LARA Tutorial

2. Dynamic Analysis

through Code Instrumentation

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ANTAREX 10^{18}

SPeCS Special-Purpose Computing Systems, languages and tools

Objectives

- Further usage of LARA
- Capture and report runtime information
- Use code instrumentation
  - *insert* action

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/

2.1 Timing Code Fragments – Goals

- Measure the execution time of code points
- Print current time and total elapsed time

Expected output:

```
...
current time of square: 704593.42us
current time of square: 716286.09us
current time of square: 727852.52us
current time of square: 739440.62us
elapsed time for square: 739440.62us
```

2.1 Timing Code Fragments – Strategy

- Instantiate a timing monitor
- Add C code to setup monitor

- Select target code to measure
  - Surround with start/pause statements
  - Add printing code for current time

- Add printing code before main return

```
aspectdef InstrumentApplication

  input functionName, timer end

  select call{functionName} end
  apply
    insert before '[[timer.start]]';
    insert after  '[[timer.pause]]';
  end
end
```

2.1 Timing Code Fragments – Diff

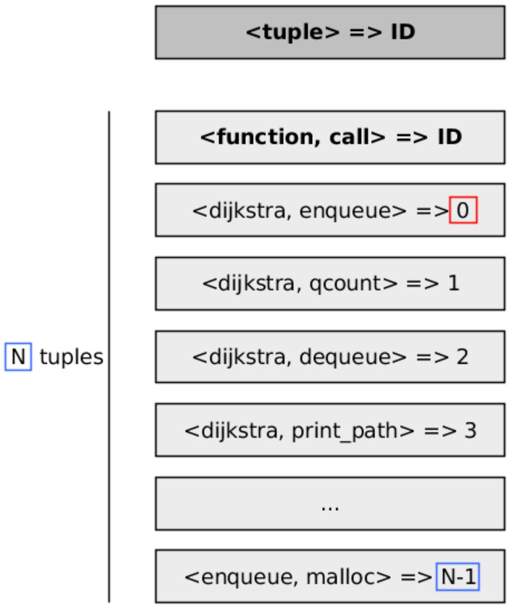
```
#include <stdio.h>
int square( int c )
{
    return ( c * c );
}

int sum_squares( int a, int b )
{
    int a2;
    int b2;
    a2 = square( a );
    b2 = square( b );
    return ( a2 + b2 );
}

int main()
{
    int a = 10;
    int b = 25;
    int c;
    c = sum_squares( a, b );
    printf( "Result: %d\n", c );
    return 0;
}
```

```
#include <stdio.h>
#include "timer.h"
Timer * tim = NULL;
int square( int c )
{
    return ( c * c );
}

int sum_squares( int a, int b )
{
    int a2;
    int b2;

    timer_start( tim );
    a2 = square( a );
    timer_pause( tim );
    printf( "current elapsed time of square: %.2fus\n", timer_get_time( tim ) );

    timer_start( tim );
    b2 = square( b );
    timer_pause( tim );
    printf( "current elapsed time of square: %.2fus\n", timer_get_time( tim ) );

    return ( a2 + b2 );
}

int main()
{
    int a = 10;
    int b = 25;
    int c;
    tim = timer_init();
    c = sum_squares( a, b );
    printf( "Result: %d\n", c );
    printf( "elapsed time for square: %.2fus\n", timer_get_time( tim ) );
    timer_destroy( tim );
    return 0;
}
```

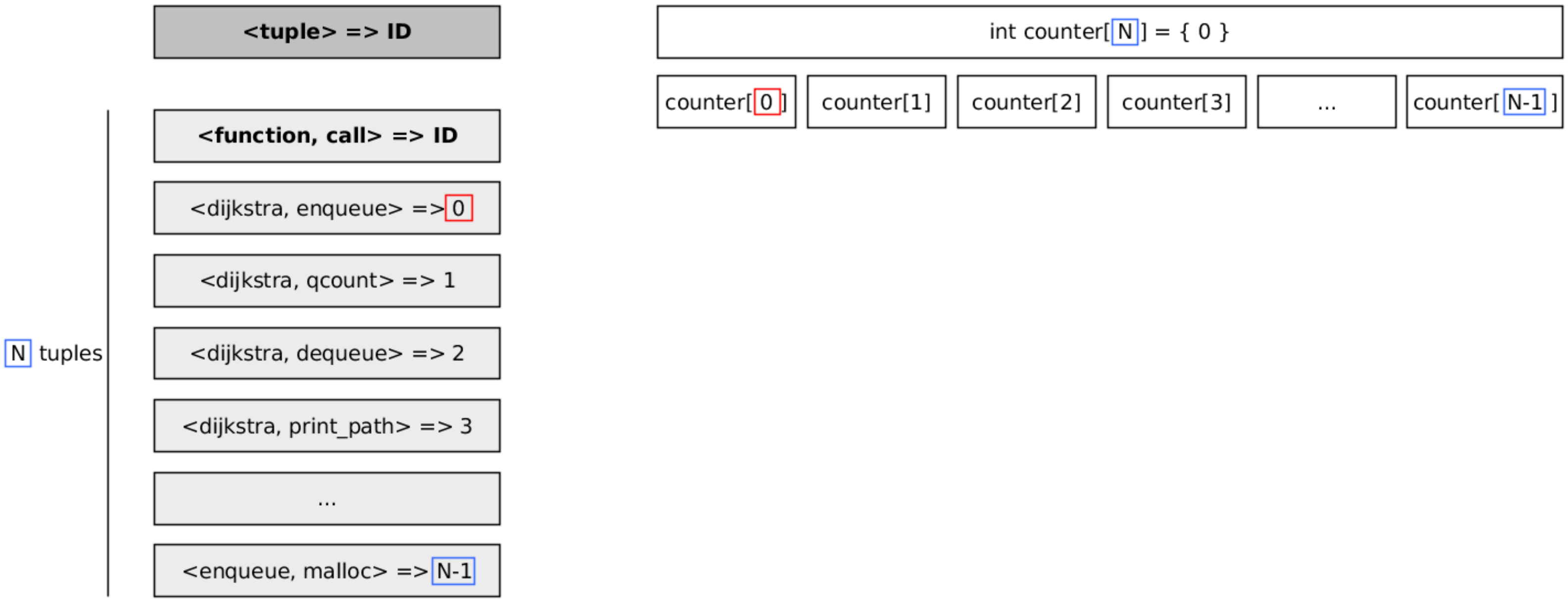
Main LARA code:

```
insert before '[[timer.start]]';
insert after  '[[timer.pause]]';
```

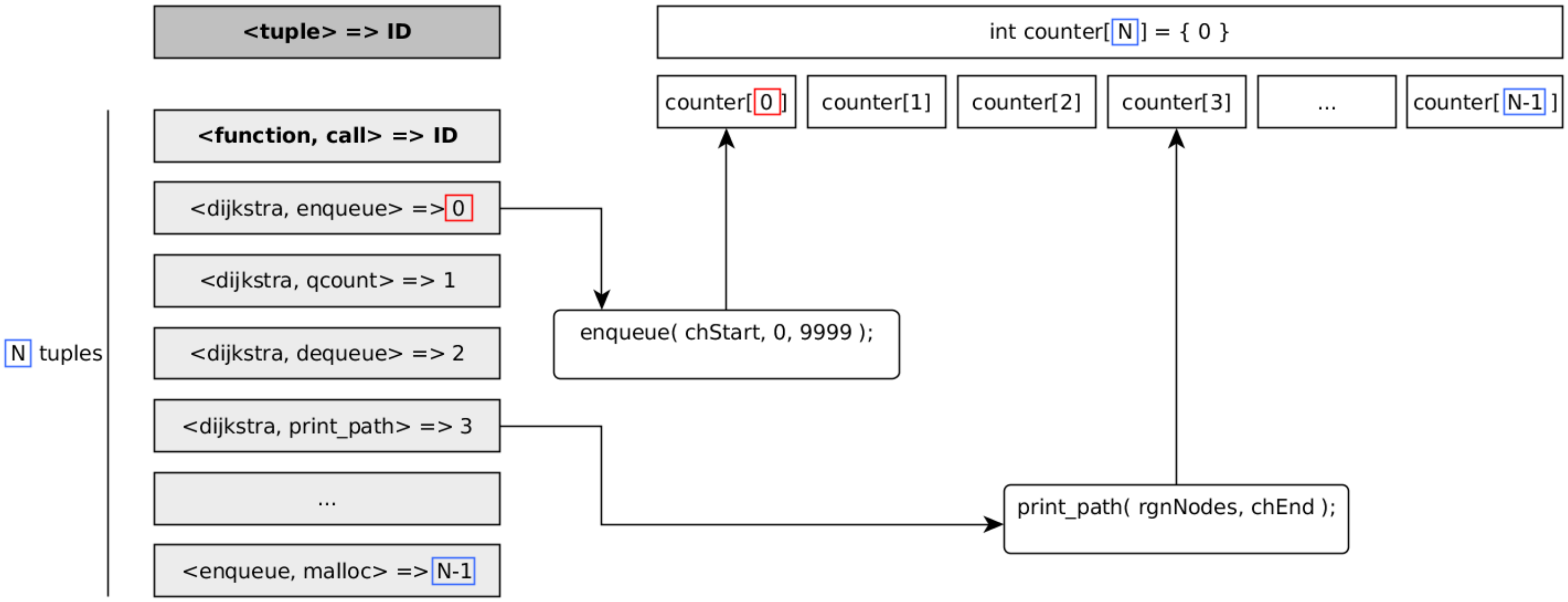
Capturing and Using Tuples



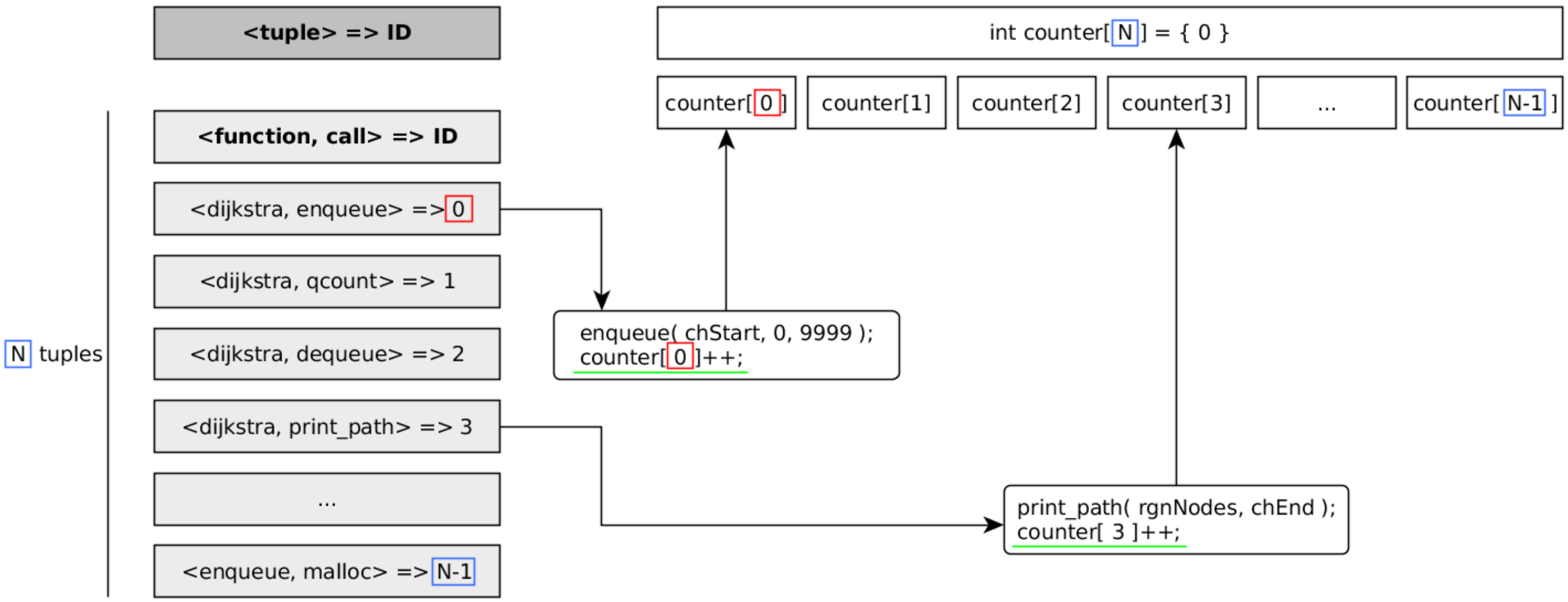
Capturing and Using Tuples



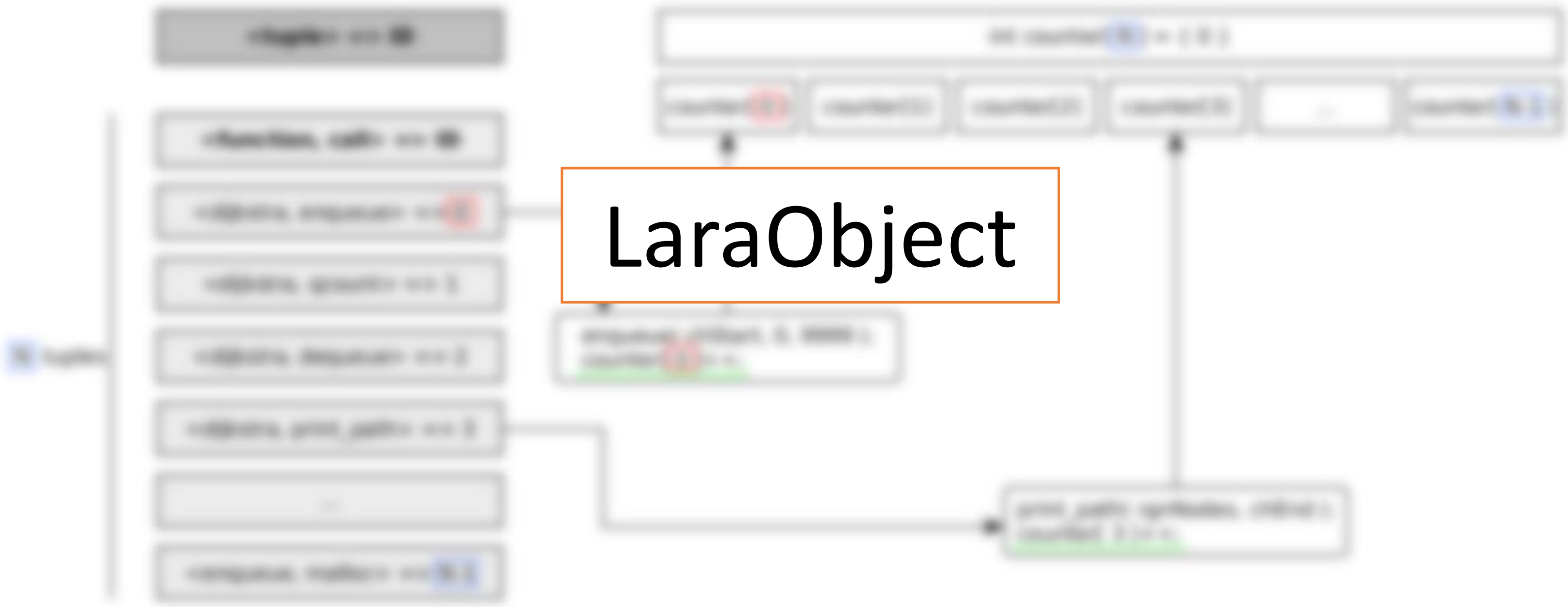
Capturing and Using Tuples



Capturing and Using Tuples



Capturing and Using Tuples



2.2 Branch Coverage – Goal

- Calculate hits counts on *if* statements
  - And corresponding *then* statements
- Possible to calculate branch frequency
- Generate a JSON report

Example output:


```
{
  "ifs": [{
      "file": "getDisparity.c",
      "line": 27,
      "total": 1,
      "positive": 1
  }, {
      "file": "findDisparity.c",
      "line": 19,
      "total": 132710400,
      "positive": 12289820
  }]
}
```

2.2 Branch Coverage – Strategy

- Select *if* statement and *then* block
  - Associate an unique id
- Declare counting arrays
  - counter[id] → *if* statement
  - pos_counter[id] → *then* block
- Inject code to increment counters
  - Before *if* → total
  - Inside *then* → positive branch
- Insert code to print JSON report

```
select file.function.if.then.first_stmt end
apply
 var id = ifIDs.getId($function.name, $if.rank);

 ifInfo.set($function.name,
            $if.rank,
            {'line': $if.line, 'file':$file.name});

 $if.insert before 'counter[[[id]]]++;';
 $first_stmt.insert before 'pos_counter[[[id]]]++;';
end
```

2.2 Branch Coverage – Diff

```c
void grid_iterate_kernel( float potential[32][64][16], int obstacles[32][64][16] )
{
    unsigned int i, j, k, steps;
    int val;
    float acc;
    float c = ( 1.0F / 6.0F );

    for ( steps = 0; steps < ( 3 * ( 64 / 16 ) ); steps ++ ) {
        for ( i = 1; i < ( 32 - 1 ); i += 1 ) {
            for ( j = 1; j < ( 64 - 1 ); j ++ ) {
                for ( k = 1; k < ( 16 - 1 ); k ++ ) {

                    val = obstacles[i][j][k];
                    if ( ( val == 1 ) ) {
                        potential[i][j][k] = 0.0F;
                    } else {
                        if ( ( val == ( - 1 ) ) ) {
                            potential[i][j][k] = 1.0F;
                        } else {
                            acc =   potential[( i - 1 )][j][k] +
                                    potential[( i + 1 )][j][k] +
                                    potential[i][( j - 1 )][k] +
                                    potential[i][( j + 1 )][k] +
                                    potential[i][j][( k - 1 )] +
                                    potential[i][j][( k + 1 )];
                            potential[i][j][k] = ( acc * c );
                        }
                    }
                }
            }
        }
    }
}
```

```c
extern int __if_counter[ 2 ];
extern int __if_pos_counter[ 2 ];

void grid_iterate_kernel( float potential[32][64][16], int obstacles[32][64][16] )
{
    unsigned int i, j, k, steps;
    int val;
    float acc;
    float c = ( 1.0F / 6.0F );

    for ( steps = 0; steps < ( 3 * ( 64 / 16 ) ); steps ++ ) {
        for ( i = 1; i < ( 32 - 1 ); i += 1 ) {
            for ( j = 1; j < ( 64 - 1 ); j ++ ) {
                for ( k = 1; k < ( 16 - 1 ); k ++ ) {

                    val = obstacles[i][j][k];
                    __if_counter[ 0 ]++;
                    if ( ( val == 1 ) ) {
                        __if_pos_counter[ 0 ]++;
                        potential[i][j][k] = 0.0F;
                    } else {
                        __if_counter[ 1 ]++;
                        if ( ( val == ( - 1 ) ) ) {
                            __if_pos_counter[ 1 ]++;
                            potential[i][j][k] = 1.0F;
                        } else {
                            acc =   potential[( i - 1 )][j][k] +
                                    potential[( i + 1 )][j][k] +
                                    potential[i][( j - 1 )][k] +
                                    potential[i][( j + 1 )][k] +
                                    potential[i][j][( k - 1 )] +
                                    potential[i][j][( k + 1 )];
                            potential[i][j][k] = ( acc * c );
                        }
                    }
                }
            }
        }
    }
}
```

Counter Declaration

Counter Increments

Main LARA code:

```
$if.insert before 'counter[[[id]]]++;';
$first_stmt.insert before 'pos_counter[[[id]]]++;';
```

2.2 Branch Coverage – Diff

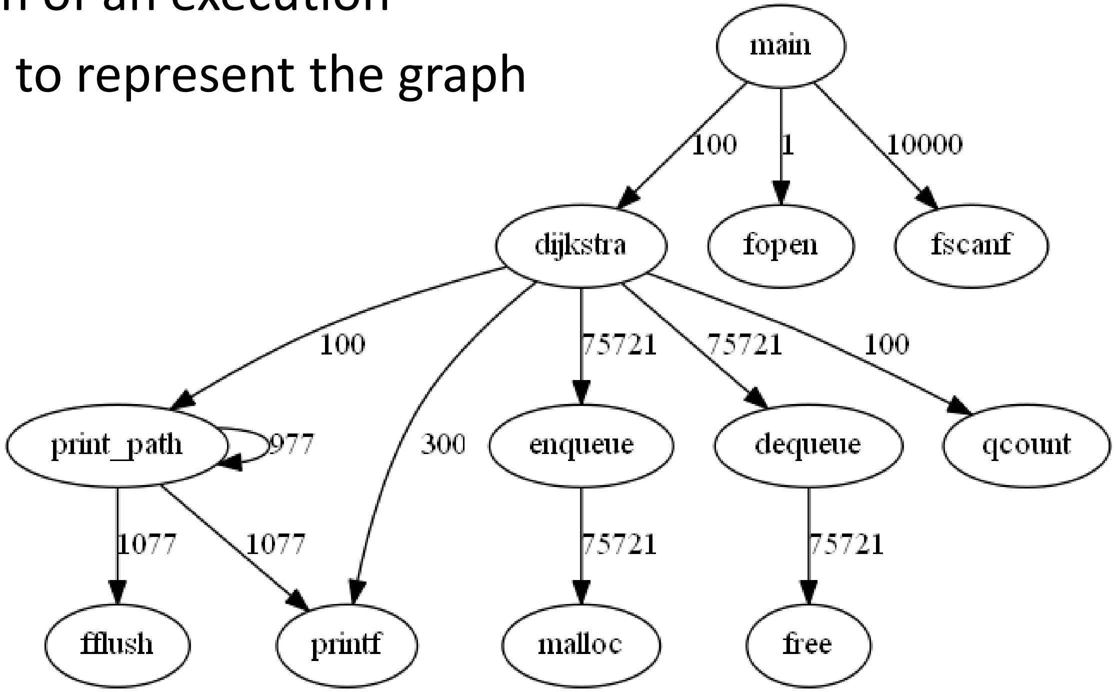
```
for ( steps = 0; steps < ( 3 * ( 64 / 16 ) ); steps ++ ) {
    for ( i = 1; i < ( 32 - 1 ); i += 1 ) {
        for ( j = 1; j < ( 64 - 1 ); j ++ ) {
            for ( k = 1; k < ( 16 - 1 ); k ++ ) {

                val = obstacles[i][j][k];
                __if_counter[ 0 ]++;
                if ( ( val == 1 ) ) {
                    __if_pos_counter[ 0 ]++;
                    potential[i][j][k] = 0.0F;
                } else {
                    __if_counter[ 1 ]++;
                    if ( ( val == ( - 1 ) ) ) {
                        __if_pos_counter[ 1 ]++;
                        potential[i][j][k] = 1.0F;
                    } else {
                        acc =   potential[( i - 1 )][j][k] +
                                potential[( i + 1 )][j][k] +
                                potential[i][( j - 1 )][k] +
                                potential[i][( j + 1 )][k] +
                                potential[i][j][( k - 1 )] +
                                potential[i][j][( k + 1 )];
                        potential[i][j][k] = ( acc * c );
                    }
                }
            }
        }
    }
}
```

Same if
=
Same ID

Same if
=
Same ID

2.3 Dynamic Call Graph (DCG) – Goals

- Capture a call graph of an execution
- Generate dot code to represent the graph



2.3 Dynamic Call Graph (DCG) – Strategy

- Select <function, call> pairs
  - Define id for each pair
  - Use id to insert counter increment before calls

- Insert counting array
  - counter[id] → pair

- Add print code to output dot

```
select function.call end
 apply
  var id = obj.getId($function.name, $call.name);
  insert after 'call_graph[ [[id]] ]++;';
 end
end
```

2.3.1 Complex DCG – Goals

- Extend previous DCG
  - Also capture execution time of call
- Generate a JSON containing timing information
- Use a second aspect to read JSON and print dot code
- This aspect can be customized and extended
  - Other approaches cannot

2.3.1 Complex DCG – Strategy

- Add timing strategy
  - *tic* before call
  - *toc* after call

```
select function.call end
apply
 var id = obj.getId($function.name, $call.name);

 var inc = cgm.inc(id);
 insert before '[[inc]]';

 var tic = cgm.tic(id);
 insert before '[[tic]]';

 var toc = cgm.toc(id);
 insert after '[[toc]]';
end
```

- Insert code to print JSON report

- A second LARA aspect to read report and print dot

2.3.1 Complex DCG – Tic and Toc Functions

```
void tic(int id) {

 gettimeofday( & cgm_tmp_timers[id], NULL);
}
```

```
void toc(int id) {

 struct timeval end;
 unsigned long seconds, useconds;

 gettimeofday( & end, NULL);
 seconds = end.tv_sec - cgm_tmp_timers[id].tv_sec;
 useconds = end.tv_usec - cgm_tmp_timers[id].tv_usec;

 cgm_timers[id] += seconds * 1000000 + useconds;
}
```

2.3.1 Complex DCG – Diff

```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"

void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved,
                      int win_sz, int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
{
    int rows, cols;
    int i, j, endRM;
    I2D * range;

    range = iMallocHandle( 1, 2 );

    range->data[( ( 0 * range->width ) + 0 )] = 0;
    range->data[( ( 0 * range->width ) + 1 )] = disparity;
    rows = Iright_moved->height;
    cols = Iright_moved->width;
    for ( i = 0; i < ( rows * cols ); i ++ ) {
        Iright_moved->data[i] = 0;
    }

    padarray4( Iright, range, ( - 1 ), Iright_moved );

    computeSAD( Ileft, Iright_moved, SAD );

    integralImage2D2D( SAD, integralImg );

    finalSAD( integralImg, win_sz, retSAD );

    return ;
}
```

```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"
#include <sys/time.h>
struct timeval cgm_tmp_timers[21];
unsigned long  cgm_timers[21];
unsigned int cgm_counters[21];
void tic( int id );
void toc( int id );

void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved,
                      int win_sz, int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
{
    int rows, cols;
    int i, j, endRM;
    I2D * range;

    cgm_counters[10]++;
    tic( 10 );
    range = iMallocHandle( 1, 2 );
    toc( 10 );

    range->data[( ( 0 * range->width ) + 0 )] = 0;
    range->data[( ( 0 * range->width ) + 1 )] = disparity;
    rows = Iright_moved->height;
    cols = Iright_moved->width;
    for ( i = 0; i < ( rows * cols ); i ++ ) {
        Iright_moved->data[i] = 0;
    }

    cgm_counters[11]++;
    tic( 11 );
    padarray4( Iright, range, ( - 1 ), Iright_moved );
    toc( 11 );

    cgm_counters[12]++;
    tic( 12 );
    computeSAD( Ileft, Iright_moved, SAD );
    toc( 12 );

    cgm_counters[13]++;
    tic( 13 );
    integralImage2D2D( SAD, integralImg );
    toc( 13 );

    cgm_counters[14]++;
    tic( 14 );
    finalSAD( integralImg, win_sz, retSAD );
    toc( 14 );

    return ;
}
```

Main LARA code:

```
insert before '[[inc]]';

insert before '[[tic]]';
insert after '[[toc]]';
```

2.3.1 Complex DCG – Diff

```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"

void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved,
                      int win_sz, int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
{
    int rows, cols;
    int i, j, endRM;
    I2D * range;

    range = iMallocHandle( 1, 2 );

    range->data[( ( 0 * range->width ) + 0 )] = 0;
    range->data[( ( 0 * range->width ) + 1 )] = disparity;
```

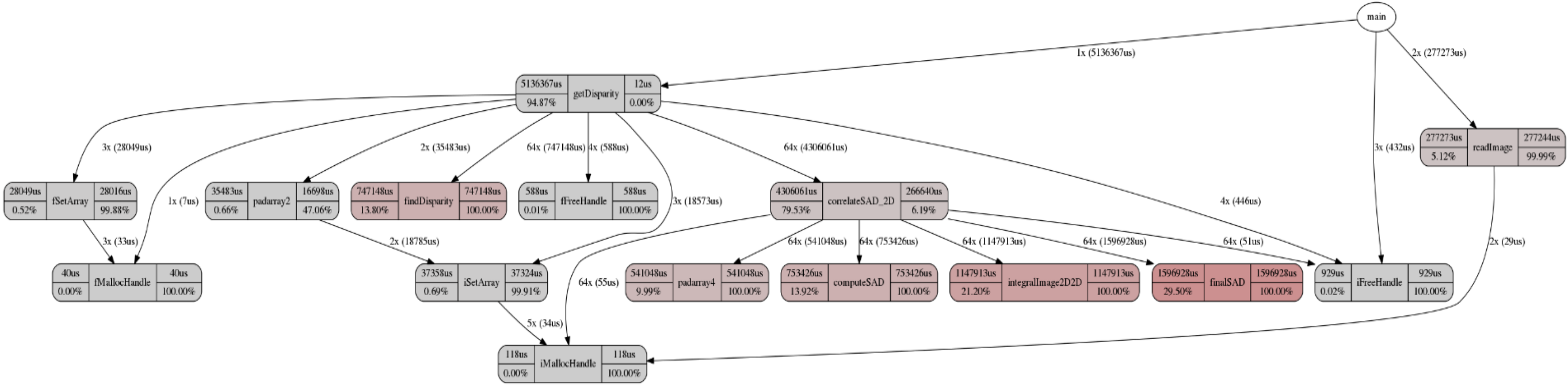
```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"
#include <sys/time.h>
struct timeval cgm_tmp_timers[21];
unsigned long  cgm_timers[21];
unsigned int cgm_counters[21];
void tic( int id );
void toc( int id );

void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved,
                        int win_sz, int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
{
    int rows, cols;
    int i, j, endRM;
```

2.3.1 Complex DCG – Diff

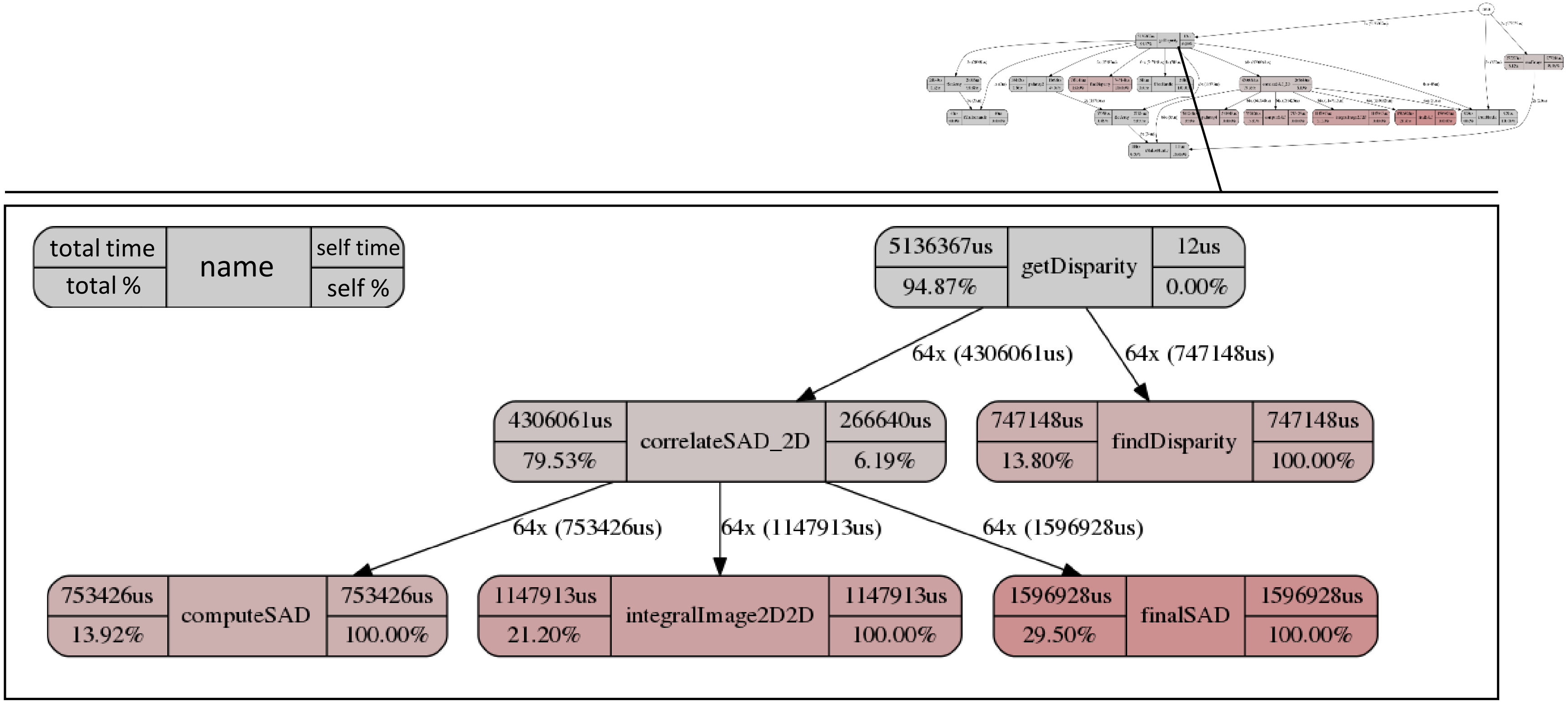
```
I2D * range;

range = iMallocHandle( 1, 2 );

range->data[( ( 0 * range->width ) + 0 )] = 0;
range->data[( ( 0 * range->width ) + 1 )] = disparity;
rows = Iright_moved->height;
cols = Iright_moved->width;
for ( i = 0; i < ( rows * cols ); i ++ ) {
    Iright_moved->data[i] = 0;
}

padarray4( Iright, range, ( - 1 ), Iright_moved );
```

```
void correlateSAD_2D( I2D * Ileft, I2D * Iright, I2D * Iright_moved,
                      int win_sz, int disparity, F2D * SAD, F2D * integralImg, F2D * retSAD )
{
    int rows, cols;
    int i, j, endRM;
    I2D * range;

    cgm_counters[10]++;
    tic( 10 );
    range = iMallocHandle( 1, 2 );
    toc( 10 );

    range->data[( ( 0 * range->width ) + 0 )] = 0;
```

2.3.1 Complex DCG – Example Graph



2.3.1 Complex DCG – Example Graph



2.4 Range Values Monitoring – Goal

- Collect range of variables for a given function
- Report the ranges

Expected output:

```
computeSAD
 rows: {296.000000, 296.000000}
 cols: {360.000000, 360.000000}
 diff: {-190.000000, 221.000000}
 data_temp_0: {0.000000, 48841.000000}
```

2.4 Range Values Monitoring – Strategy

- Deal with possible variables inside structs
  - Using a support transformation

```
aspectdef PrepareStructs
  input funcName end

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

- Insert supporting code
  - Arrays to store values, indexed by ID
  - Initialize, update and printing functions

2.4 Range Values Monitoring – Strategy

- Select variables inside a target function
  - Generate ID using function and variable names
  - Update range after a variable is assigned
  - Filter by write and location

```
select function{funcName}.var end
apply
  var id = vars.getId($function.name, $var.name);
  insert after 'range_update([[id]], [[$var.name]]);';
end
condition
  !$var.in_loop_header &&
   $var.reference == 'write' &&
  !$var.is_struct
end
```

2.4 Range Values Monitoring – Diff

```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"

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;
}
```

```c
#include <stdio.h>
#include <stdlib.h>
#include "disparity.h"

void range_update( unsigned int id, double value );
extern double range_min[ 4 ];
extern double range_max[ 4 ];
void computeSAD(I2D *Ileft, I2D* Iright_moved, F2D* SAD)
{
    int rows, cols, i, j, diff;

    rows = Ileft->height;
    range_update( 0, rows );
    cols = Ileft->width;
    range_update( 1, cols );

    for(i=0; i<rows; i++) {
        for(j=0; j<cols; j++) {
            float data_temp_0;
            diff =  Ileft->data[( ( i * Ileft->width ) + j )] -
                    Iright_moved->data[( ( i * Iright_moved->width ) + j )];
            range_update( 2, diff );

            data_temp_0 = ( diff * diff );
            range_update( 3, data_temp_0 );

            SAD->data[( ( i * SAD->width ) + j )] = data_temp_0;
        }
    }

    return;
```

Main LARA code:

```
insert after 'range_update([[id]], [[$var.name]]);';
!$var.in_loop_header && $var.reference == 'write' && !$var.is_struct
```

Takeaway Points

- Different dynamic analysis, all based on instrumentation

- *insert* action
  - A simple but powerful/versatile transformation
  - Instrumentation mechanism for monitoring, profiling, debugging,...

- LARA enables easy selection of interesting code points
  - Join point attributes to filter results