Parallel Computing
- Course Information -

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January - April, 2023

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Why Parallel Computing? Why Should We Study It?

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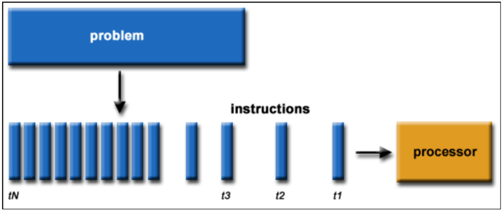
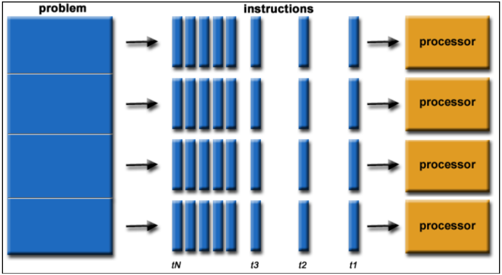


Serial Computing
Instructions are executed sequentially one after another by single processor.

Parallel Computing
Instructions execute simultaneously on different processors (an overall control/coordination mechanism is employed).



Why Parallel Computing? Why Should We Study It?

- Computational power is increasing, but so are our problems:
  - Complex problems are still waiting to be solved
  - We need answers/solutions in reasonable time
  - We need to process large volumes of data in an efficient manner
- Parallelism is a natural way of improving performance
- Adding more processors doesn't help much if programmers aren't aware of them (or don't know how to use them)!

What About This Course?

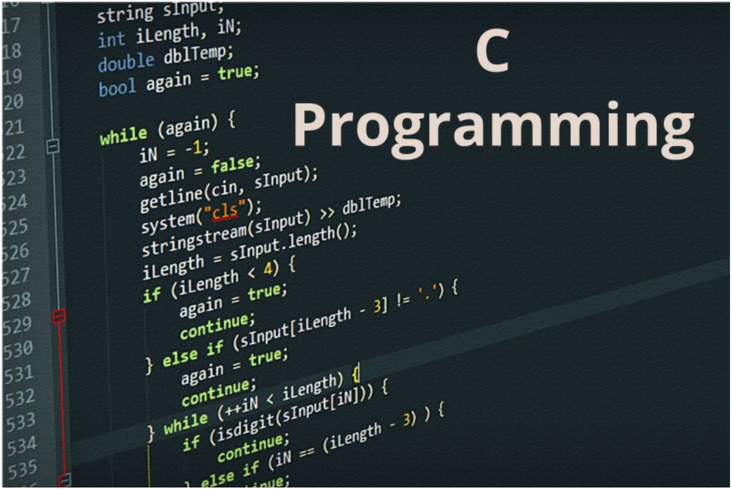
We will focus on **techniques and applications** of parallel computing, as well as on the ways to **write computer programs** using this paradigm.

Contents

- Introduction to Parallel Computing (Hardware and Software)
- Parallel Programs / Programming for Performance
- General Strategies of Parallel Computing
- Algorithms and Applications

- Shared-Memory Programming
  - Pthreads
  - OpenMP
- Distributed-Memory Programming
  - Message-Passing Interface (MPI)

Prerequisites



```
string sInput;
int iLength, iN;
double dblTemp;
bool again = true;

while (again) {
    iN = -1;
    again = false;
    getline(cin, sInput);
    system("cls");
    stringstream(sInput) >> dblTemp;
    iLength = sInput.length();
    if (iLength < 4) {
        again = true;
        continue;
    } else if (sInput[iLength - 3] != '.') {
        again = true;
        continue;
    } while (++iN < iLength) {
        if (isdigit(sInput[iN])) {
            continue;
        } else if (iN == (iLength - 3) ) {
```

Bibliography

Main textbook:

- **An Introduction to Parallel Programming.** Peter Pacheco, Morgan Kaufmann (Elsevier), 2011

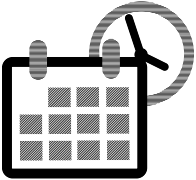
Additional books:

- **An Introduction to Parallel Computing: Design and Analysis of Algorithms.** A. Grama *et al.*, Addisson-Wesley, 2nd Ed, 2003
- **Parallel Programming in C with MPI and OpenMP.** Michael J. Quinn, McGraw-Hill, 2003

Online resources:

- **Lawrence Livermore National Laboratory** online tutorials. `https://hpc.llnl.gov/training/tutorials`

Course Information: Dates / Times



4 January - 25 April, 2023

	Time	**Room**
Tuesday:	10:00 - 12:00	A-255
Friday:	10:00 - 12:00	A-255

Course Information: Materials and Submissions

Course materials/resources will be available at:
https://www.dropbox.com/sh/w9feorc6hypfivc/AAD9n6DO2_NdhvBJqPsRL0m4a?dl=0

Submitting assignments/deliverables:

- A **Dropbox** folder will be shared with each student
- For each assignment/deliverable, create a **sub-folder** and place files inside
- **Do not send things by email!!!**

Assessment / Grading

Projects (5 deliverables)	80%
Presentation(s)	10%
Final exam	20%
Total	**110 %**

NOTE: if no "Final exam", then the value of "Projects" will be 100%.

Projects / Deliverables

- Each student will **INDIVIDUALLY execute a project**
- **A different project will be assigned to each student**
- Potential project topics will be discussed at the end of this session
- Project **involves the following deliverables:** (tentative dates)

Deliverable	Deadline	Value (%)
Sequential version	**27 January**	20%
Shared-memory version (Pthreads)	**24 February**	20%
Shared-memory version (OpenMP)	**17 March**	20%
Distributed-memory version	**7 April**	20%
Hybrid (shared/distributed) version	**21 April**	20%

Important Remarks

- **Deadlines**
  - Assignments: to be considered **iff** received by the deadline
  - Projects: value reduced **10% every 24 hours** of delay
- **Completeness**
  - Receive 100% of value if meet **100% of requirements**
  - Otherwise, value will be **proportional**
- **Individual Work and Teamwork**
  - **You will work individually** (unless otherwise indicated)
  - When working as a team, **assessment is still individual**

Assessment Criteria for Presentations

Assessment of presentations will consider:

- Contents and organization
- Knowledge / understanding
- Ability / effort to transmit knowledge
- Formality (behavioral)
- Quality of materials
- Time management

Attendance Policies

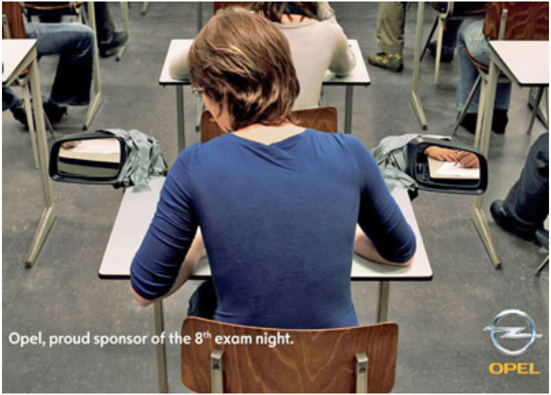
- Attendance is not a criterion for grading
- **Mandatory:** 100% attendance required to pass
- **Be on time:** 15 minute tolerance
- Absences need to be formally justified (through **Academic Tutor** or **Academic Coordinator**)

Ethics and Behaviour

Ethics and Behaviour - Honesty

Honesty will be crucial in this course!!!

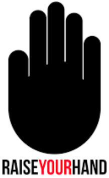
WHAT IS PLAGIARISM?



Cheating will cause **COURSE FAILURE!**

Ethics and Behaviour - Respect

- Instructor must respect students
- Students must respect instructor
- Students must respect classmates



- Avoid interruptions!
- Raise your hand!
- No phones!
- Be on time!

Exploit This Opportunity

- A graduate course is one of the **last chances to strengthen and expand our formation**
- **Contents are ambitious**, topics can't be covered with desired depth
- A graduate student must be able to **work and learn independently**
- **Do not limit yourself** to the materials seen in class
- A graduate course **assumes certain knowledge** / skills
- **Identify your weaknesses and work hard to overcome them!**

Project Deliverable 1: Sequential Version

You will submit the **source code** of your implementation **(70%)** and a **LaTeX report** with the following contents **(30%)**:

1. Title, author name
2. Abstract
3. Introduction
    - Problem / Task / Topic Description
4. Serial Algorithm
    - Pseudocode, explanation of functioning, complexity analysis
5. Results
    - Examples / verification of results
    - Plot + table: execution time vs problem size (5+ different sizes)
    - Report the fastest time observed in 10 independent executions
6. Conclusions
7. References

Results MUST be **interpreted** / **discussed!** (not enough to include plots)

Selection of a Project Topic: Rules

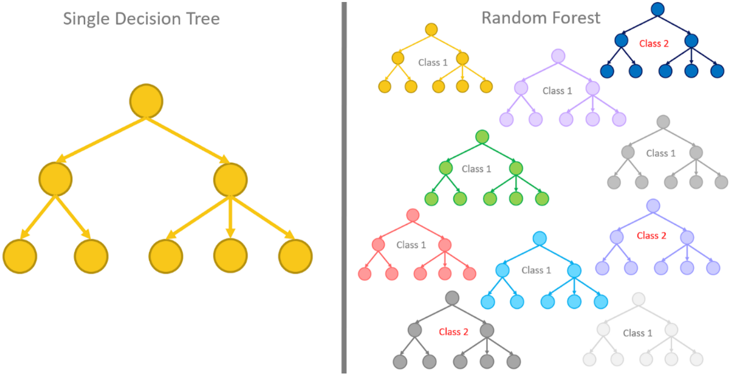
- A **different project** will be **INDIVIDUALLY** executed by each student
- Some project options have been pre-assigned to each of you
  - Make your **final choice** by **Friday, January 13, 2023**
  - Communicate this by placing a text file (**PROJECT.txt**) in your Dropbox folder with your decision(s)
  - **No changes after this** (unless discussed and authorized)
- **You will be the only responsible** for investigating and understanding the problem/algorithm, as well as for the design and implementation of the serial/parallel programs

Abraham - Parallelization of Optimization Algorithms

- Option 1: **Branch and Bound**
  - `https://en.wikipedia.org/wiki/Branch_and_bound`
- Option 2: **Population-based Metaheuristics**
  - `https://en.wikipedia.org/wiki/Metaheuristic`
- **Use the chosen algorithm to solve a problem such as:**
  - Graph coloring, quadratic assignment problem, ...
  - Any NP-complete problem (`https://en.wikipedia.org/wiki/List_of_NP-complete_problems`)
  - A particular problem you are interested in!

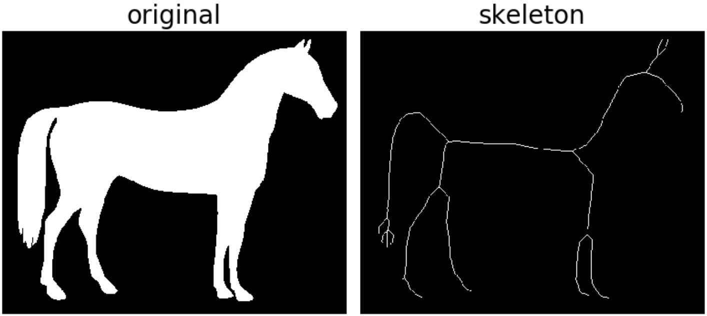
Michel - Option 1: Ensemble Machine Learning Methods

Random Forests Classification Algorithm



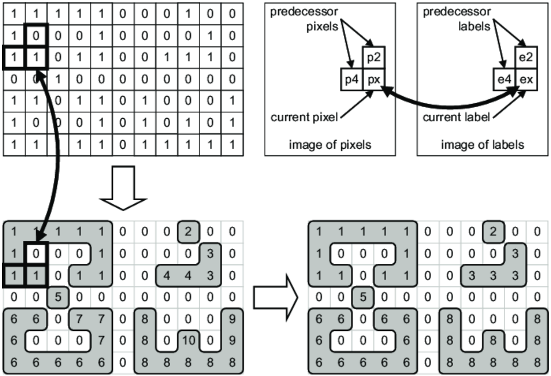
```
https://en.wikipedia.org/wiki/Random_forest
https://en.wikipedia.org/wiki/Ensemble_learning
https://builtin.com/data-science/random-forest-algorithm
https://www.stat.berkeley.edu/~breiman/RandomForests/cc_home.htm
```

Michel - Option 2: Image Thinning (Skeletonization)



https://homepages.inf.ed.ac.uk/rbf/HIPR2/thin.htm
https://scikit-image.org/docs/dev/auto_examples/edges/plot_skeleton.html
https://boofcv.org/index.php?title=Example_Morphological_Thinning
https://reference.wolfram.com/language/ref/Thinning.html?view=all
https://rosettacode.org/wiki/Zhang-Suen_thinning_algorithm

Michel - Op. 3: Connected-Component Labeling (Region Labeling)



1	1	1	1	1	0	0	0	1	0	0
1	0	0	0	1	0	0	0	0	1	0
1	1	0	1	1	0	0	1	1	1	0
0	0	1	0	0	0	0	0	0	0	0
1	1	0	1	1	0	1	0	0	0	1
1	0	0	0	1	0	1	0	1	0	1
1	1		1	1	0	1	1	1	1	1

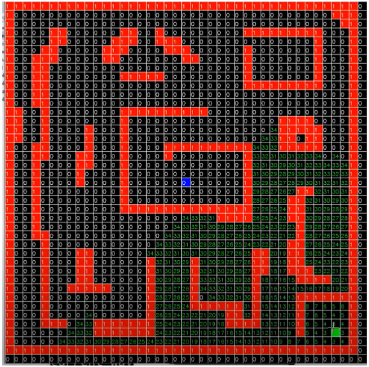
1	1	1	1	1	0	0	0	2	0	0
1	0	0	0	1	0	0	0	0	3	0
1	1	0	1	1	0	0	4	4	3	0
0	0	5	0	0	0	0	0	0	0	0
6	6	0	7	7	0	8	0	0	0	9
6	0	0	0	7	0	8	0	10	0	9
6	6	6	6	6	0	8	8	8	8	8

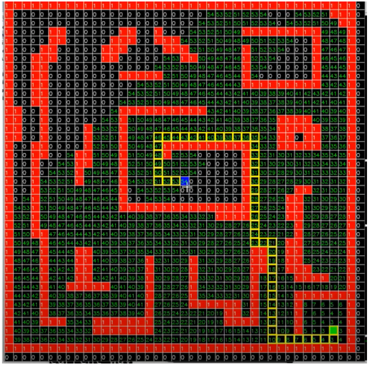
1	1	1	1	1	0	0	0	2	0	0
1	0	0	0	1	0	0	0	0	3	0
1	1	0	1	1	0	0	3	3	3	0
0	0	5	0	0	0	0	0	0	0	0
6	6	0	6	6	0	8	0	0	0	8
6	0	0	0	6	0	8	0	8	0	8
6	6	6	6	6	0	8	8	8	8	8

```
https://en.wikipedia.org/wiki/Connected-component_labeling
https://homepages.inf.ed.ac.uk/rbf/HIPR2/label.htm
http://aishack.in/tutorials/connected-component-labelling/
```

Luis - Option 1: Wavefront Expansion Algorithm

Implement for N robots, each with a specific start position and destination.

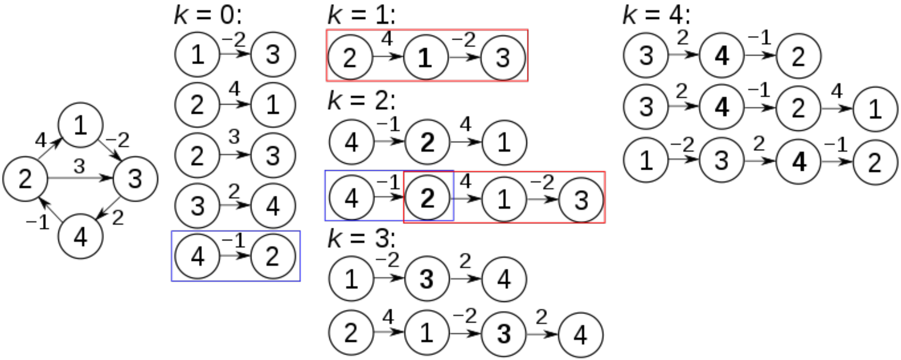




https://en.wikipedia.org/wiki/Wavefront_expansion_algorithm
https://www.youtube.com/watch?v=yeL7ICc8g4A

Luis - Option 2: Floyd's Algorithm

Shortest Paths Between All Pairs of Nodes



https://www-m9.ma.tum.de/graph-algorithms/spp-floyd-warshall/index_en.html
https://en.wikipedia.org/wiki/Floyd%E2%80%93Warshall_algorithm

Infrastructure: Shared-Memory Programming

For projects based on **Pthreads** and **OpenMP**, experiments will be run in the following server:

polifemo.tamps.cinvestav.mx (148.247.202.45)

You will use username "**cpar**" to connect to this server using **ssh**:

```
ssh cpar@polifemo.tamps.cinvestav.mx
```

Upload/download files to/from the server using commands **scp** or **rsync**.

Please **respect the times** assigned to each of you for using this server!

Infrastructure: Distributed-Memory Programming

For projects based on **MPI**, experiments will be run in **Cluster Neptuno**:

neptuno.tamps.cinvestav.mx (148.247.202.41)

You will use username "**cpar**" to connect to this server using **ssh**:

```
ssh cpar@neptuno.tamps.cinvestav.mx
```

Upload/download files to/from the server using commands **scp** or **rsync**.

Please **respect the times** assigned to each of you for using this server!