Parallel and Distributed Computing

CS3006

Lecture 5

Parallel Algorithm Design Life Cycle

19th February 2024

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Agenda

- A Quick Review
- Parallel Algorithm Design Life Cycle
- Tasks, Decomposition, and Task-dependency graphs
- Granularity
  - Fine-grained
  - Coarse-grained
- Concurrency
  - Max-degree of concurrency
  - Critical path length
  - Average-degree of concurrency
- Task-interaction Diagrams
  - Processes and mapping

Quick Review to the Previous Lecture

- Static vs Dynamic Interconnections
- Static Network Topologies
  - Linear array
  - Star
  - Mesh
  - Tree
  - Fully-connected
  - Hypercube
- Evaluating Static interconnections
  - Cost
  - Diameter
  - Bisection-width
  - Arc-connectivity

Principles of Parallel Algorithm Design

Principles of Parallel Algorithm Design

Steps in Parallel Algorithm Design

1. **Identification:** Identifying portions of the work that can be performed concurrently.
   - Work-units are also known as tasks
   - E.g., Initializing two mega-arrays are two tasks and can be performed in parallel
2. **Mapping:** The process of mapping concurrent pieces of the work or tasks onto multiple processes running in parallel.
   - Multiple processes can be physically mapped on a single processor.

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Steps in Parallel Algorithm Design

3. **Data Partitioning:** Distributing the input, output, and intermediate data associated with the program.
   - One way is to copy whole data at each processing node
     - Memory challenges for huge-size problems
   - Other way is to give fragments of data to each processing node
     - Communication overheads
4. **Defining Access Protocol**: Managing accesses to data shared by multiple processors (i.e., managing communication).
5. **Synchronizing** the processors at various stages of the parallel program execution.

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- **Decomposition:**
  - The process of dividing a computation into smaller parts, some or all of which may potentially be executed in parallel.
- ***Tasks***
  - **Programmer-defined units of computation** into which the main computation is subdivided by means of decomposition
  - Tasks can be of **arbitrary size**, but once defined, they are regarded as **indivisible units of computation**.
  - The tasks into which a problem is decomposed may not all be of the same size
  - Simultaneous execution of multiple tasks is the key to reducing the time required to solve the entire problem.

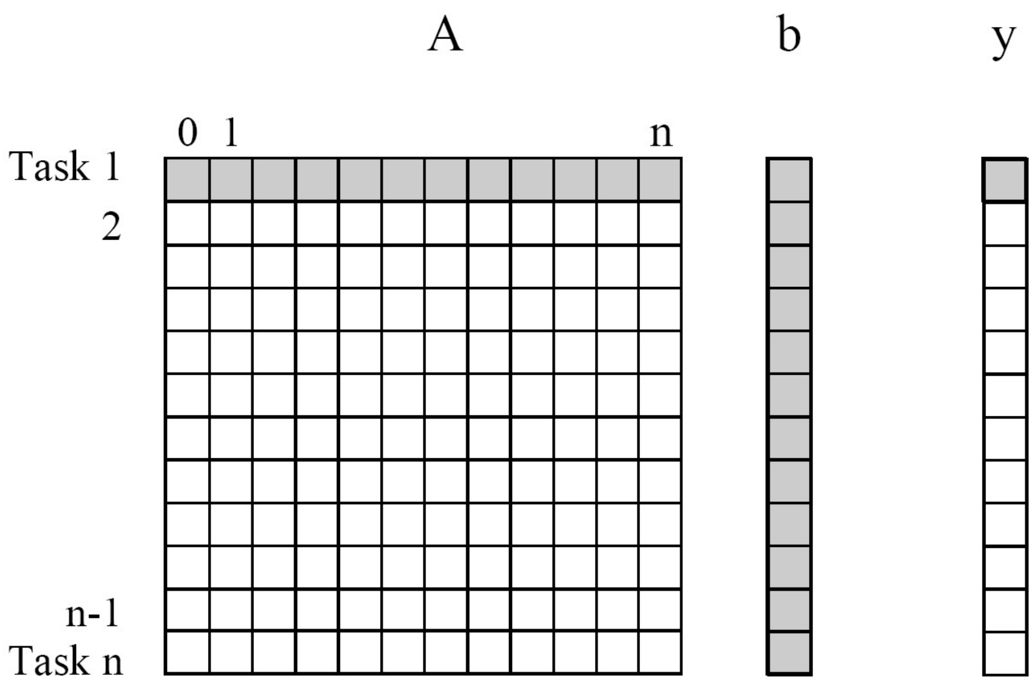

Figure 3.1 Decomposition of dense matrix-vector multiplication into n tasks, where n is the number of rows in the matrix. The portions of the matrix and the input and output vectors accessed by Task 1 are highlighted.

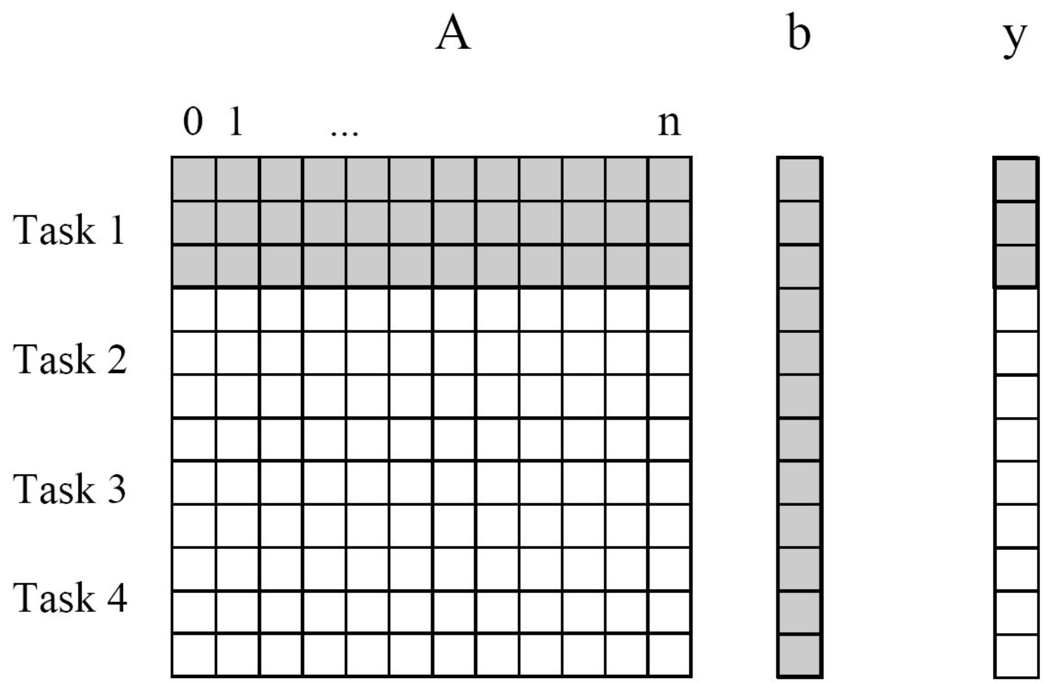

Figure 3.4 Decomposition of dense matrix-vector multiplication into four tasks. The portions of the matrix and the input and output vectors accessed by Task 1 are highlighted.

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Granularity

- The **number and sizes** of tasks into which a problem is decomposed determines the ***granularity*** of the decomposition
  - A decomposition into a large number of small tasks is called ***fine-grained***
  - A decomposition into a small number of large tasks is called ***coarse-grained***
- For matrix-vector multiplication Figure 3.1 would usually be considered fine-grained
- Figure 3.4 shows a coarse-grained decomposition as each tasks computes $n/4$ of the entries of the output vector of length n

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Task-Dependency Graph

- The tasks in the previous examples are independent and can be performed in any sequence.
- In most of the problems, there exist some sort of dependencies between the tasks.
- An abstraction used to express such **dependencies** among tasks and their **relative order of execution** is known as a **task-dependency graph**
- It is a **directed acyclic graph** in which node are tasks and the directed edges indicate the dependencies between them
- The task corresponding to a node can be executed when all tasks connected to this node by incoming edges have completed.

Select ID, model, year, color from dbtable where model=‘civic’ and year=‘2001’ and (color=‘White’ OR color=‘Green’)

ID#	Model	Year	Color	Dealer	Price
4523	Civic	2002	Blue	MN	$18,000
3476	Corolla	1999	White	IL	$15,000
7623	Camry	2001	Green	NY	$21,000
9834	Prius	2001	Green	CA	$18,000
6734	Civic	2001	White	OR	$17,000
5342	Altima	2001	Green	FL	$19,000
3845	Maxima	2001	Blue	NY	$22,000
8354	Accord	2000	Green	VT	$18,000
4395	Civic	2001	Red	CA	$17,000
7352	Civic	2002	Red	WA	$18,000

Table 3.1 A database storing information about used vehicles.

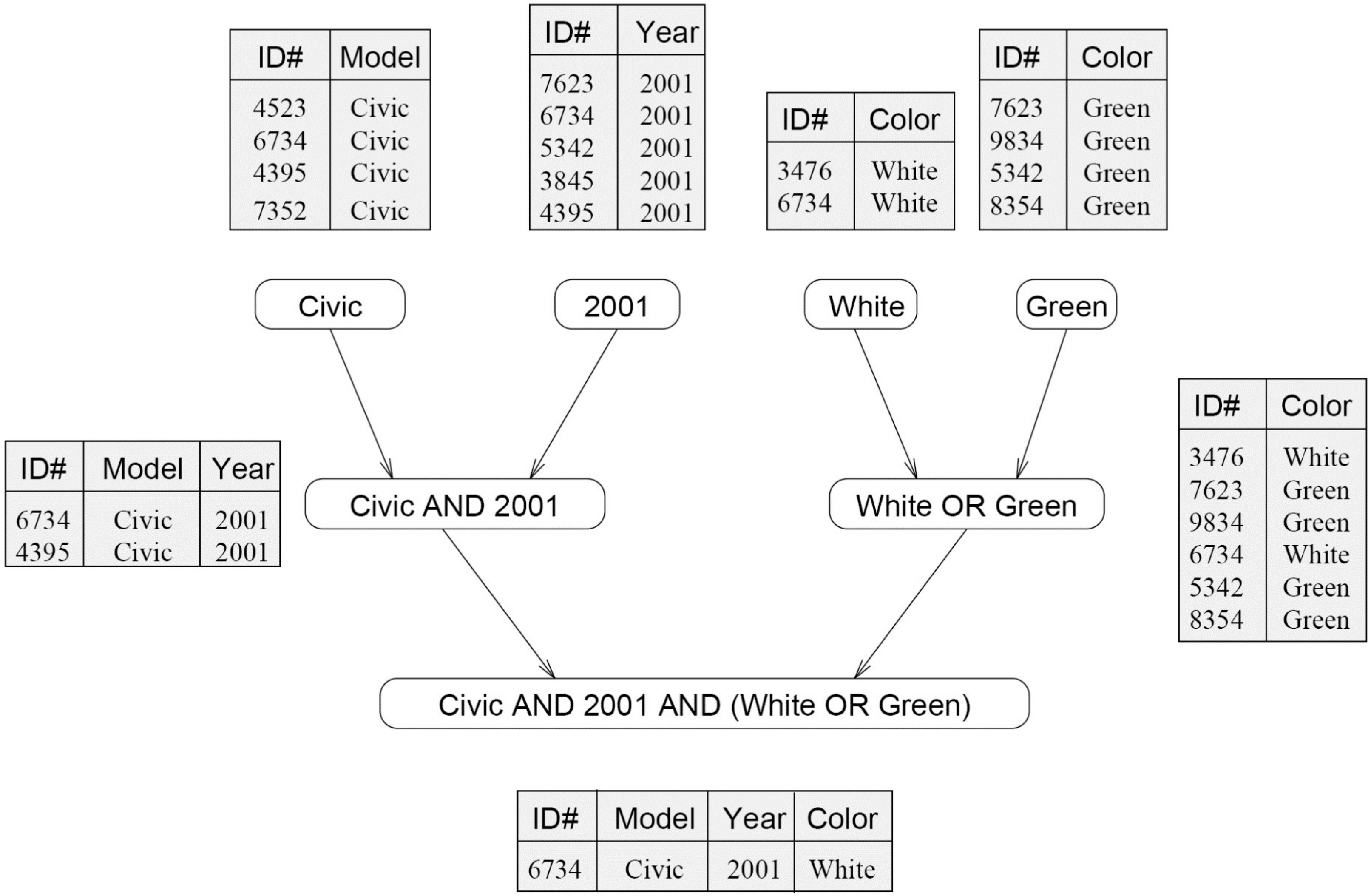

Figure 3.2 The different tables and their dependencies in a query processing operation.

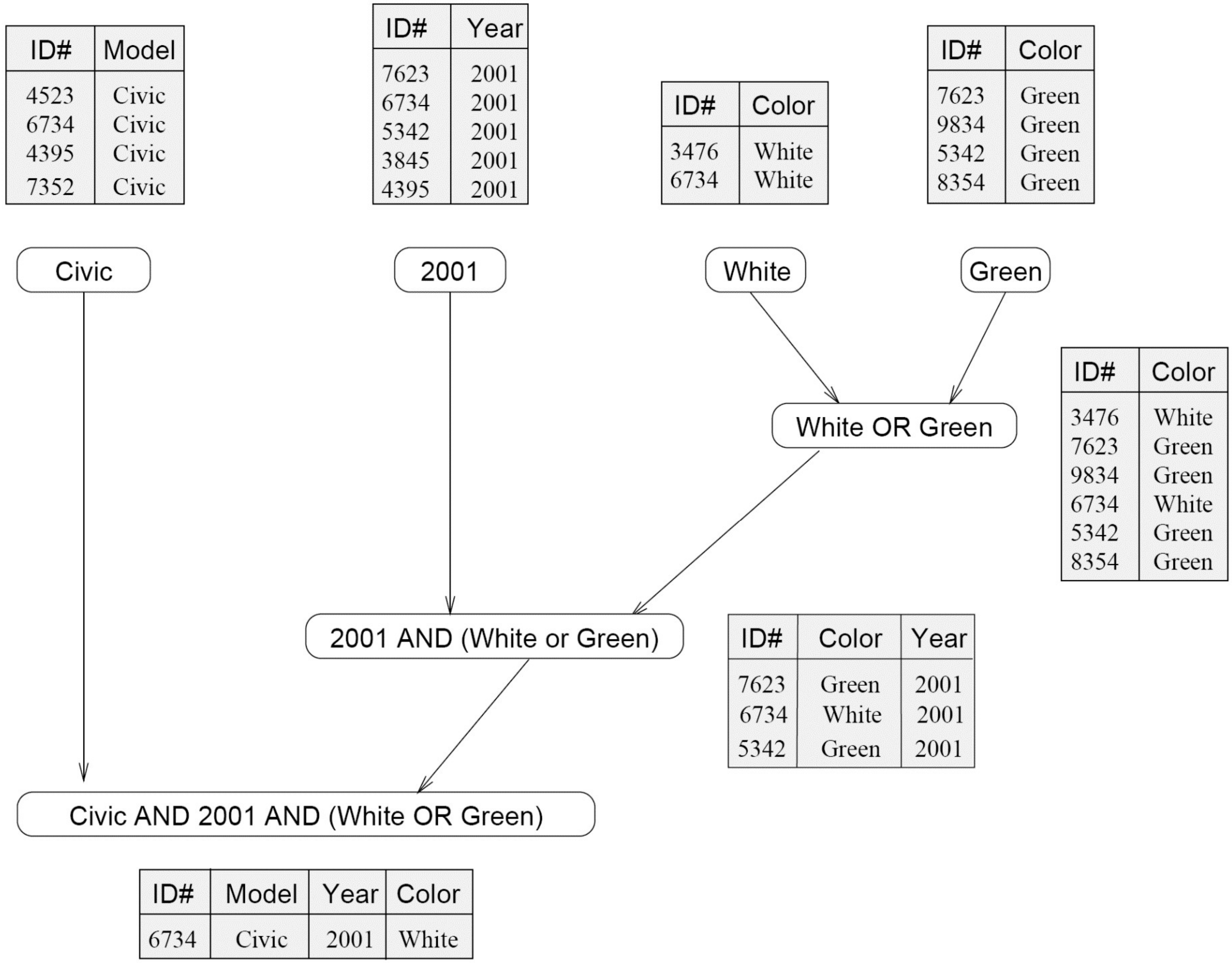

Figure 3.3 An alternate data-dependency graph for the query processing operation.

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Maximum Degree of Concurrency

- The maximum number of tasks that can be executed simultaneously in a parallel program at any given time is known as its *maximum degree of concurrency*
- Usually, it is always less than total number of tasks due to dependencies.
- E.g., max-degree of concurrency in the task-graphs of Figures 3.2 and 3.3 is 4.
- **Rule of thumb:** For task-dependency graphs that are trees, the maximum degree of concurrency **is always equal to the number of leaves in the tree**

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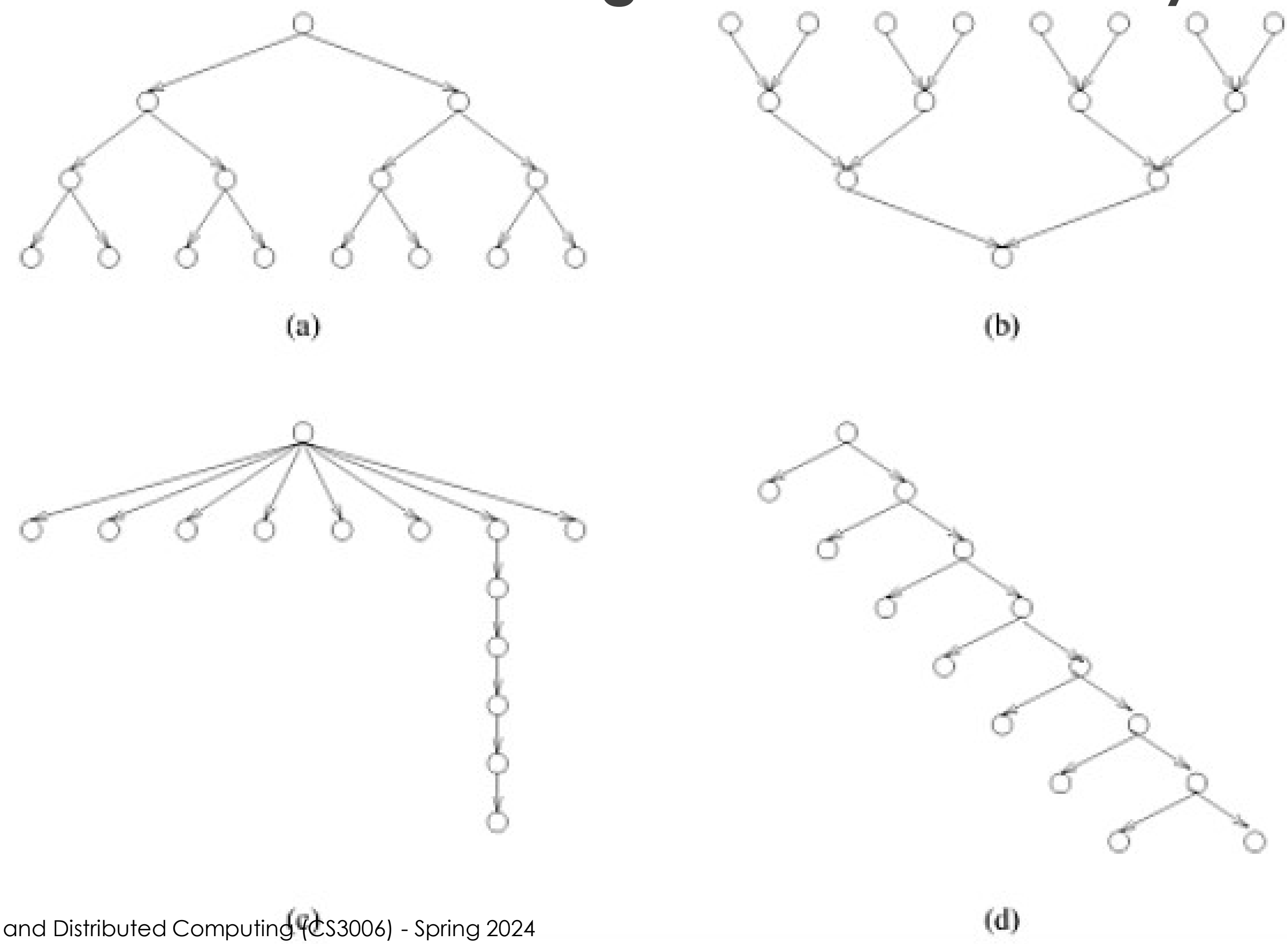
Determine Maximum Degree of Concurrency?



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Average Degree of Concurrency

- A relatively better measure for the performance of a parallel program
- The average number of tasks that can run concurrently over the entire duration of execution of the program
- The ratio of the ***total amount of work*** to the ***critical-path length***
  - So, what is the critical path in the graph**?**

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Average Degree of Concurrency

- **Critical Path:** The longest directed path between any pair of start and finish nodes is known as the critical path.
- **Critical Path Length:** The sum of the weights of nodes along this path
  - the weight of a node is the size or the amount of work associated with the corresponding task.
- A shorter critical path favors a higher average-degree of concurrency.
- Both, maximum and average degree of concurrency increases as tasks become smaller(finer)

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Average Degree of Concurrency

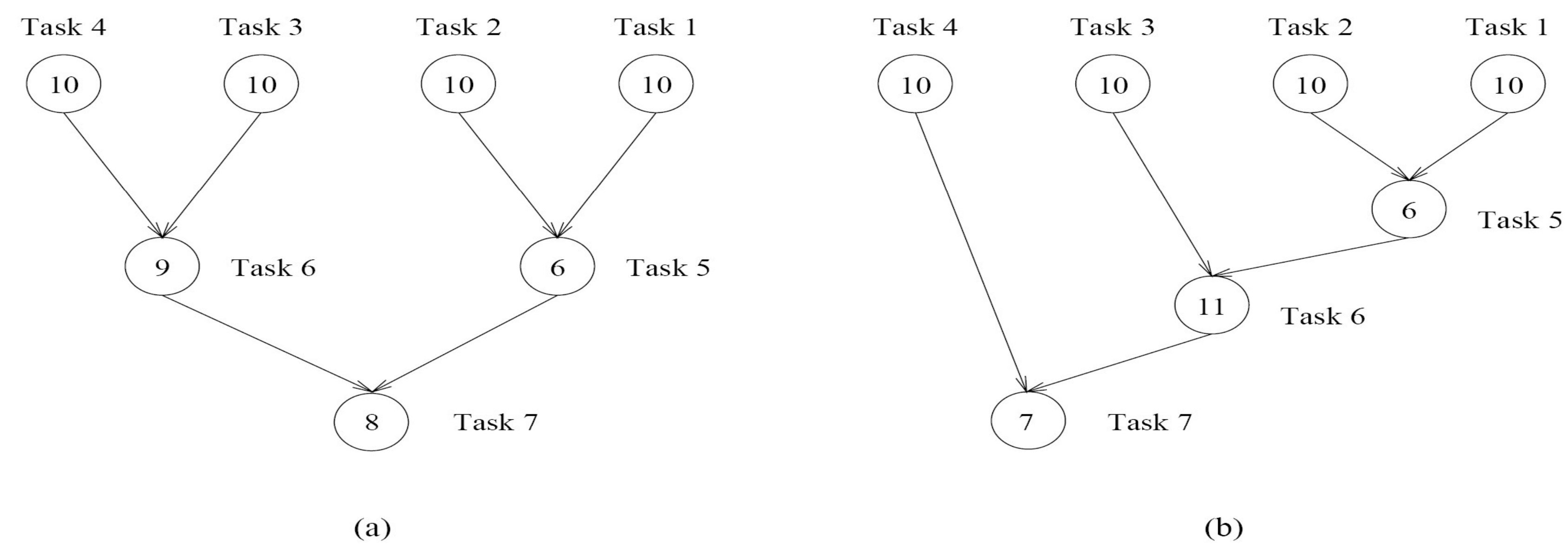

Figure 3.5 Abstractions of the task graphs of Figures 3.2 and 3.3, respectively.

Critical path lengths: 27 and 34

AVG DEG = 63/27 = 2.33

Total amount of work: 63 and 64

Average degree of concurrency: 2.33 and 1.88

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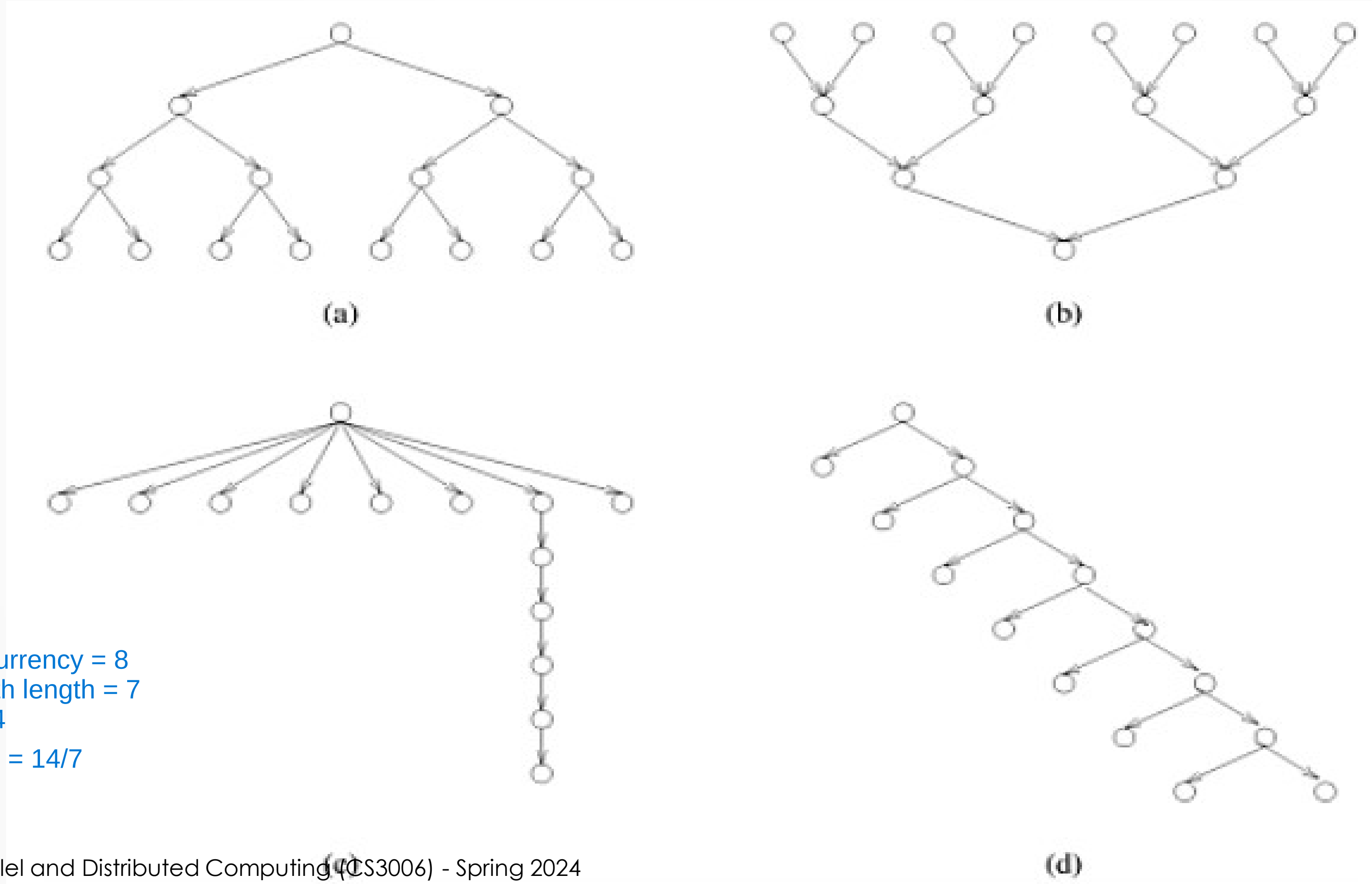
Determine critical path length and average-concurrency?



max concurrency = 8
critical path length = 7
total = 14
avg conc = 14/7

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Task Interact Graph

- Depicts pattern of interaction between the tasks
- Dependency graphs only show that how output of first task becomes input to the next level task.
- But how the tasks interact with each other to access distributed data is only depicted by task interaction graphs
- The nodes in a task-interaction graph represent tasks
- The edges connect tasks that interact with each other

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Task Interact Graph

- The edges in a task interaction graph are usually **undirected**
  - but directed edges can be used to indicate the direction of flow of data, if it is unidirectional.
- The edge-set of a task-interaction graph is usually a **superset** of the edge-set of the task-dependency graph
- In database query processing example, the task-interaction graph is the **same** as the task-dependency graph.

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Task Interact Graph (Sparse-matrix multiplication)

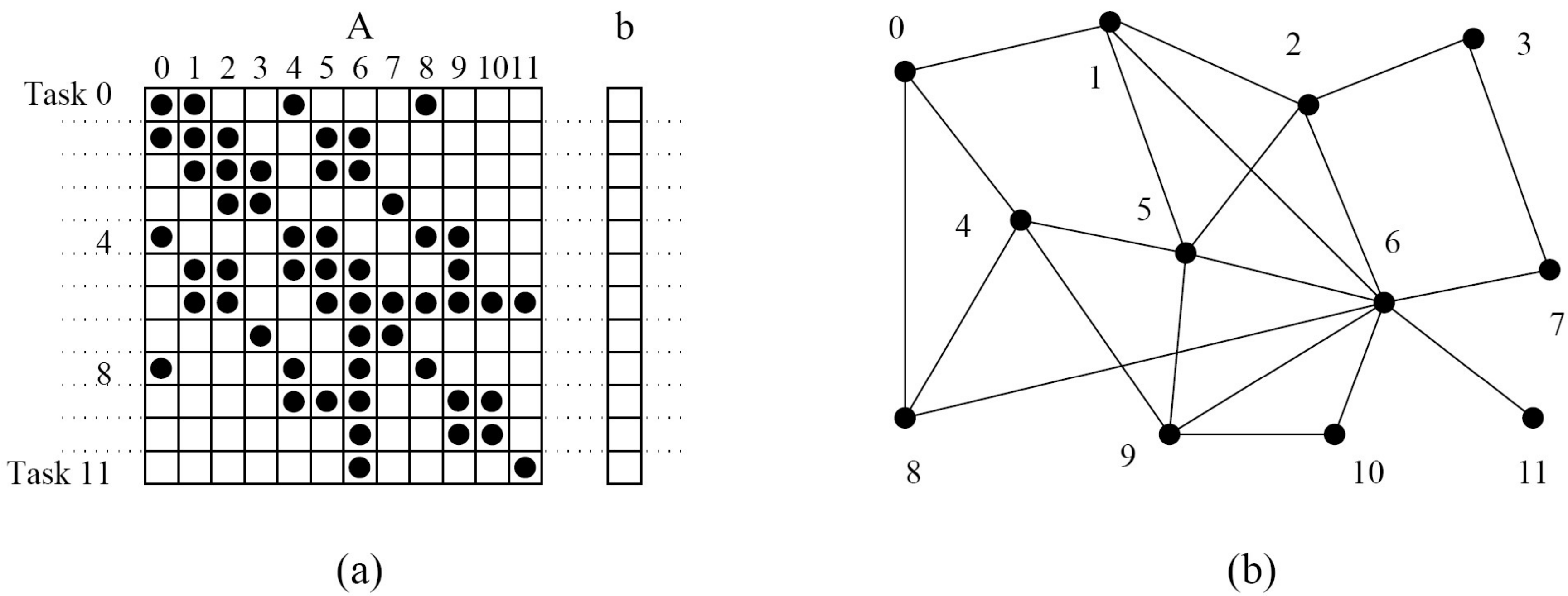

Figure 3.6 A decomposition for sparse matrix-vector multiplication and the corresponding task-interaction graph. In the decomposition Task i computes $\sum_{0 \le j \le 11, A[i,j] \ne 0} A[i, j].b[j]$.

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Processes and Mapping

- Logical processing or computing agent that performs tasks is called **process**.
- The mechanism by which tasks are assigned to processes for execution is called ***mapping.***
- Multiple tasks can be mapped on a single process
- Independent task should be mapped onto different processes
- Map tasks with high mutual-interactions onto a single process

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Processes and Mapping

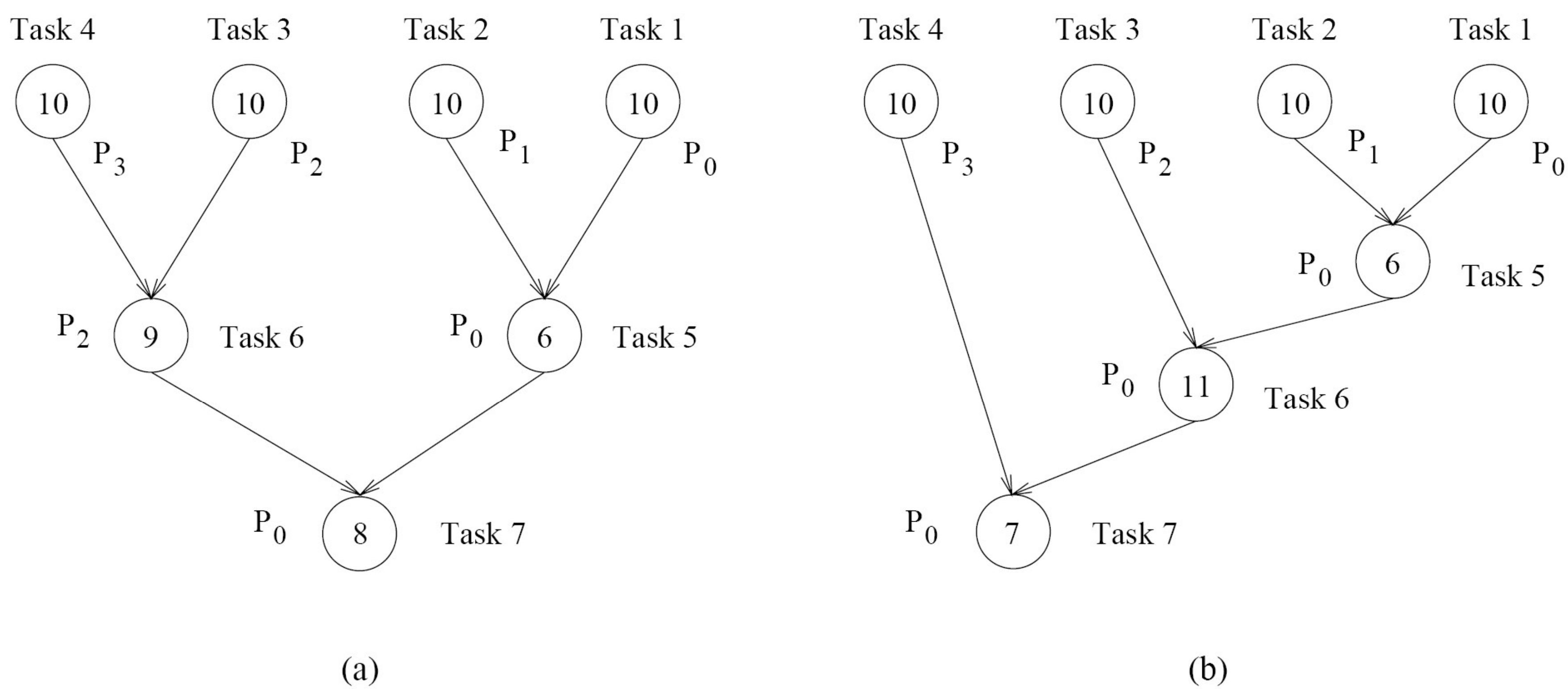

Figure 3.7 Mappings of the task graphs of Figure 3.5 onto four processes.

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Processes and Processors

- **Processes** are logical computing agents that perform tasks
- **Processors** are the hardware units that physically perform computations
- Depending on the problem, multiple processes can be mapped on a single processor
- But, in most of the cases, there is one-to-one correspondence between processors and processes
- So, we assume that there are as many processes as the number of physical CPUs on the parallel computer

Questions

References

1. Kumar, V., Grama, A., Gupta, A., & Karypis, G. (1994). *Introduction to parallel computing* (Vol. 110). Redwood City, CA: Benjamin/Cummings.
2. Quinn, M. J. Parallel Programming in C with MPI and OpenMP,(2003).