Introducing Parallel Computing in Undergraduate Curriculum

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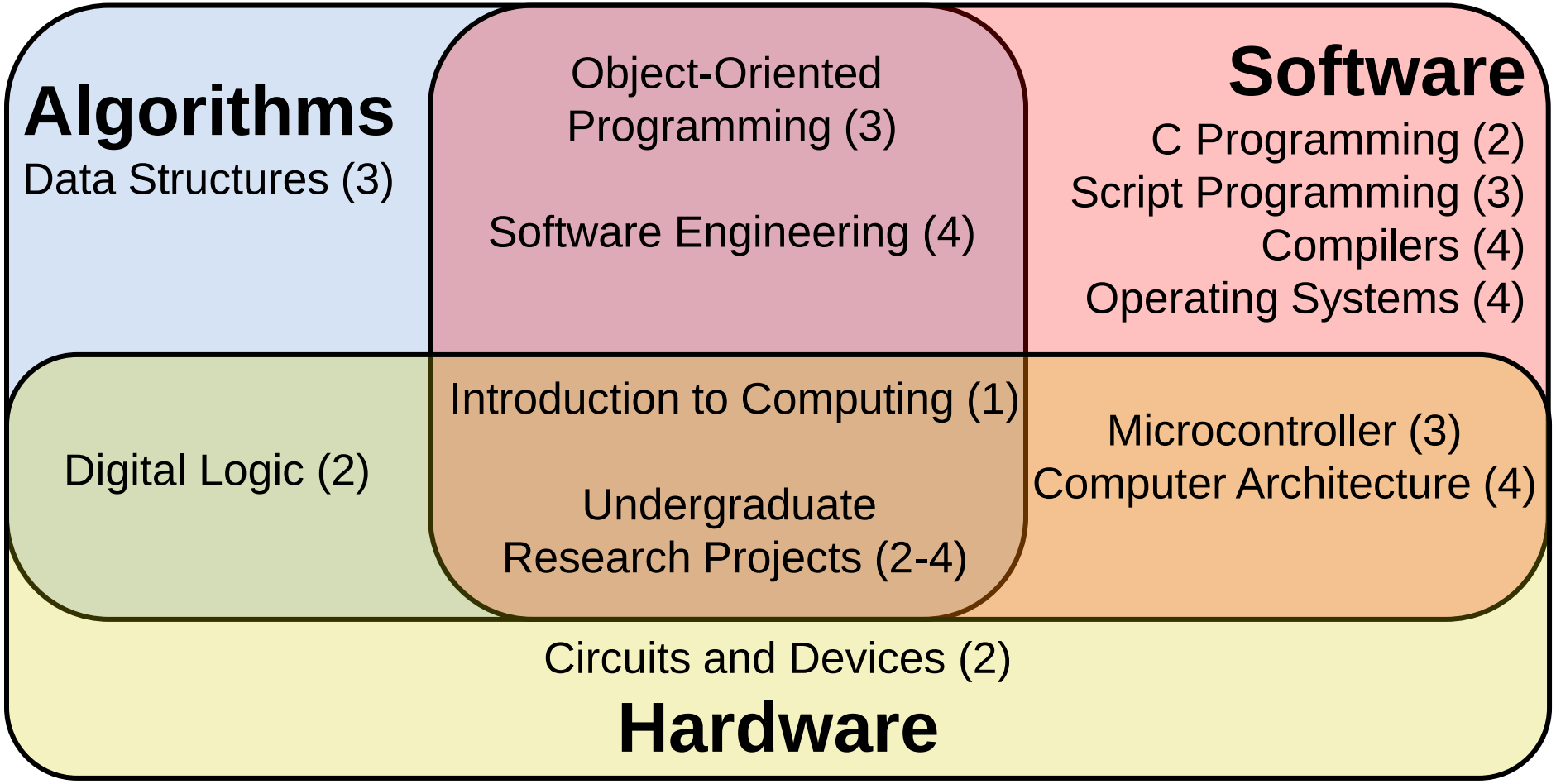
Curriculum Update

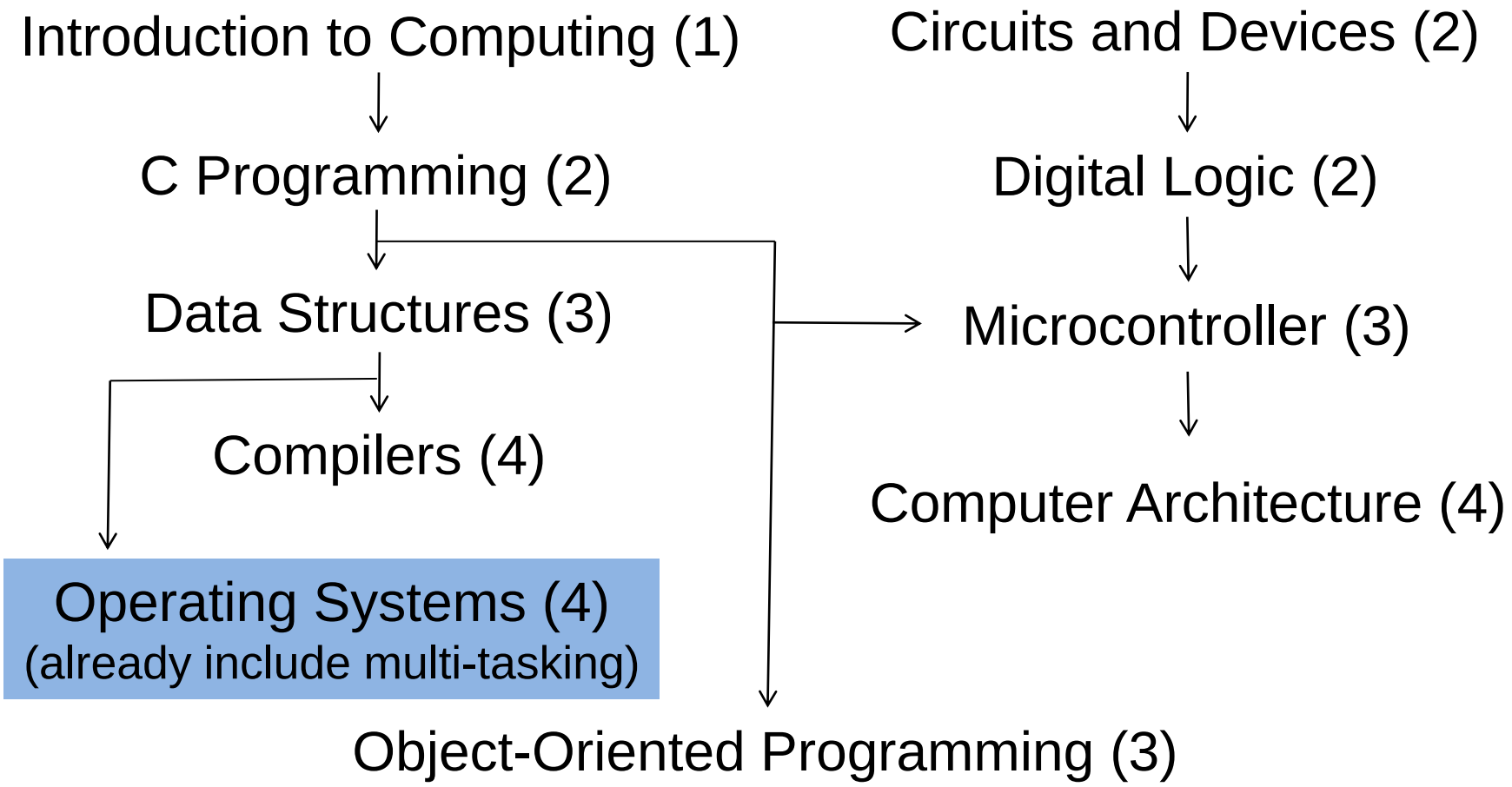
- Goal: Include parallel computing in ***many*** undergraduate courses, not a special new one
- Reason: Students learn different aspects of parallel computing throughout the four years.
- Steps:
  - Identify which courses to change
  - Determine the orders of the changes
  - Eliminate duplicates and unnecessary contents
  - Change the course requirements (ABET)
  - Implement and integrate changes

Identify the Courses to Change



* The numbers mean the years when students take the courses.
Most courses are offered twice a year.

Determine the Order of Changes



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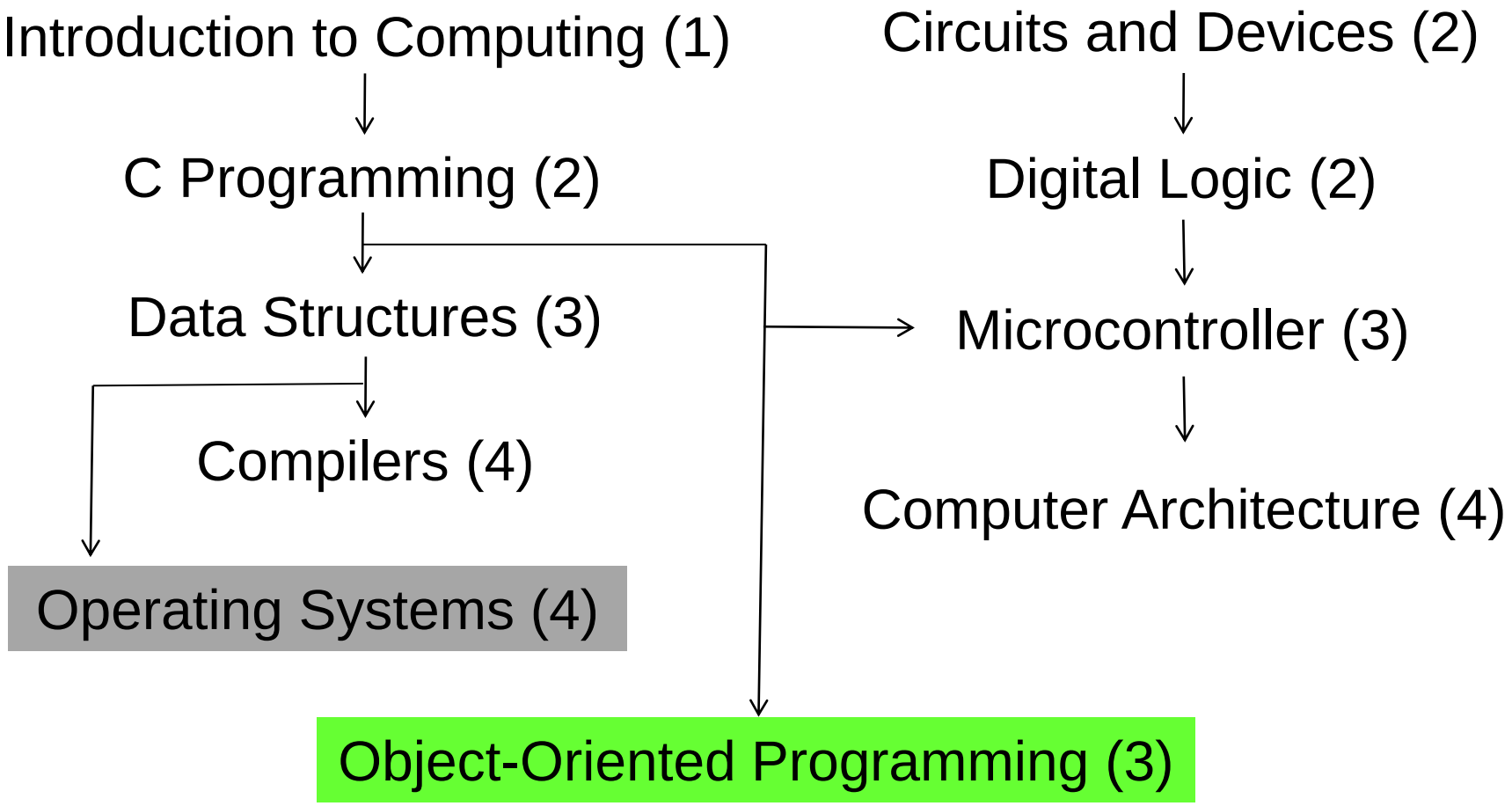
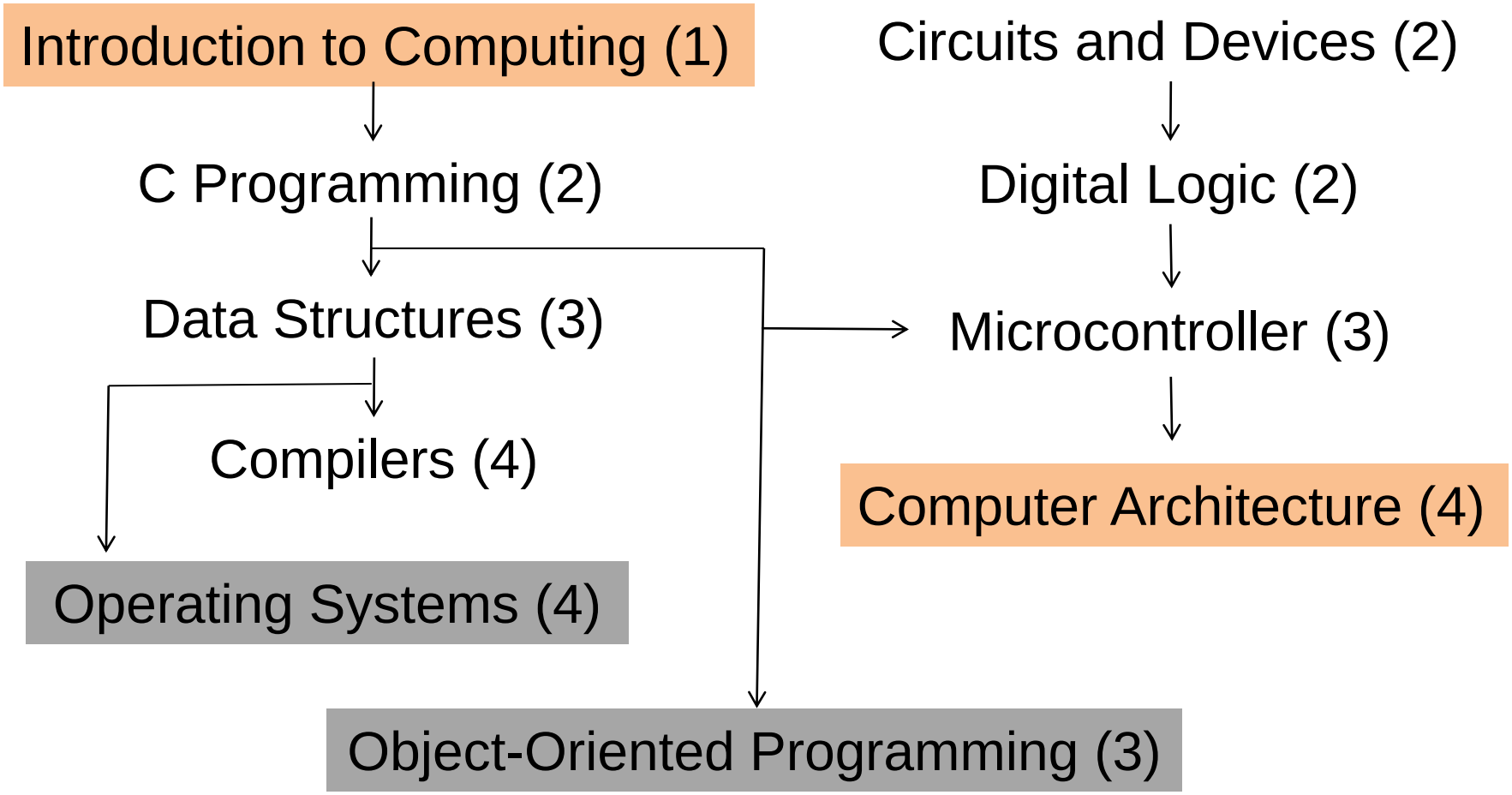
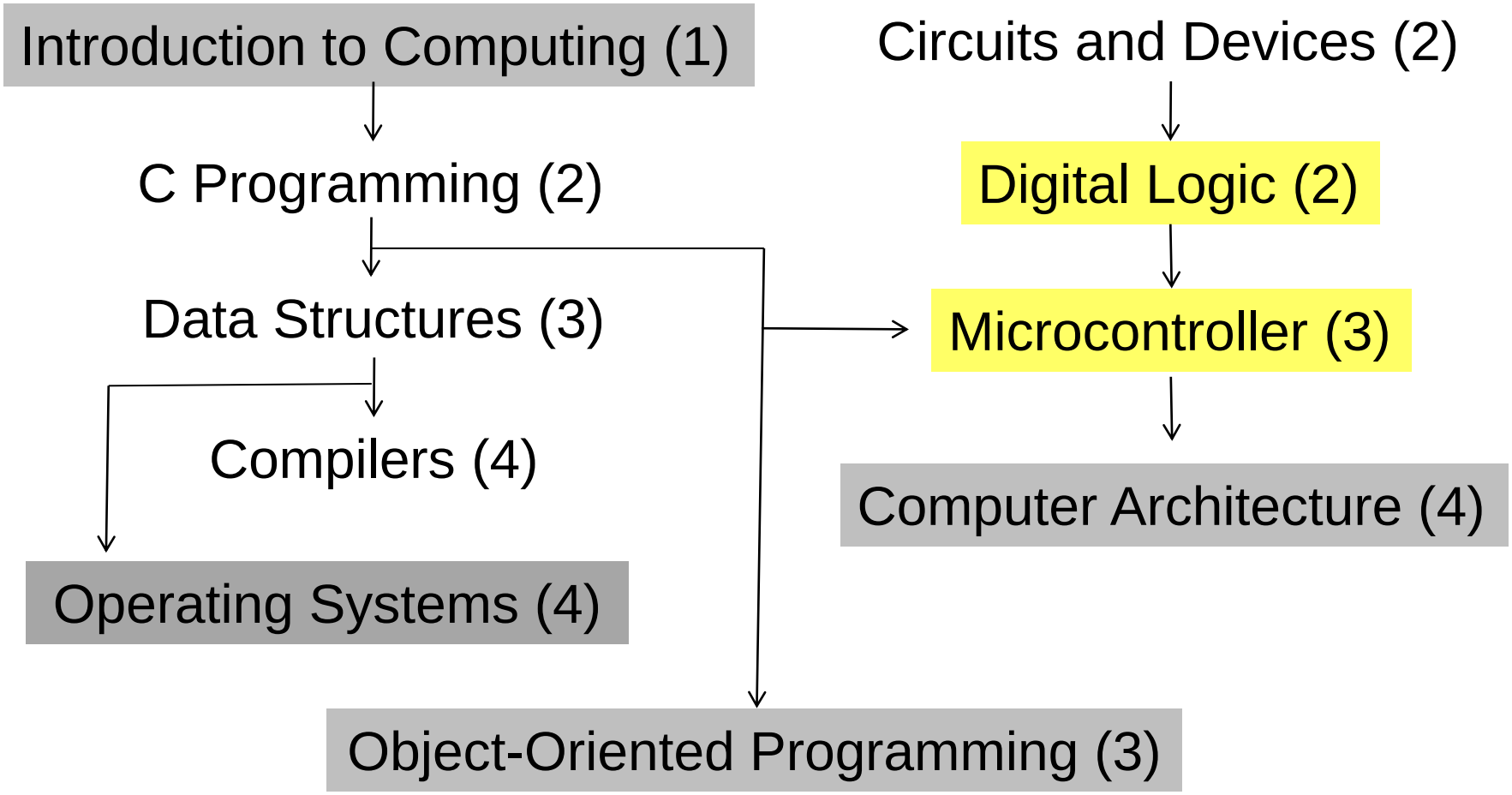
First Change: Elective Course



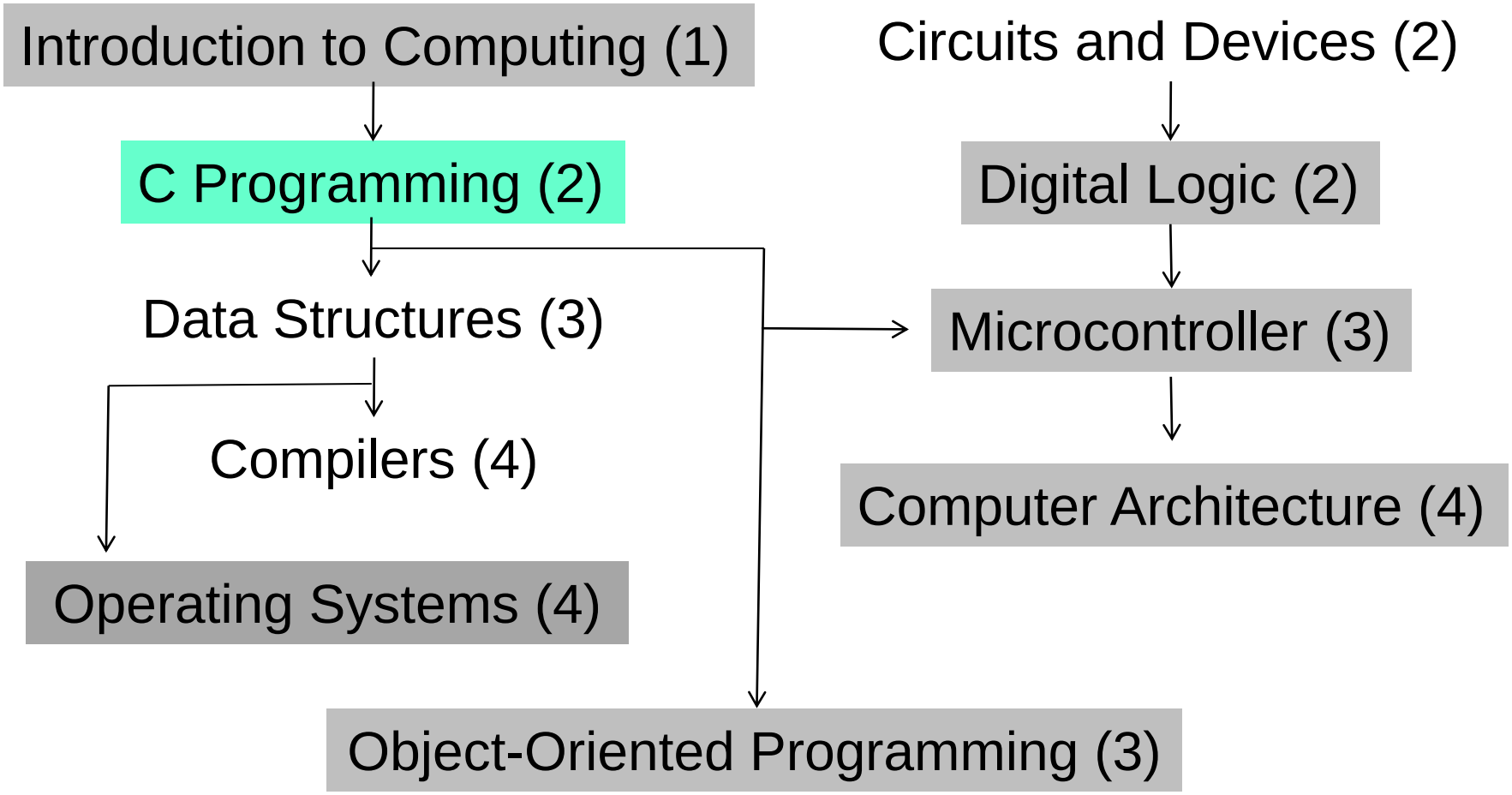
Second Changes from the Ends



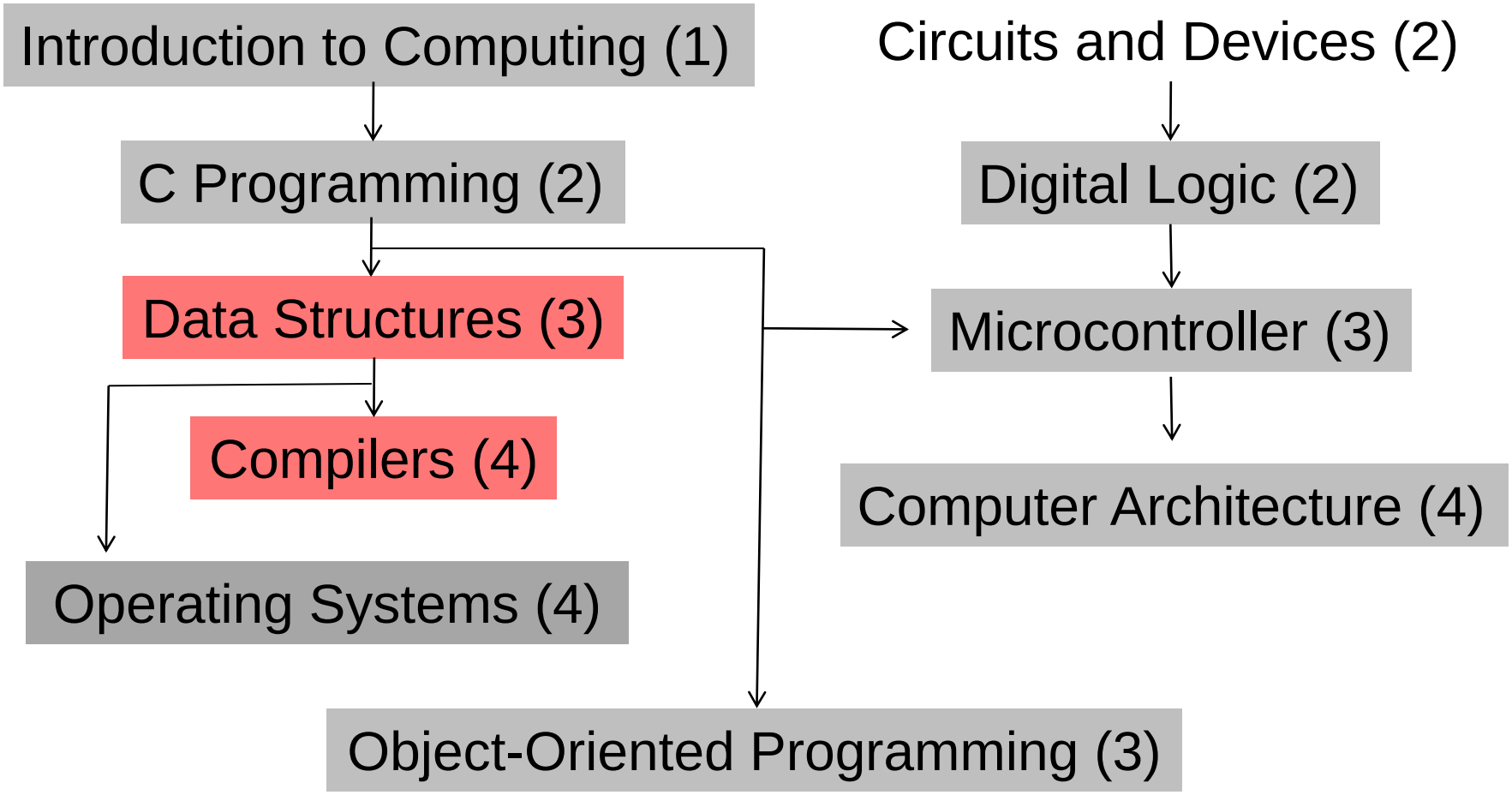
Changes in Intermediate Levels



Latest Change



Not Changed (Yet)



First Change (OOP)

- It is elective and not a prerequisite of any required course.
- Java has built-in support for threads with synchronized methods. C++ can use library (Qt) for threads. GUI uses threads.
- The original course content include duplicate materials that can be eliminated: how to use and ~~how to implement~~ container classes

  $\Rightarrow$ already taught in data structures.

Connect Parallelism with Life

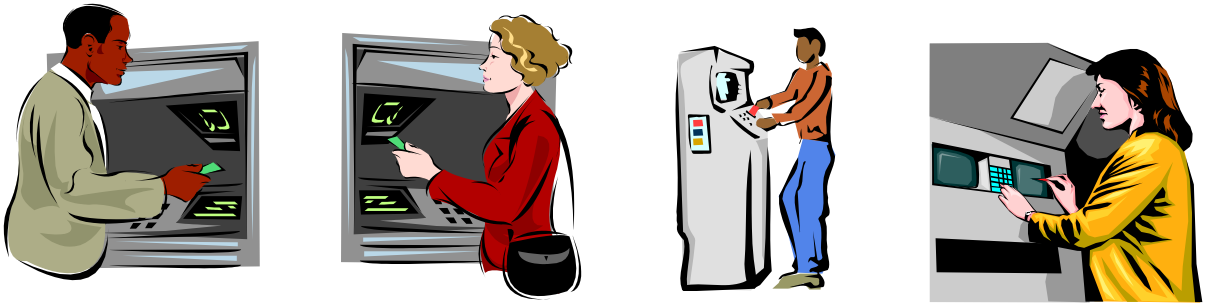
- Use laundry room as examples.
- Many washers + dryers ⇒ hardware resources.
- Many loads of clothes ⇒ data-level parallelism.
- Washing before drying ⇒ dependence and pipeline.

Pipeline in Everyday Life

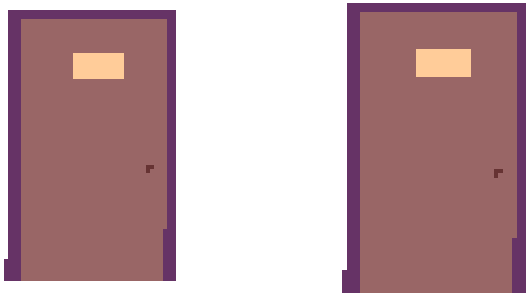
- factory assembly line
- buffet line

Synchronization

- ATM withdrawal to motivate the need of synchronization.



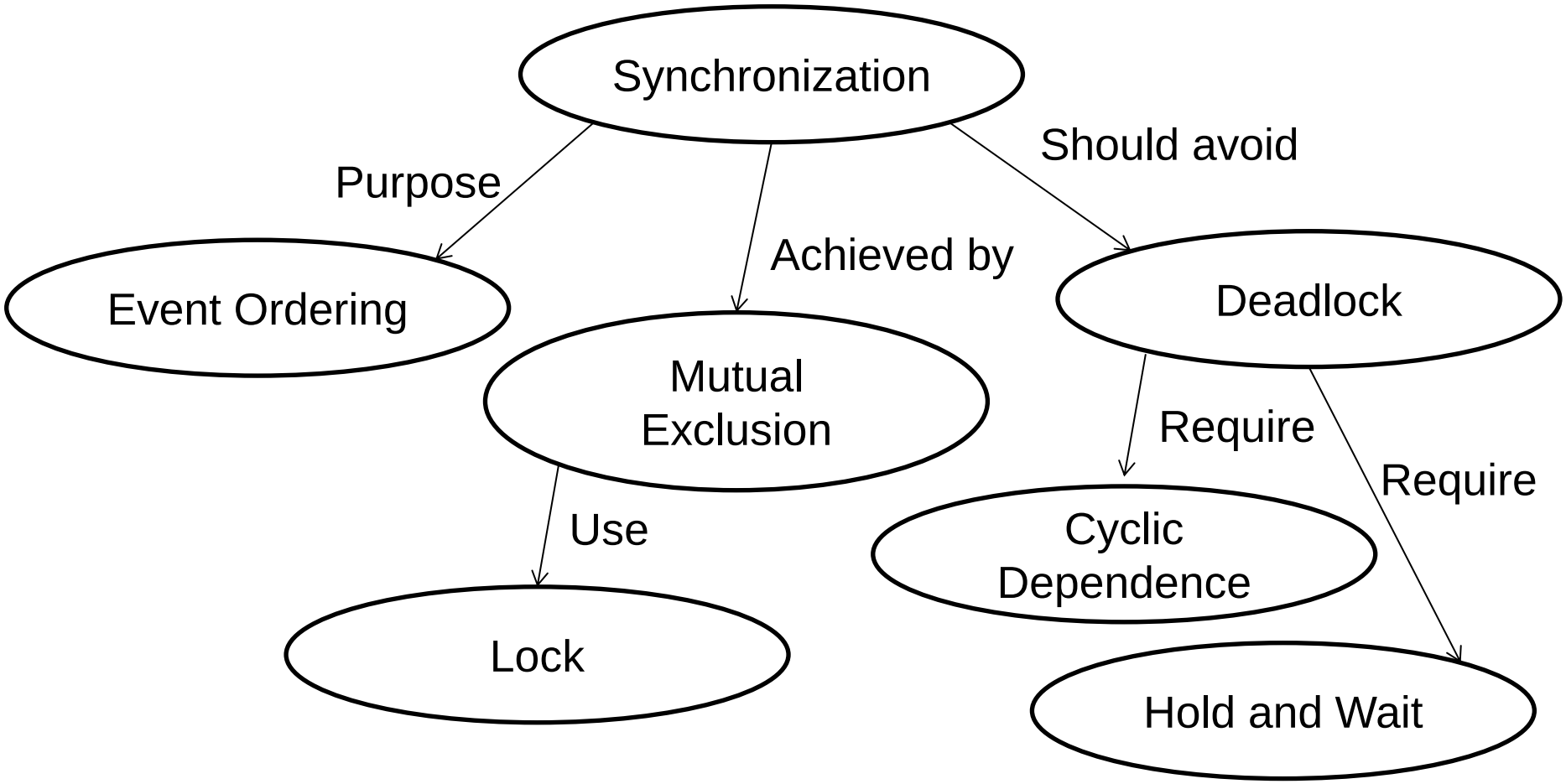
- Library study room with a lock and only one key to explain mutual exclusion.



Concept Inventory

- Purpose: develop a set of questions to evaluate students' understanding of parallel computing ***across their four years of studies.***
- It is a guideline for updating courses and designing assessments for multiple courses.
- Requirements: The questions must be understandable ***without*** using terminology introduced later (e.g. synchronization, mutual exclusion, lock, locality, cache miss ...)
- Approach: use everyday examples to motivate and to describe the problems

Concept Inventory (Excerpt)



The complete concept inventory is in the paper.

Sample Assignments

- Programming assignments
  - Matrix multiplication
  - Image pixel-wise color inversion
  - Network echo server
- Non-programming assignments
  - Amdahl's Law
  - Distinguish SISD/SIMD/MISD/MIMD
  - Conditions and sample code for deadlocks

Most Recent Changes

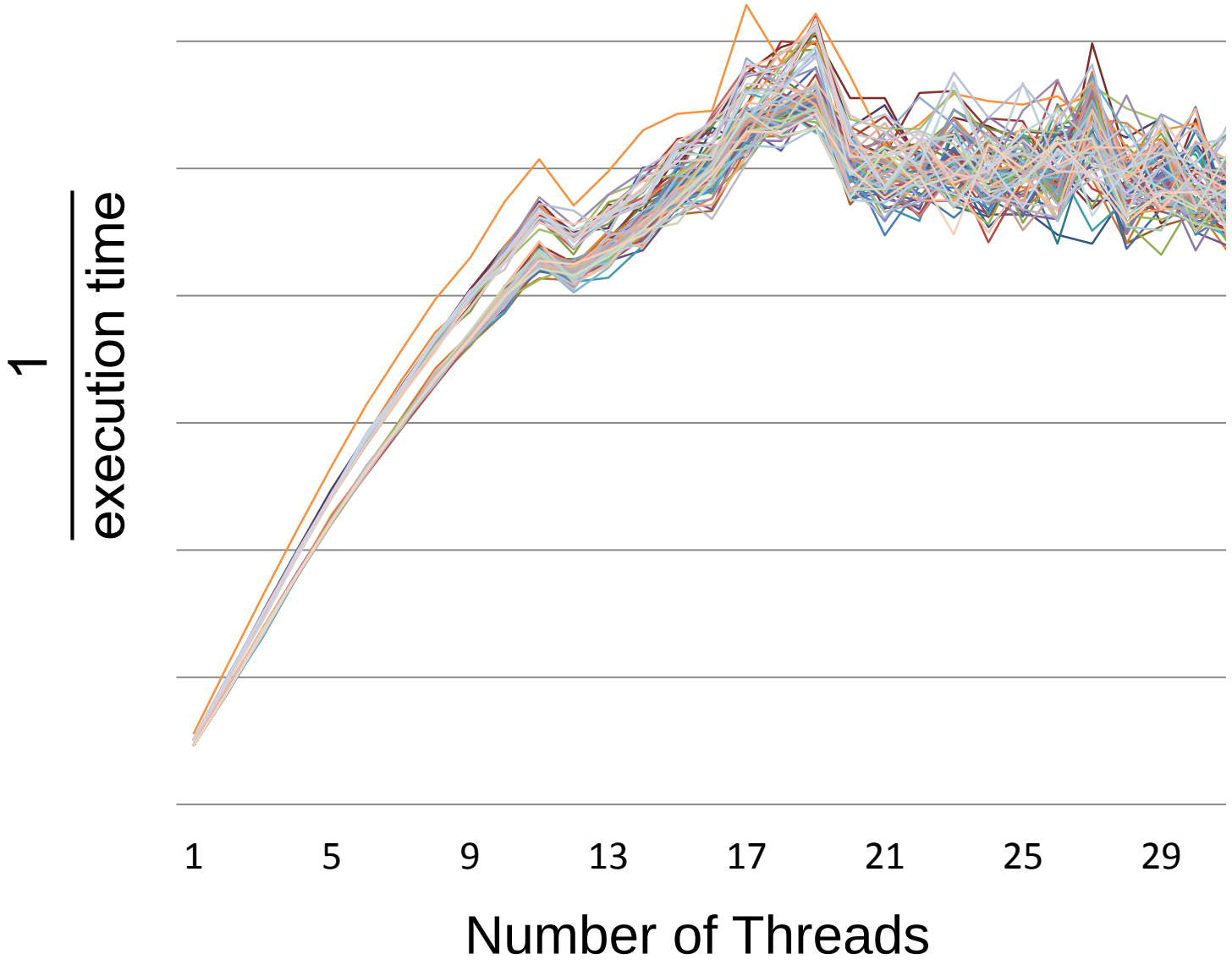
- Second programming class (C)
- 2012 IEEE/TCPP Early Adopter Grant
- two $\Rightarrow$ three credit units since Fall 2012
- For most students, this is the first experience of writing programs with threads
- Programming assignments:
  - Image pixel-wise color inversion
  - Subset sums (count the number of solutions)
- Non-programming assignments: Amdahl's Law and distinguish SISD/SIMD/MISD/MIMD

Evaluation (SIMD, pthreads)

Image color inversion

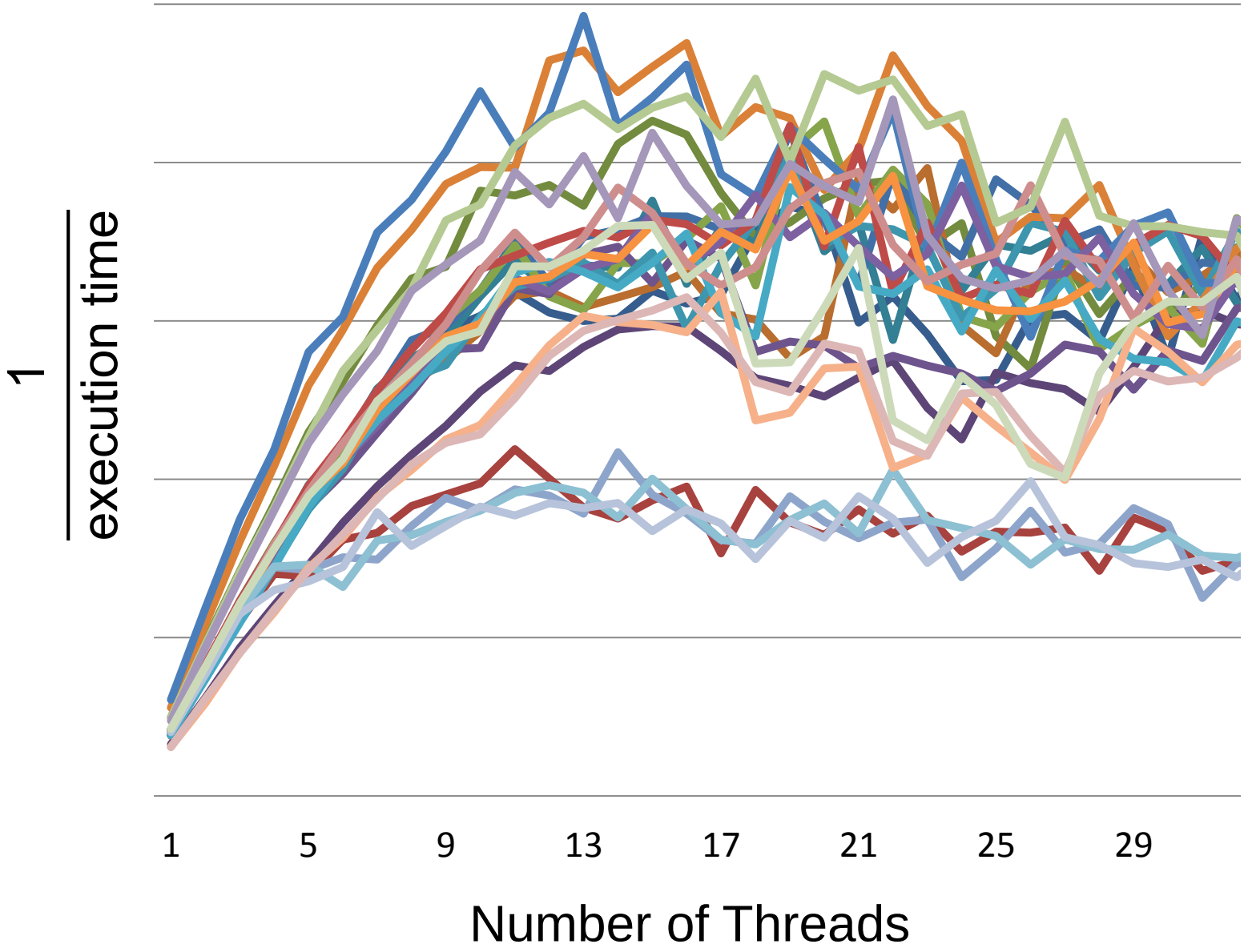
```
for (p = 0; p < numPixels; p ++)
{
    for (c = 0; c < 3; c ++) // RGB 3 colors
        {
            pixels[p].color[c] = 255 -
                    pixels[p].color[c];
        }
}
// parallelization: divide numPixels into
// non-overlapping regions for the threads
```

The time for color inversion
The time for reading and writing files is excluded



Evaluation (SIMD, pthreads)

- Subset sum
- Given a positive integer n and a set of positive integers $S = \{s_1, s_2, ..., s_k\}$
- Find all subsets $A = \{a_1, a_2, ..., a_m\}$ ($A \subseteq S$, $m \leq k$) such that $a_1 + a_2 + ... + a_m = n$
- Count the number of subsets
- Parallelization:
  - Divide the 2^n-1 subsets into regions
  - Each thread checks all subsets in that region
  - If a solution is found, a shared variable numberSolution increments


1
execution time
1
5
9
13
17
21
25
29
Number of Threads

Observations

- Most students understand the concepts and can write correct parallel programs using pthreads.
- Some are not aware of the performance impacts of redundant statements in inner loops.
- Some students know the need of mutual exclusion but each thread has a unique lock.
- Some students put private data (not shared) inside the critical sections.
- Some use expensive operations (for example multiplication or division instead of shifts).

Lessons Learned

- Students are excited learning new concepts related to parallel computing.
- Curriculum update can take several years.
- The changes should be introduced gradually, with the consideration of dependence among courses. The changes should start from a course which has topics that can be eliminated.
- Students should know efficient algorithms are more important than parallelization only.

Lessons Learned

- Assignments should be designed to reduce dependence. For example, many students do not know locality yet $\Rightarrow$ The speedup of matrix multiplication is limited by cache performance
- Some assignments should have high computation and low communication or IO (e.g. subset sum).
- Performance competition can encourage students to pay attention to details.

Conclusion

- We present our experience updating the curriculum including parallel computing in multiple courses throughout the four years.
- We explain the sequence of changes and the rationales of the sequences.
- We describe the concept inventory for cross-cohort evaluations.
- The early-adopter changes provide promising results; most students understand the concepts and can write simple parallel programs.