LARA Tutorial

3. Code Transformations

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ANTAREX 10^{18}

SPeCS
Special-Purpose Computing Systems, languages and tools

Objectives

- Present code transformation concepts in LARA

- Show actions for
  - Optimization
  - Specialization
  - Type definition

Some Information

MANET:

- LARA + Cetus*
- ANSI C
- http://specs.fe.up.pt/tools/manet/

- The presented examples
  - Dijkstra from MiBench
  - Disparity from San Diego Vision Benchmark Suite

*Cetus compiler: http://cetus.ecn.purdue.edu/

3.1 Simple Loop Transformations – Goal

- Show how to use actions in LARA
  - Present the actions available in MANET
  - The *exec* keyword
- Use loop unroll as an example and parameterize it

3.1 Simple Loop Unroll – Strategy

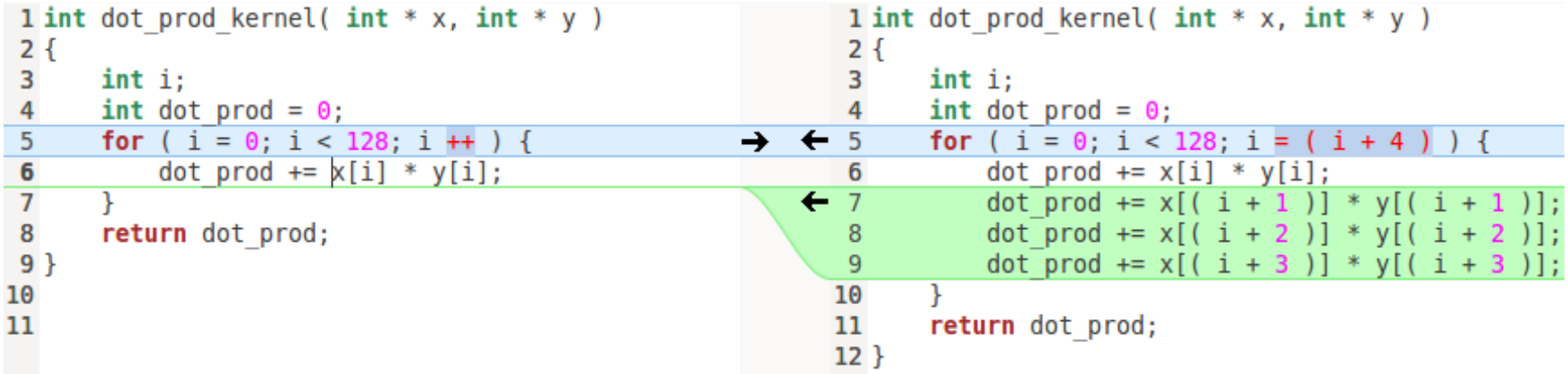
- Capture relevant loops
- Filter them using attributes
  - *is_innermost*
  - *num_iterations*
- *exec* Unroll with different parameters

```
aspectdef SimpleLoopUnroll

  input funcName, factor end

  select function{funcName}.loop end
  apply
    exec Unroll(factor); // 0 for full
  end
  condition
    $loop.is_innermost
  end
end
```

3.1 Simple Loop Transformations – Diff



```
1  int dot_prod_kernel( int * x, int * y )
2  {
3      int i;
4      int dot_prod = 0;
5      for ( i = 0; i < 128; i ++ ) {
6          dot_prod += x[i] * y[i];
7      }
8      return dot_prod;
9  }
10
11
```

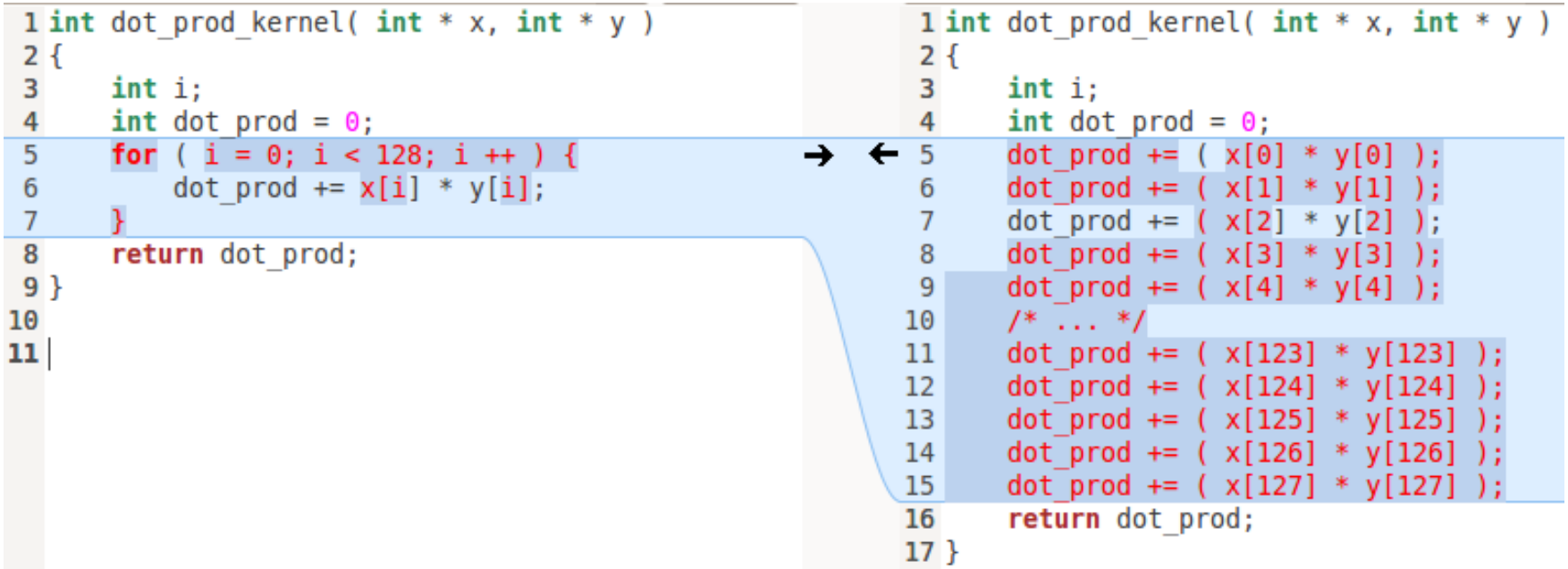
```
1  int dot_prod_kernel( int * x, int * y )
2  {
3      int i;
4      int dot_prod = 0;
5      for ( i = 0; i < 128; i = ( i + 4 ) ) {
6          dot_prod += x[i] * y[i];
7          dot_prod += x[( i + 1 )] * y[( i + 1 )];
8          dot_prod += x[( i + 2 )] * y[( i + 2 )];
9          dot_prod += x[( i + 3 )] * y[( i + 3 )];
10     }
11     return dot_prod;
12 }
```

Unroll with factor 4 and known iteration count

Main LARA code:

```
exec Unroll(factor);
```

3.1 Simple Loop Transformations – Diff



```
 1 int dot_prod_kernel( int * x, int * y )
 2 {
 3     int i;
 4     int dot_prod = 0;
 5     for ( i = 0; i < 128; i ++ ) {
 6         dot_prod += x[i] * y[i];
 7     }
 8     return dot_prod;
 9 }
10
11
```

```
 1 int dot_prod_kernel( int * x, int * y )
 2 {
 3     int i;
 4     int dot_prod = 0;
 5     dot_prod += ( x[0] * y[0] );
 6     dot_prod += ( x[1] * y[1] );
 7     dot_prod += ( x[2] * y[2] );
 8     dot_prod += ( x[3] * y[3] );
 9     dot_prod += ( x[4] * y[4] );
10     /* ... */
11     dot_prod += ( x[123] * y[123] );
12     dot_prod += ( x[124] * y[124] );
13     dot_prod += ( x[125] * y[125] );
14     dot_prod += ( x[126] * y[126] );
15     dot_prod += ( x[127] * y[127] );
16     return dot_prod;
17 }
```

Unroll with factor 0 (full unroll) and known iteration count

3.1 Simple Loop Transformations – Diff

```
1  int dot_prod_kernel( int * x, int * y )
2  {
3      int i;
4      int dot_prod = 0;
5      for ( i = 0; i < SIZE; i ++ ) {
6          dot_prod += x[i] * y[i];
7      }
8      return dot_prod;
9  }
10
11
```

```
1  int dot_prod_kernel( int * x, int * y )
2  {
3      int i;
4      int dot_prod = 0;
5      for ( i = 0; i < ( -1 + SIZE ) + ( -1 * ( ( -1 + SIZE ) % 4 ) ); i = i + 4 ) {
6          dot_prod += x[i] * y[i];
7          dot_prod += x[( i + 1 )] * y[( i + 1 )];
8          dot_prod += x[( i + 2 )] * y[( i + 2 )];
9          dot_prod += x[( i + 3 )] * y[( i + 3 )];
10     }
11     /*
12     Epilogue
13     */
14     for ( i = ( -1 + SIZE ) + ( -1 * ( ( -1 + SIZE ) % 4 ) ); i < SIZE; i ++ ) {
15         dot_prod += ( x[i] * y[i] );
16     }
17     return dot_prod;
18 }
```

Unroll with factor 4 and unknown iteration count

3.1 Simple Loop Unroll – Another Strategy

- Account for the number of iterations
- Insert a simple conditional statement
  - Full unroll if it performs up to 8 iterations
- More sophisticated aspects
  - Attributes
  - Metrics
  - Parameters

```
aspectdef SimpleLoopUnroll

  input funcName, factor end

  select function{funcName}.loop end
  apply
    if($loop.num_iterations <= 8)
      exec Unroll(0);
    else
      exec Unroll(factor);
  end
  condition
    $loop.is_innermost
  end
end
```

3.2 Change Data Types – Goal

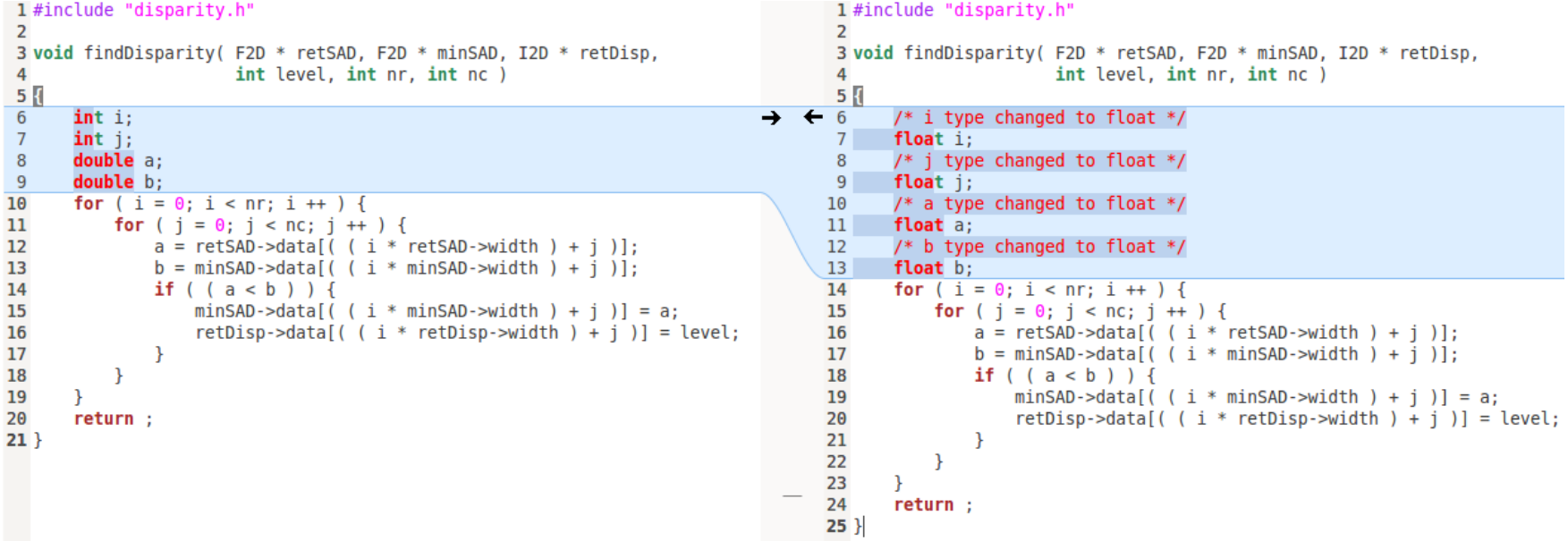
- Change the types of certain variables
  - Using the *def* action
- Filter unwanted variables
  - type, operation, location, name, …
- Can also change types of function returns and parameters
- Could be based on a variable range analysis

3.2 Change Data Types – Strategy

- Prepare variable declarations
  - *exec* SingleDeclarator()
- Select target variables
  - Searching for declarations inside functions
- Use the *def* action to define the value of the *native_type* attribute

```
select function{funcName}.decl end
apply
  def native_type = newT;
end
```

3.2 Change Data Types – Diff



```
#include "disparity.h"

void findDisparity( F2D * retSAD, F2D * minSAD, I2D * retDisp,
                    int level, int nr, int nc )
{
    int i;
    int j;
    double a;
    double b;
    for ( i = 0; i < nr; i ++ ) {
        for ( j = 0; j < nc; j ++ ) {
            a = retSAD->data[( ( i * retSAD->width ) + j )];
            b = minSAD->data[( ( i * minSAD->width ) + j )];
            if ( ( a < b ) ) {
                minSAD->data[( ( i * minSAD->width ) + j )] = a;
                retDisp->data[( ( i * retDisp->width ) + j )] = level;
            }
        }
    }
    return ;
}
```

```
#include "disparity.h"

void findDisparity( F2D * retSAD, F2D * minSAD, I2D * retDisp,
                    int level, int nr, int nc )
{
    /* i type changed to float */
    float i;
    /* j type changed to float */
    float j;
    /* a type changed to float */
    float a;
    /* b type changed to float */
    float b;
    for ( i = 0; i < nr; i ++ ) {
        for ( j = 0; j < nc; j ++ ) {
            a = retSAD->data[( ( i * retSAD->width ) + j )];
            b = minSAD->data[( ( i * minSAD->width ) + j )];
            if ( ( a < b ) ) {
                minSAD->data[( ( i * minSAD->width ) + j )] = a;
                retDisp->data[( ( i * retDisp->width ) + j )] = level;
            }
        }
    }
    return ;
}
```

Main LARA code:

```
def native_type = newT;
```

Without control variable filtering

3.2 Change Data Types – Avoid Control Variables

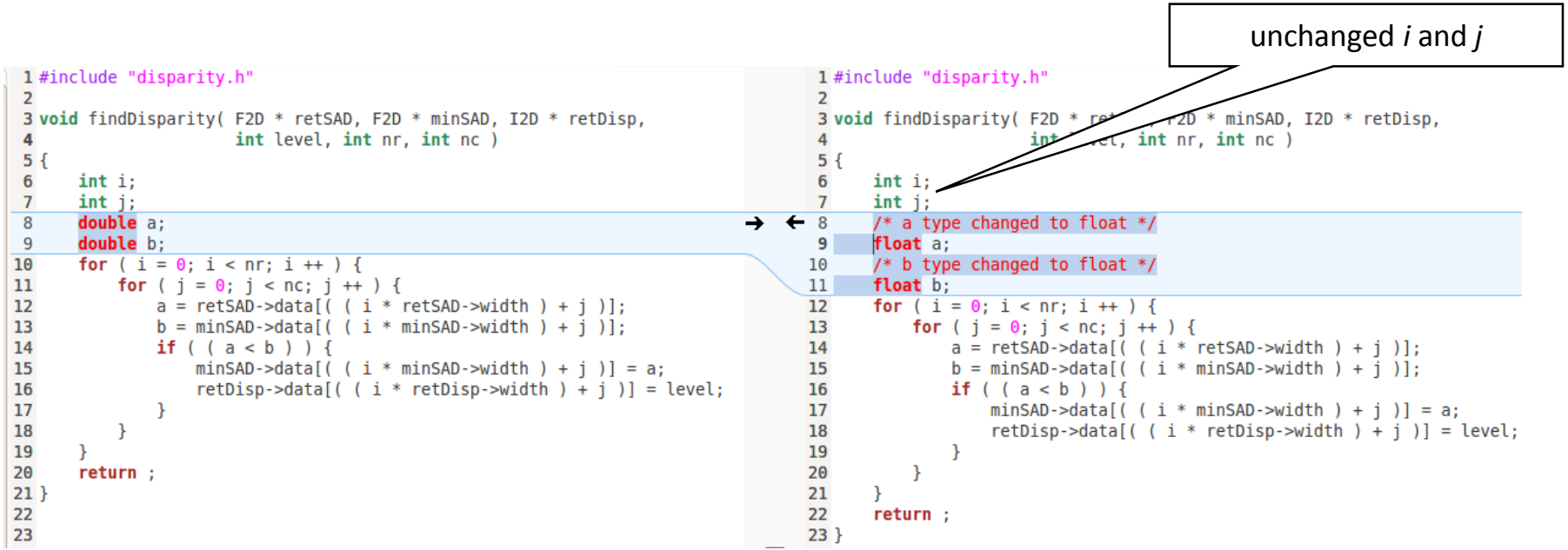
- Use join point attributes to filter the results
  - Select all loops in target function
  - Collect their control variables in a set
- How to avoid loop control variables
  - This way
  - Common names (i, j, k, …)
  - *in_loop_header* attribute
  - …

```
var loopControlVars = new Set();

select function{funcName}.loop end
apply
  loopControlVars.add($loop.control_var);
end

select function{funcName}.decl end
apply
  def native_type = newT;
end
condition
  !loopControlVars.contains($decl.name)
end
```

3.2 Change Data Types – Diff



With control variable filtering

3.3 Cloning and Transformations – Goal

- Change a program for possible specialization / adaptation
- Generate several versions of a target function
  - Using the *Clone* action
- Apply transformations to the clones
- Add a way of selecting the newly generated versions

3.3 Cloning and Transformations – Strategy

- Clone a critical function and assign a new name to the clone
- The *Clone* action generates new copies after the selected function

```
var tiled = funcName + '_tiled';

select function{funcName} end
apply
  exec Clone(tiled);
end
```

3.3 Cloning and Transformations – Diff

```
1 #include "disparity.h"
2
3 void computeSAD( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
4 {
5     int rows, cols, i, j, diff;
6     rows = Ileft->height;
7     cols = Ileft->width;
8     for ( i = 0; i < rows; i ++ ) {
9         for ( j = 0; j < cols; j ++ ) {
10            diff = Ileft->data[( ( i * Ileft->width ) + j )] -
11                   Iright_moved->data[( ( i * Iright_moved->width ) + j )];
12            SAD->data[( ( i * SAD->width ) + j )] = ( diff * diff );
13        }
14    }
15    return ;
16 }
```

```
1 #include "disparity.h"
2
3 void computeSAD_tiled( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
4 {
5     int rows, cols, i, j, diff;
6     rows = Ileft->height;
7     cols = Ileft->width;
8     for ( i = 0; i < rows; i ++ ) {
9         for ( j = 0; j < cols; j ++ ) {
10            diff = Ileft->data[( ( i * Ileft->width ) + j )] -
11                   Iright_moved->data[( ( i * Iright_moved->width ) + j )];
12            SAD->data[( ( i * SAD->width ) + j )] = ( diff * diff );
13        }
14    }
15    return ;
16 }
17
18 void computeSAD( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
19 {
20    int rows, cols, i, j, diff;
21    rows = Ileft->height;
22    cols = Ileft->width;
23    for ( i = 0; i < rows; i ++ ) {
24        for ( j = 0; j < cols; j ++ ) {
25            diff = Ileft->data[( ( i * Ileft->width ) + j )] -
26                   Iright_moved->data[( ( i * Iright_moved->width ) + j )];
27            SAD->data[( ( i * SAD->width ) + j )] = ( diff * diff );
28        }
29    }
30    return ;
31 }
```

Main LARA code:

```
exec Clone(tiled);
```

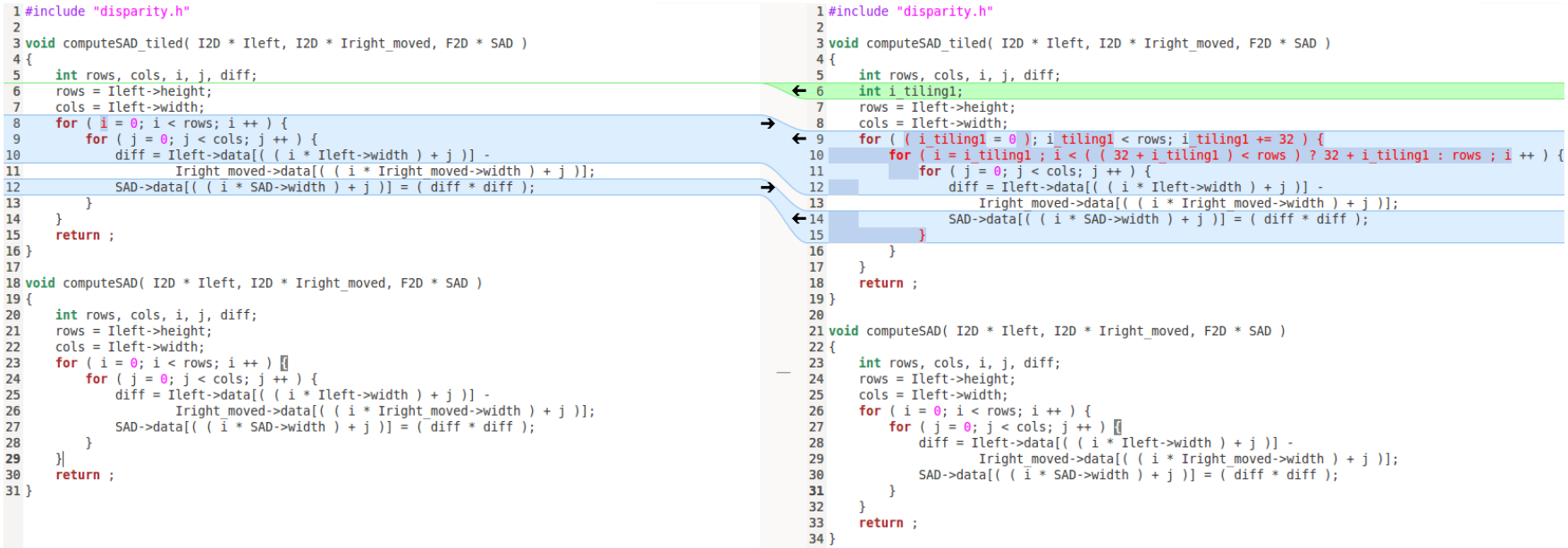
3.3 Cloning and Transformations – Strategy

- Select functions with the new names

- Transform them
  - Loop Tiling
  - Loop Interchange
  - …

```
select function{tiled}.loop end
apply
  exec Tile(32);
end
condition
  $loop.is_outermost
end
```

3.3 Cloning and Transformations – Diff



```
#include "disparity.h"

void computeSAD_tiled( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
{
    int rows, cols, i, j, diff;
    rows = Ileft->height;
    cols = Ileft->width;
    for ( i = 0; i < rows; i ++ ) {
        for ( j = 0; j < cols; j ++ ) {
            diff = Ileft->data[( i * Ileft->width ) + j )] -
                    Iright_moved->data[( i * Iright_moved->width ) + j )];
            SAD->data[( i * SAD->width ) + j )] = ( diff * diff );
        }
    }
    return ;
}

void computeSAD( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
{
    int rows, cols, i, j, diff;
    rows = Ileft->height;
    cols = Ileft->width;
    for ( i = 0; i < rows; i ++ ) {
        for ( j = 0; j < cols; j ++ ) {
            diff = Ileft->data[( i * Ileft->width ) + j )] -
                    Iright_moved->data[( i * Iright_moved->width ) + j )];
            SAD->data[( i * SAD->width ) + j )] = ( diff * diff );
        }
    }
    return ;
}
```

```
#include "disparity.h"

void computeSAD_tiled( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
{
    int rows, cols, i, j, diff;
    int i_tiling1;
    rows = Ileft->height;
    cols = Ileft->width;
    for ( i_tiling1 = 0 ); i_tiling1 < rows; i_tiling1 += 32 ) {
        for ( i = i_tiling1 ; i < ( ( 32 + i_tiling1 ) < rows ) ? 32 + i_tiling1 : rows ; i ++ ) {
            for ( j = 0; j < cols; j ++ ) {
                diff = Ileft->data[( i * Ileft->width ) + j )] -
                        Iright_moved->data[( i * Iright_moved->width ) + j )];
                SAD->data[( i * SAD->width ) + j )] = ( diff * diff );
            }
        }
    }
    return ;
}

void computeSAD( I2D * Ileft, I2D * Iright_moved, F2D * SAD )
{
    int rows, cols, i, j, diff;
    rows = Ileft->height;
    cols = Ileft->width;
    for ( i = 0; i < rows; i ++ ) {
        for ( j = 0; j < cols; j ++ ) {
            diff = Ileft->data[( i * Ileft->width ) + j )] -
                    Iright_moved->data[( i * Iright_moved->width ) + j )];
            SAD->data[( i * SAD->width ) + j )] = ( diff * diff );
        }
    }
    return ;
}
```

Main LARA code:

```
exec Tile(32);
```

3.3 Cloning and Transformations – Strategy

- Find calls to the old function and add new logic
- Inserting simple switch with a user-generated function

```
select call{funcName} end
apply
  var originalCode = $call.code + ';';
  var tiledCode = originalCode.replace(funcName, tiled);
  insert before '/*';
  insert after '*/';

  insert after %{
    switch (get_best_version(/*...*/)) {
      case 0: [[originalCode]] break;
      case 1: [[tiledCode]] break;
      /* other user versions */
      default: [[originalCode]] break;
    }
  }%;
end
```

3.3 Cloning and Transformations – Diff

```
1 #include "disparity.h"
2
3 void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved, int win_sz,
4                       int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
5 {
6     int rows, cols;
7     int i, j, endRM;
8     I2D * range;
9     range = iMallocHandle( 1, 2 );
10    range->data[( ( 0 * range->width ) + 0 )] = 0;
11    range->data[( ( 0 * range->width ) + 1 )] = disparity;
12    rows = Iright_moved->height;
13    cols = Iright_moved->width;
14    for ( i = 0; i < ( rows * cols ); i ++ ) {
15        Iright_moved->data[i] = 0;
16    }
17    padarray4( Iright, range, ( - 1 ), Iright_moved );
18    computeSAD( Ileft, Iright_moved, SAD );
19    integralImage2D2D( SAD, integralImg );
20    finalSAD( integralImg, win_sz, retSAD );
21    iFreeHandle( range );
22    return ;
23 }
```

```
1 #include "disparity.h"
2
3 void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved, int win_sz,
4                       int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
5 {
6     int rows, cols;
7     int i, j, endRM;
8     I2D * range;
9     range = iMallocHandle( 1, 2 );
10    range->data[( ( 0 * range->width ) + 0 )] = 0;
11    range->data[( ( 0 * range->width ) + 1 )] = disparity;
12    rows = Iright_moved->height;
13    cols = Iright_moved->width;
14    for ( i = 0; i < ( rows * cols ); i ++ ) {
15        Iright_moved->data[i] = 0;
16    }
17    padarray4( Iright, range, ( - 1 ), Iright_moved );
18    /*
19    computeSAD(Ileft, Iright_moved, SAD);
20    */
21
22    switch ( get_best_version( /*...*/ ) ) {
23    case 0:
24        computeSAD( Ileft, Iright_moved, SAD );
25        break;
26    case 1:
27        computeSAD_tiled( Ileft, Iright_moved, SAD );
28        break;
29        /* other user versions */
30    default:
31        computeSAD( Ileft, Iright_moved, SAD );
32        break;
33    }
34
35    integralImage2D2D( SAD, integralImg );
36    finalSAD( integralImg, win_sz, retSAD );
37    iFreeHandle( range );
38    return ;
39 }
```

Main LARA code:

```
insert after %{
    switch (get_best_version(/*...*/))
    /*...*/
}%;
```

Takeaway Points

- Code transformations in LARA rely on
  - *def*
  - *insert*
  - All others actions, called with *exec*
- Enhance simple transformation strategies with attribute filtering
- Strategies can be used as standalone or prepare code for
  - Other aspects
  - Other tools
  - User development