EasyPAP: a Framework for Learning Parallel Programming

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Background of students @Univ. of Bordeaux

- “Licence” of Computer Science (3 years) ≈ Bachelor’s degree
  - C Programming
  - Computer Architecture
  - System Programming
  - …
- “Master” of Computer Science (2 years) ≈ Master’s degree
  - Operating Systems
  - Parallel Programming
  - Advanced Parallel Programming
  - …

Background of students @Univ. of Bordeaux

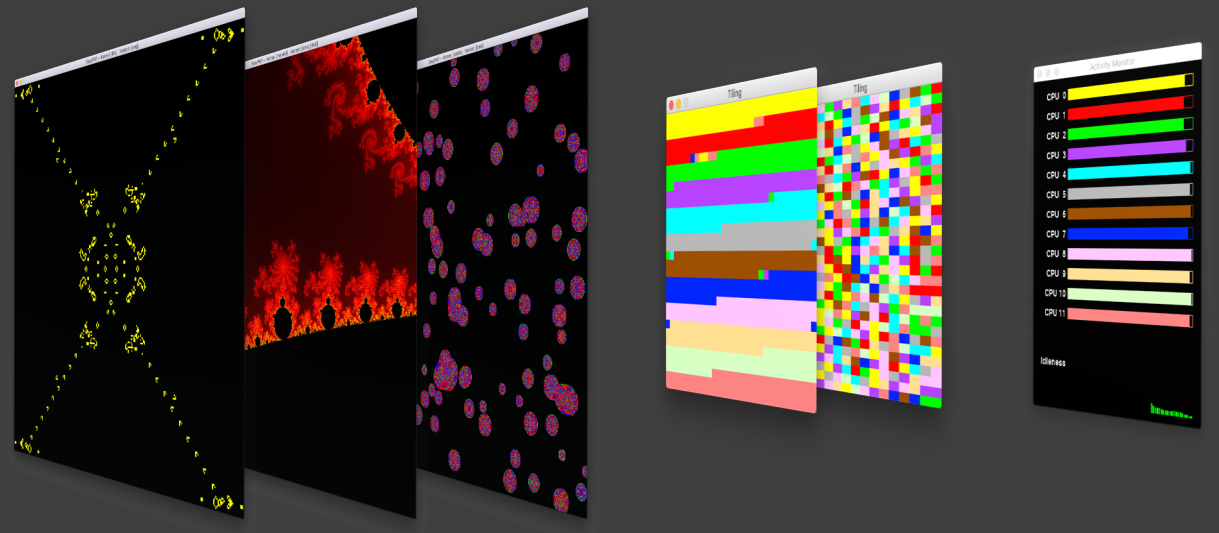
- “Licence” of Computer Science (3 years) ≈ Bachelor’s degree
  - C Programming
  - Computer Architecture
  - System Programming → Introduction to threads
  - …
- “Master” of Computer Science (2 years) ≈ Master’s degree
  - Operating Systems
  - Parallel Programming → Vector instructions, OpenMP, OpenCL, MPI
  - Advanced Parallel Programming → MPI + X, OpenACC
  - …

A case for a comprehensive framework

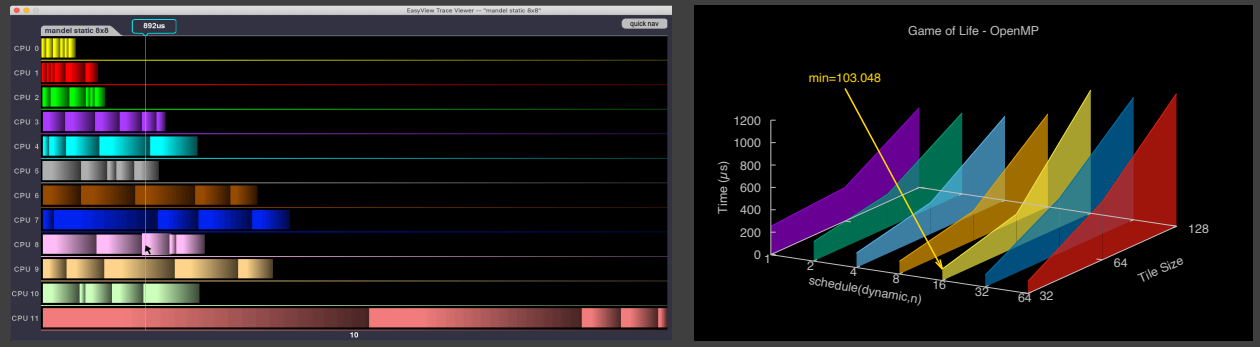
- Parallel programming is not trivial
  - Debugging and understanding (bad) performance is challenging
- Like many teachers, we progressively added visualization facilities to our lab applications
  - Increased student's motivation
  - Greatly helped to improve correctness
- EasyPAP goes further
  - Minimize time spent to become familiar with new problems
  - Enable quick OpenMP/MPI/OpenCL prototyping
  - Provide simple tools to analyze parallel behavior

EasyPAP: focus on parallelism!

- C library + utilities
  - Support for Pthreads, OpenMP, MPI, OpenCL
- Online rendering of 2D computations
  - Work distribution monitoring
- Trace visualization
  - Side-by-side comparison
- Plotting facilities
  - Thorough experiments & analysis



Online visualization and thread monitoring



Offline trace visualization and plotting facilities

Kernels and variants

- Students are provided with sequential implementations of various *kernels*
  - Mandelbrot Set, Game of Life, Abelian Sandpiles, Picture Blur
  - ✓ Just add a C file to create a new kernel, then compile & run
- They can design and experiment with as many *variants* as they can think of
  - Kernels and variants are selected on command line
  - ✓ Just add a function to create a new variant, then compile & run

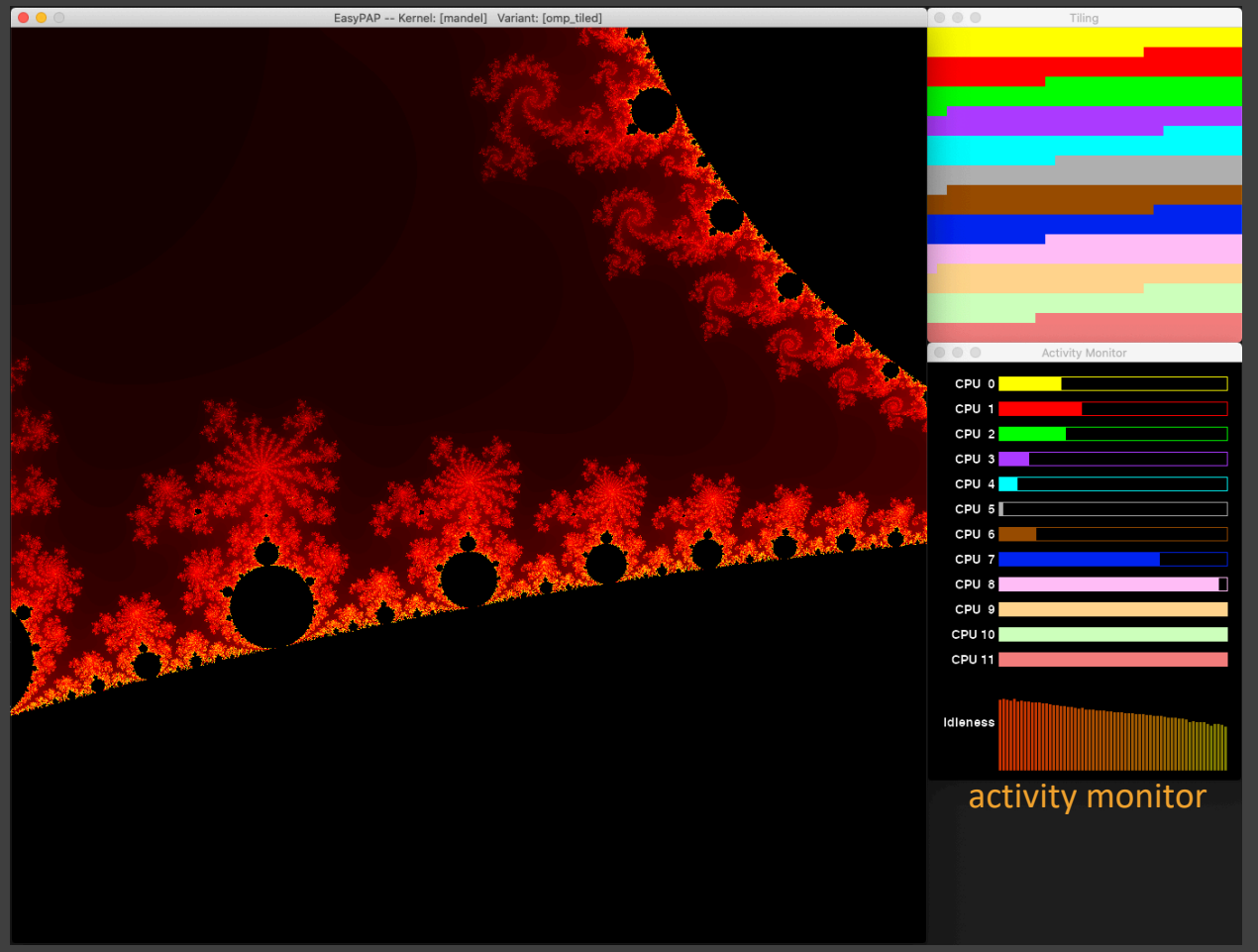
```
///////////////////////////// Simple sequential version (seq)
// Suggested cmdline:
// easypap --kernel mandelset --variant seq
//
unsigned mandelset_compute_seq (unsigned nb_iter)
{
  for (unsigned it = 1; it <= nb_iter; it++) {
    for (int y = 0; y < DIM; y++)
      for (int x = 0; x < DIM; x++)
        cur_img (y, x) = compute_one_pixel (y, x);

    zoom ();
  }
  return 0;
}

unsigned mandelset_compute_omp (unsigned nb_iter) { }

unsigned mandelset_compute_omp_tiled (unsigned nb_iter) { }

unsigned mandelset_compute_mpi (unsigned nb_iter) { }
```

Code instrumentation and monitoring

```
// Tile inner computation
static inline void do_tile (int x, int y, int width, int height, int thread)
{
  monitoring_start_tile (thread);
  for (int i = y; i < y + height; i++)
    for (int j = x; j < x + width; j++)
      cur_img (i, j) = compute_one_pixel (i, j);
  monitoring_end_tile (x, y, width, height, thread);
}
///////////////// Tiled OpenMP version (omp_tiled)
// Suggested cmdline: easypap -k mandelset -v omp_tiled -ts 32 -m
unsigned mandelset_compute_omp_tiled (unsigned nb_iter)
{
  for (unsigned it = 1; it <= nb_iter; it++) {
#pragma omp parallel for collapse(2) schedule(runtime)
    for (int y = 0; y < DIM; y += TILE_SIZE)
      for (int x = 0; x < DIM; x += TILE_SIZE)
        do_tile (x, y, TILE_SIZE, TILE_SIZE, omp_get_thread_num ());
    zoom ();
  }
return 0;
}
```

main window

tiling window

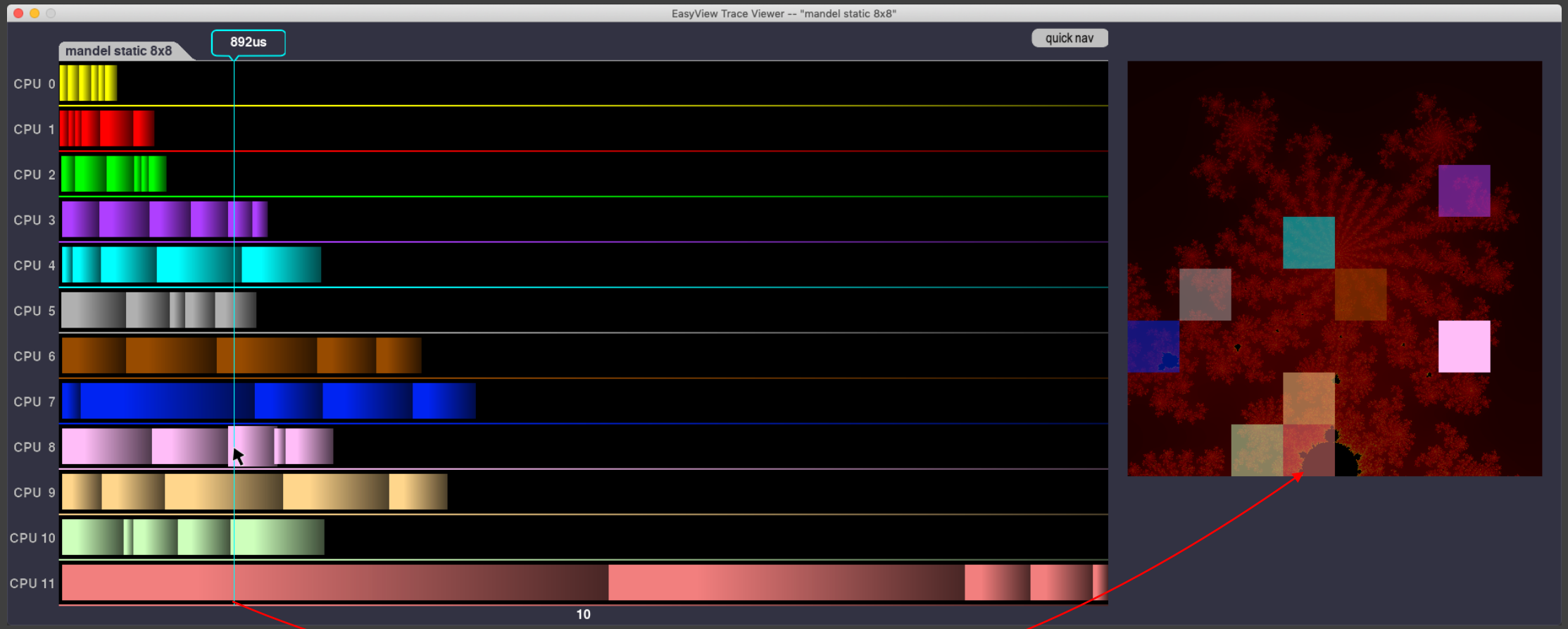


activity monitor

Off-line Trace Visualization

Task scheduling chart

Task-data mapping



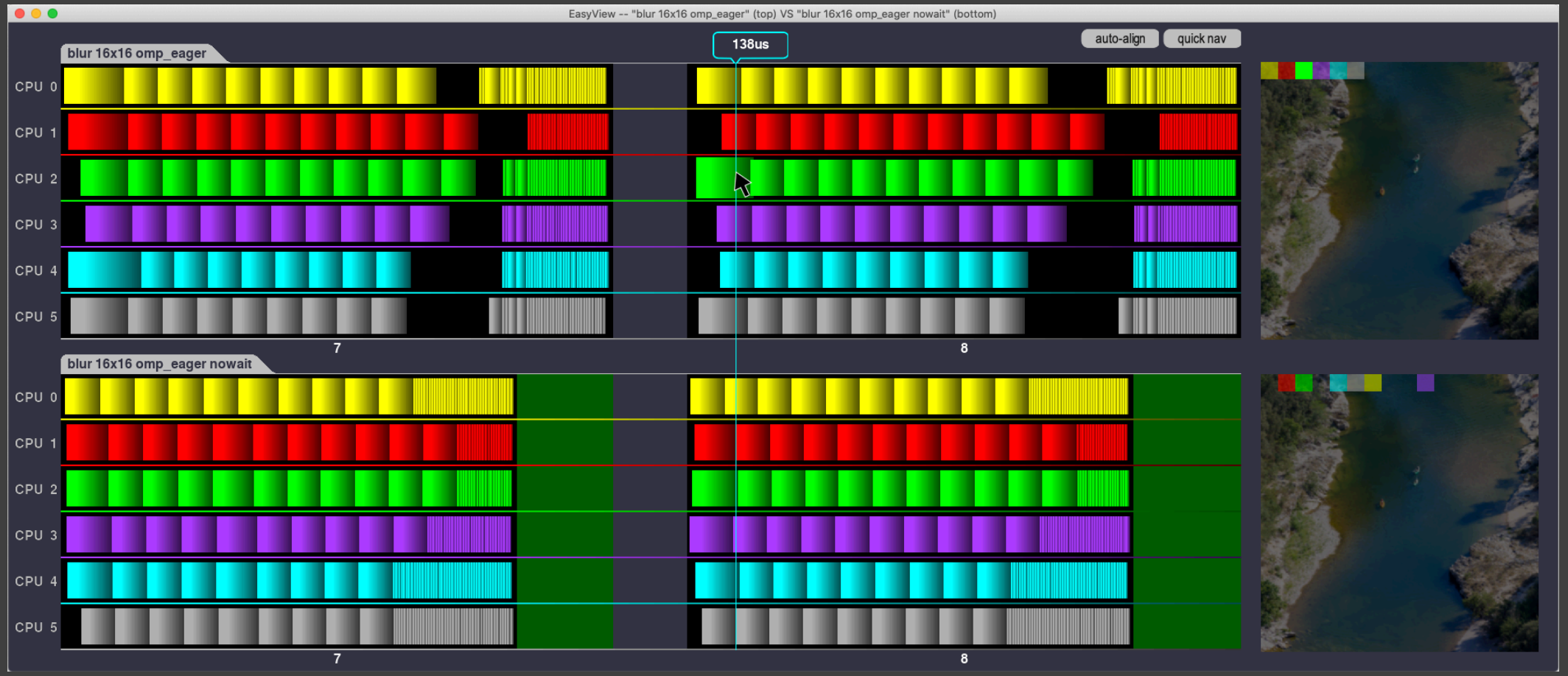
Trace comparison

Example: What happens if we forget to remove the forthcoming implicit barrier?

```
///////////////////////////// 2-steps Tiled optimized OpenMP version (omp_eager)
// Suggested cmdline:
// easypap -l images/1024.png -k blur -v omp_eager -g 32 -m
//
unsigned blur_compute_omp_eager (unsigned nb_iter)
{
  for (unsigned it = 1; it <= nb_iter; it++) {

#pragma omp parallel
    {
#pragma omp for collapse(2) schedule(runtime) nowait
      for (int i = 0; i < NB_TILES; i++)
        for (int j = 0; j < NB_TILES; j++)
          if (i == 0 || j == 0 || i == NB_TILES - 1 || j == NB_TILES - 1)
            do_border_tile (j * TILE_SIZE, i * TILE_SIZE, TILE_SIZE, TILE_SIZE,
                            omp_get_thread_num ());

#pragma omp for collapse(2) schedule(runtime)
      for (int i = 1; i < NB_TILES - 1; i++)
        for (int j = 1; j < NB_TILES - 1; j++)
          do_inner_tile (j * TILE_SIZE, i * TILE_SIZE, TILE_SIZE, TILE_SIZE,
                         omp_get_thread_num ());
    }
    swap_images ();
  }

  return 0;
}
```

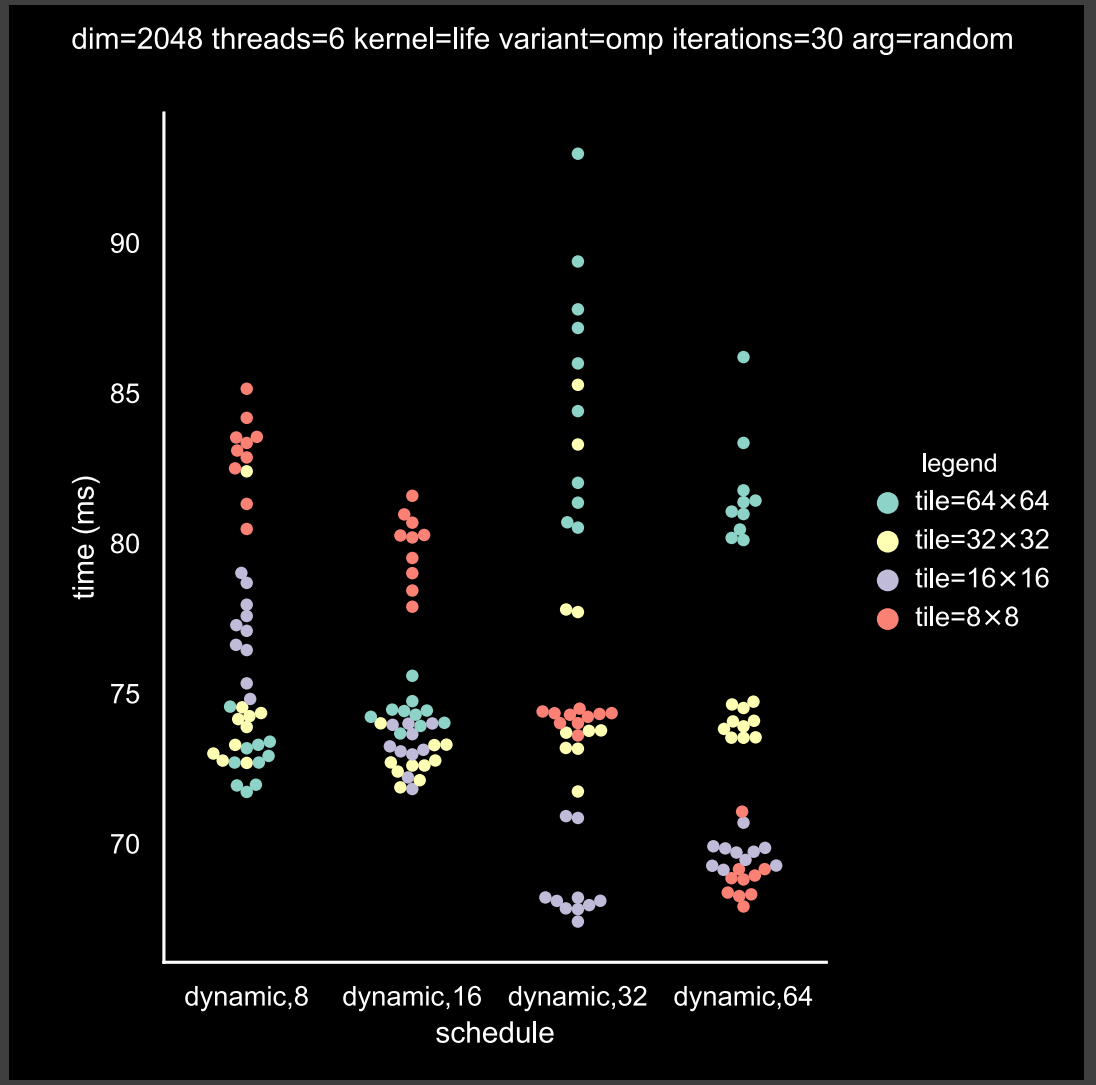
Trace comparison

"diff" mode: iterations are re-aligned



Plotting facilities

- Experiments can easily be automated using scripts
  - No need to recompile
  - Each run records all experimental details in a CSV file
- Plotting (python) scripts
  - Ease graph selection
  - Make sure results are sound
    - Speedups automatically computed
    - Parameter consistency check



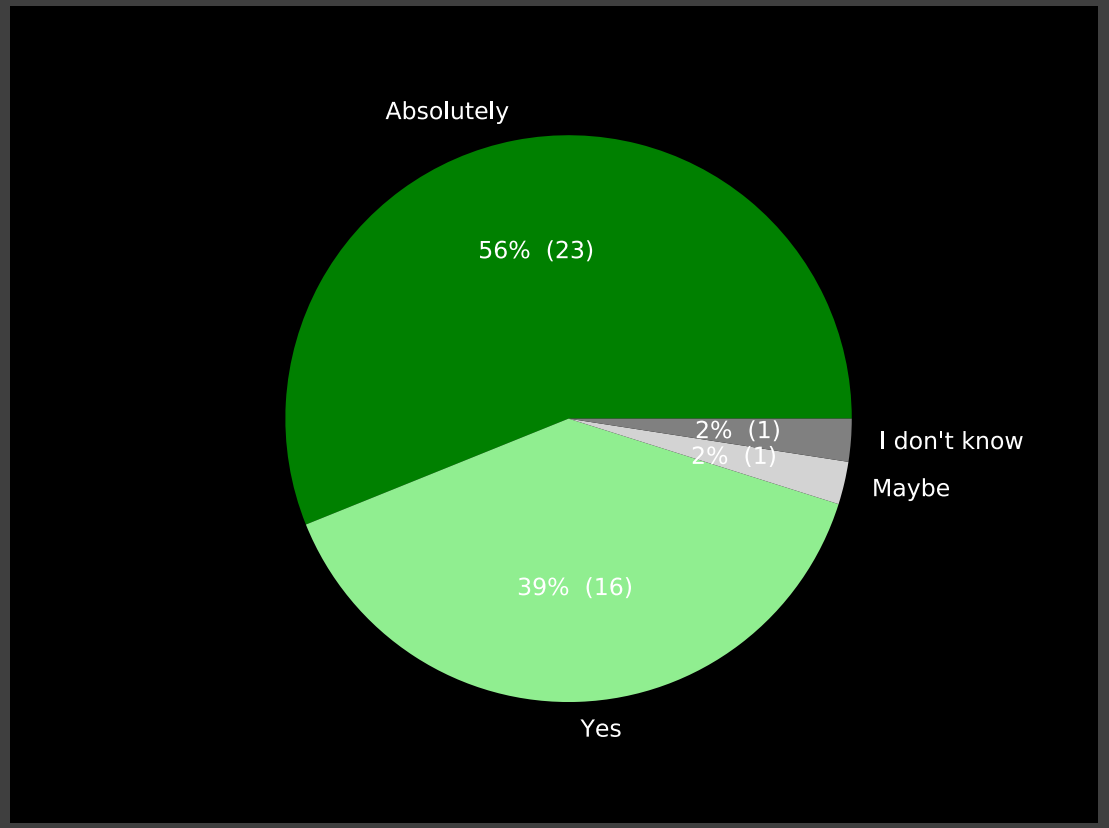
What are the main benefits?

- Focus on parallelism
  - Implement many variants
  - Experiment with multiple parameters
  - Adopt a scientific methodology
- Quicker and deeper understanding of
  - Scheduling
    - Load balancing, data affinity
  - Cache
    - Tiling, false sharing
  - Synchronization
    - Race conditions, barriers, task dependencies
  - Hardware specific optimizations
    - Code specialization, vectorization

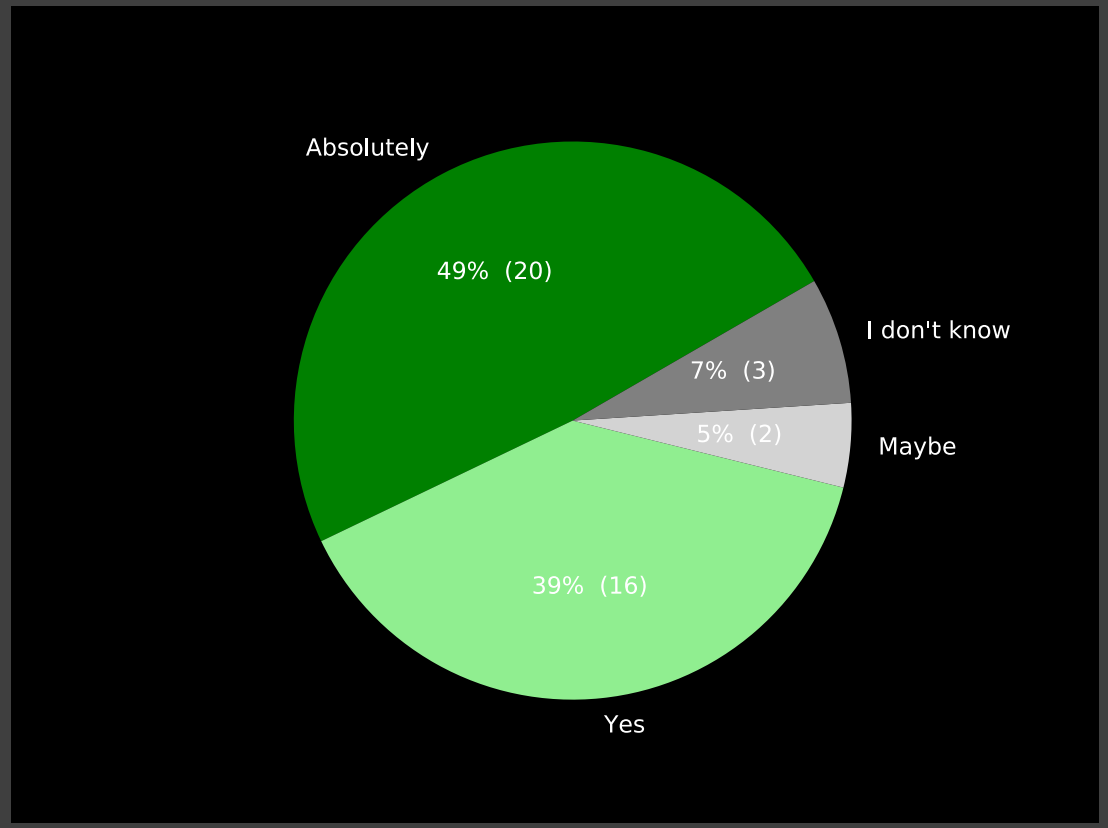
CPU coverage map across multiple iterations revealing task-data affinity

What do students think?

Does EasyPAP facilitate learning of parallel concepts?



Does EasyPAP increase your motivation?



EasyPAP documentation and download:

http://gforgeron.gitlab.io/easypap/