=inc)
 S1.1
 S1.2      } body1
 S1.3
}
for(i=low;i<sup;i+=inc)
 S2.1
 S2.2      } body2
 S2.3
}
```

```
list fused = gen_concatenate(copy_statement(body1),
                             copy_statement(body2));
```



```
{
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Build&validate a new candidate body

aka "*(might be) easy part...*"

```
for(i=low;i<sup;i+=inc)
 S1.1
 S1.2      } body1
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for(i=low;i<sup;i+=inc)
 S2.1
 S2.2      } body2
 S2.3
}
```

```
list fused = gen_concatenate(copy_statement(body1),
                             copy_statement(body2));
```

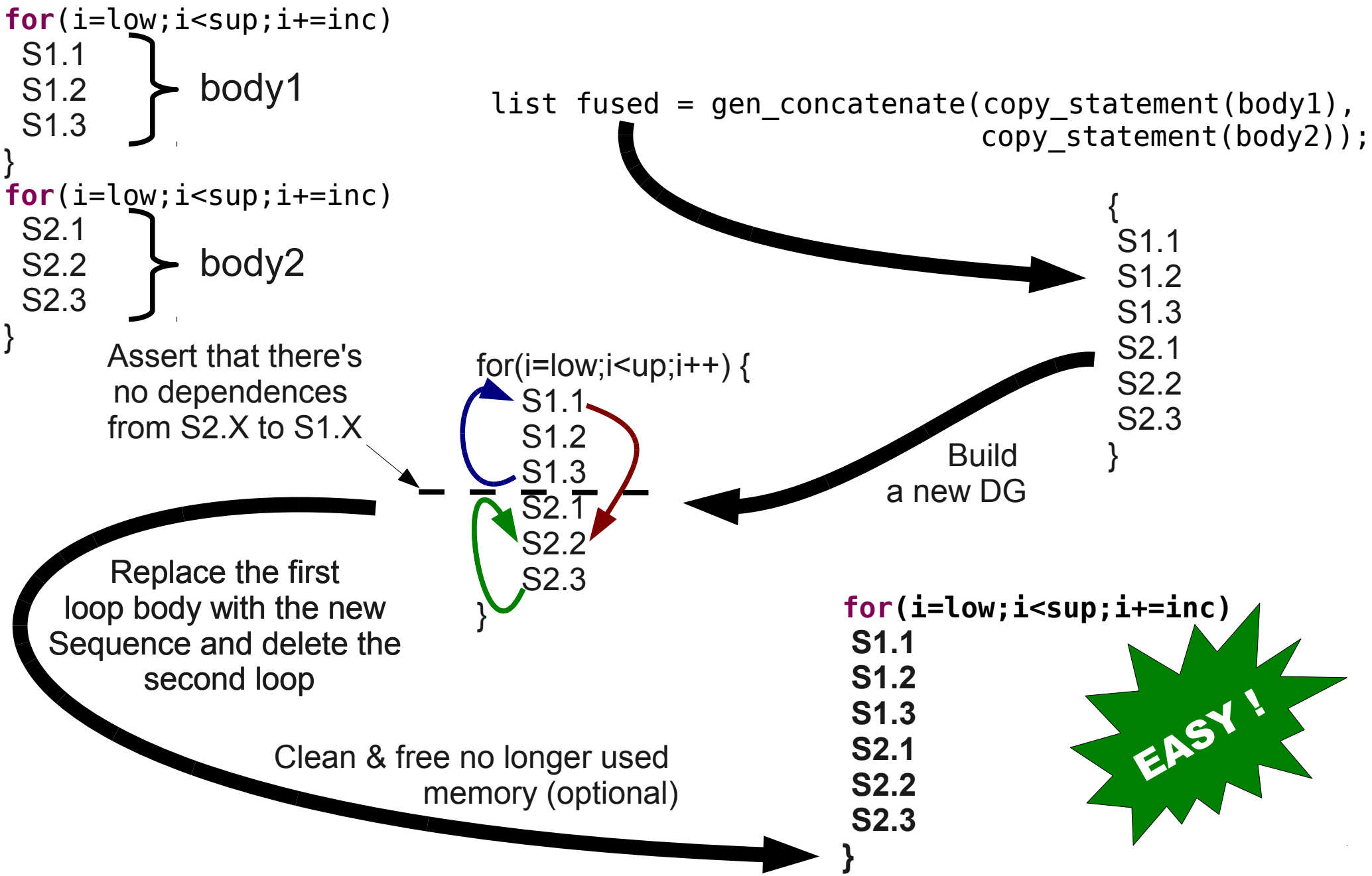
```
{
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Build
a new DG

```
for(i=low;i<up;i++) {
  S1.1
  S1.2
  S1.3
  S2.1
  S2.2
  S2.3
}
```

Build&validate a new candidate body

aka "*(might be) easy part...*"



Build&validate a new candidate body

aka "*(might be) easy part...*"

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```
list fused = gen_concatenate(copy_statement(body1),
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```

```
{
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Build a new DG

Assert that there's no dependences from S2.X to S1.X

```
for(i=low;i<up;i++) {
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Replace the first loop body with the new Sequence and delete the second loop

Clean & free no longer used memory (optional)

```
for(i=low;i<sup;i+=inc)
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Build&validate a new candidate body

aka "*(might be) easy part...* ***Or not !*** "

```
for(i=low;i<sup;i+=inc)
 S1.1
 S1.2   } body1
 S1.3
}
for(i=low;i<sup;i+=inc)
 S2.1
 S2.2   } body2
 S2.3
}
```

```
list fused = gen_concatenate(copy_statement(body1),
                             copy_statement(body2));
```

```
{
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

We are out of the PipsMake way !

Build
a new DG

Assert that there's
no dependences
from S2.X to S1.X

```
for(i=low;i<up
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Replace the first
loop body with the new
Sequence and delete the
second loop

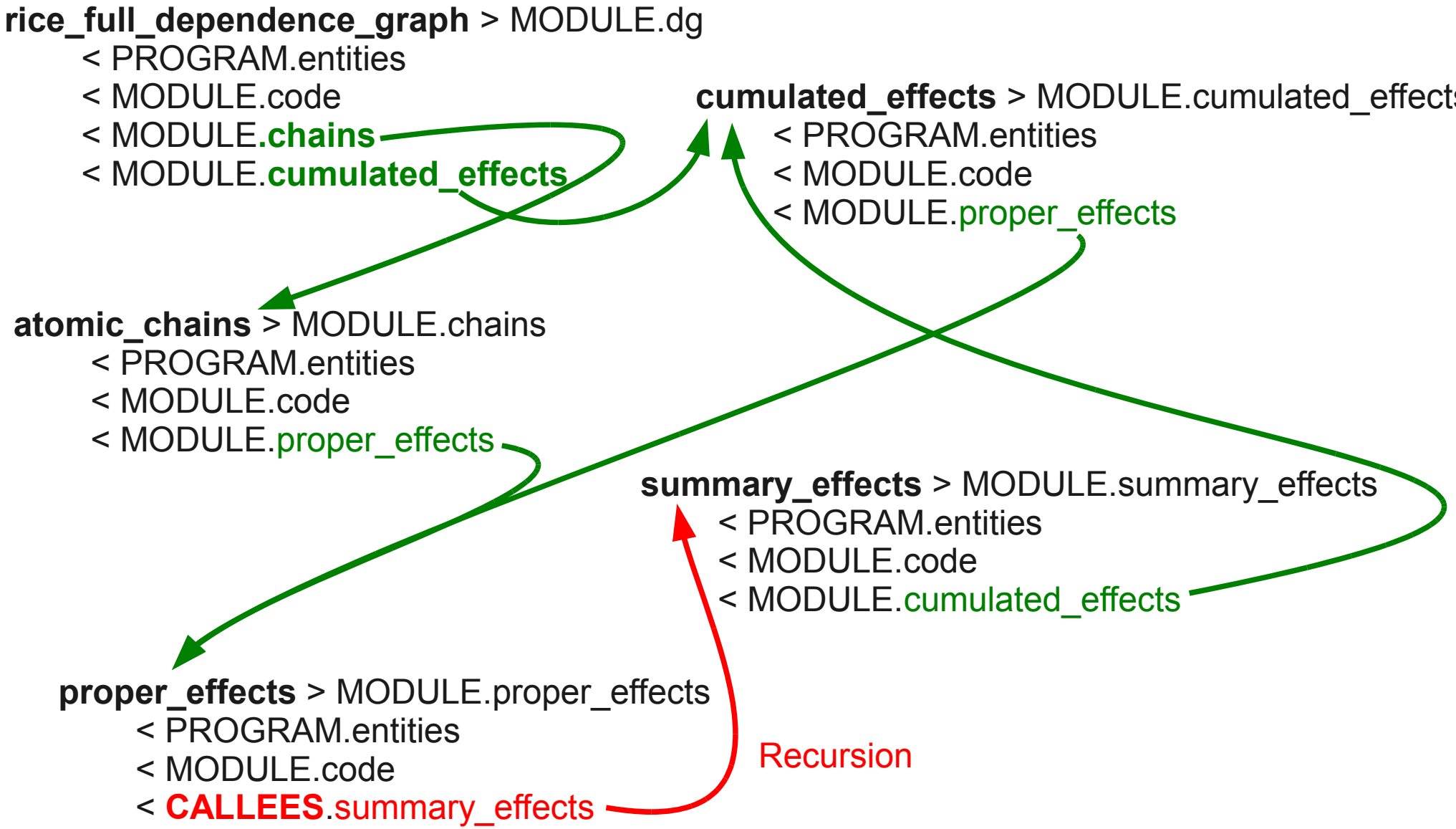
Clean & free no longer used
memory (optional)

```
for(i=low;i<sup;i+=inc)
 S1.1
 S1.2
 S1.3
 S2.1
 S2.2
 S2.3
}
```

Not in PIPS !

Build a DG out of PipsMake

aka “*the tricky part...*”

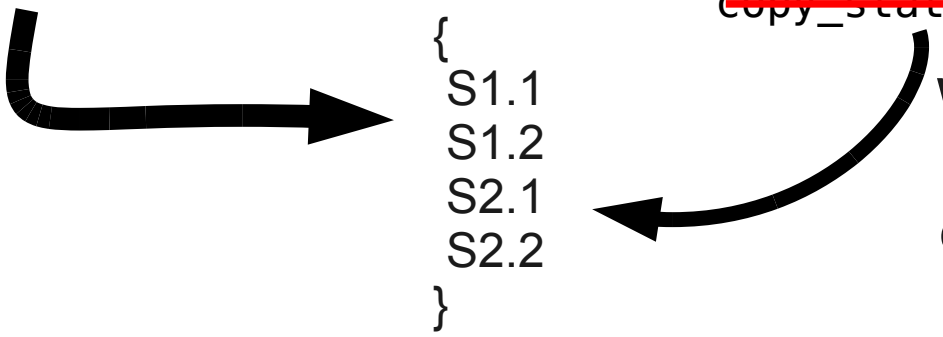


We'll *cheat* a little instead of mimic PipsMake

Prepare DG construction

aka "*the cheating & hacking part*"

```
list fused = gen_concatenate(copy_statement(body1),
                             copy_statement(body2));
```



We are working on the real original statements, **with effects attached to them !**

```
// Construct the fused body statement
statement fused_statement = make_block_statement(fused);

// Replace the loop body with the fused one
loop_body( loop1 ) = fused_statement;

// Cheat chains & dg on ordering
statement_ordering( fused_statement) = 999999999; // FIXME : dirty
add_ordering_of_the_statement_to_current_mapping(fused_statement);

// Cheat chains on proper_effects
store_proper_rw_effects_list(fused_statement, NIL);

// Cheat DG on enclosing_loops
set_enclosing_loops_map(loops_mapping_of_statement(sloop1));
```

Get the DG out of PIPS

aka "*should have been easy part*"

```
// Build chains on the new loop
graph chains = statement_dependence_graph(sloop1);

// Build DG on the new loop
graph dg = rdg_on_statement(sloop1);
```

If only it was so simple.... Rice dependence graph building is a kind of opaque black box, with a lot of static global variable, and rdg_on_statement is static and need initialization.

When hacking PIPS, axe might not be enough,
sometimes chain saw is required.
Go inside ricedg source code and add new entry point :

```
// have to be done before call :
// * set_ordering_to_statement
// * set_enclosing_loops_map
// * loading cumulated effects
graph compute_dg_on_statement_from_chains( statement s, graph chains )
```

LOOP FUSION

Part 2 : selection algorithm

Mehdi AMINI – PIPS DAYS 25/10/2010

```c
#define N 100
void loop_fusion03( int a[N][N], int b[N][N] ) {
  int i, j;
  int k;

  /* These loop nests can be fused together, even
with the reduction on k */
  k = 0;
  for ( i = 0; i < N; i++ ) {
    for ( j = 0; j < N; j++ ) {
      a[i][j] = i + j;
    }
    k += a[i][j];
    for ( j = 0; j < N; j++ ) {
      b[i][j] += a[i][j];
    }
  }


}
```

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#define N 100
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    }
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}
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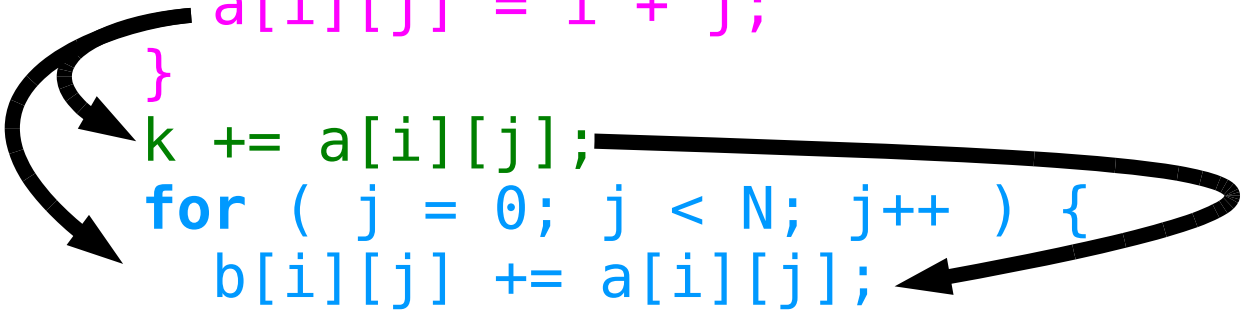
    }
    k += a[i][j];
    for ( j = 0; j < N; j++ ) {
      b[i][j] += a[i][j];
    }
  }


}
```



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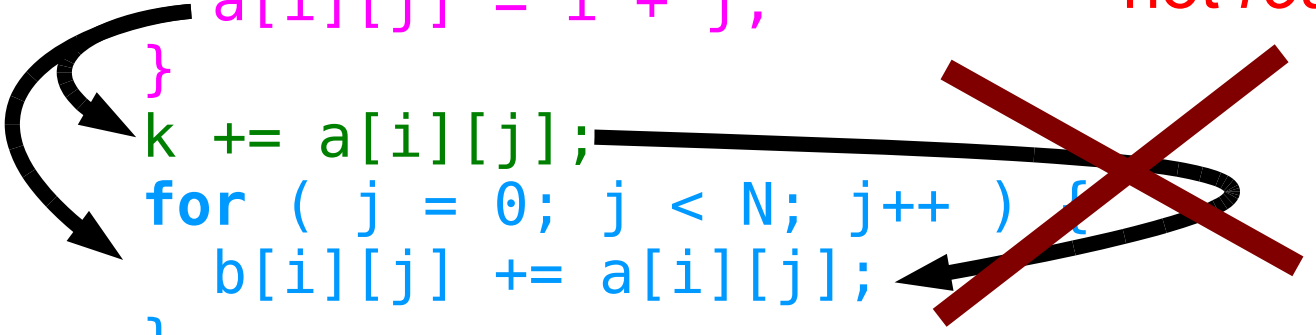

Read after read are not *real* dependence !

```
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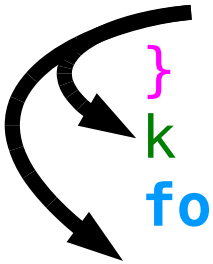
    for ( j = 0; j < N; j++ ) {
      b[i][j] += a[i][j];
    }
  }


}
```



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      b[i][j] += a[i][j];
    }
    k += a[i][j];
  }
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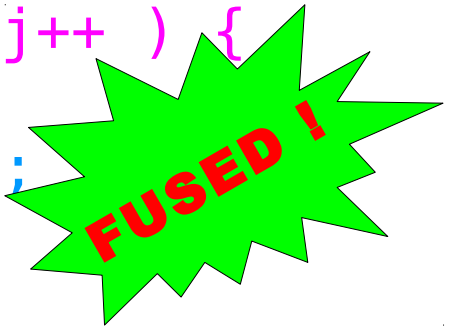

Current limitations

- Fuse only inside sequence
- No fusion possible without dependence
- Headers compatible but with different loop indices are unsafe :-(
- Limited by DG accuracy, which is limited by chains & effects, which are waiting some work on *points_to* for C language
- Don't even think about running valgrind ! ;-)

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