Lecture 4: Principles of Parallel Algorithm Design (part 1)

Constructing a Parallel Algorithm

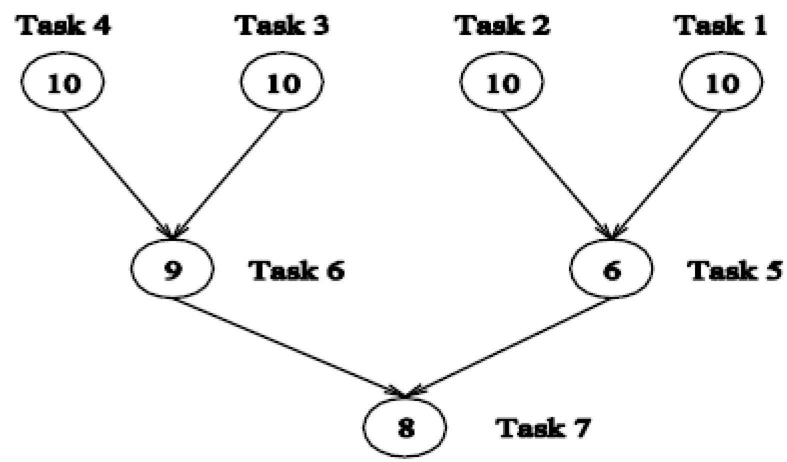
- identify portions of work that can be performed concurrently
- map concurrent portions of work onto multiple processes running in parallel
- distribute a program’s input, output, and intermediate data
- manage accesses to shared data: avoid conflicts
- synchronize the processes at stages of the parallel program execution

Task Decomposition and Dependency Graphs

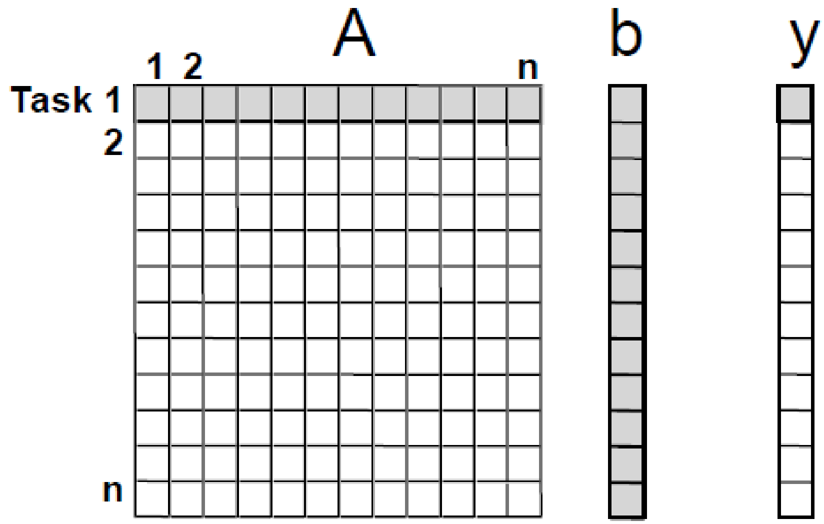
Decomposition: divide a computation into smaller parts, which can be executed concurrently

Task: programmer-defined units of computation.

Task-dependency graph:
Node represent s task.
Edge represents control dependence.



Example 1: Dense Matrix-Vector Multiplication



- Computing y[i] only use ith row of *A* and *b* – treat computing y[i] as a task.
- Remark:
  - Task size is uniform
  - No dependence between tasks
  - All tasks need *b*

Example 2: Database Query Processing

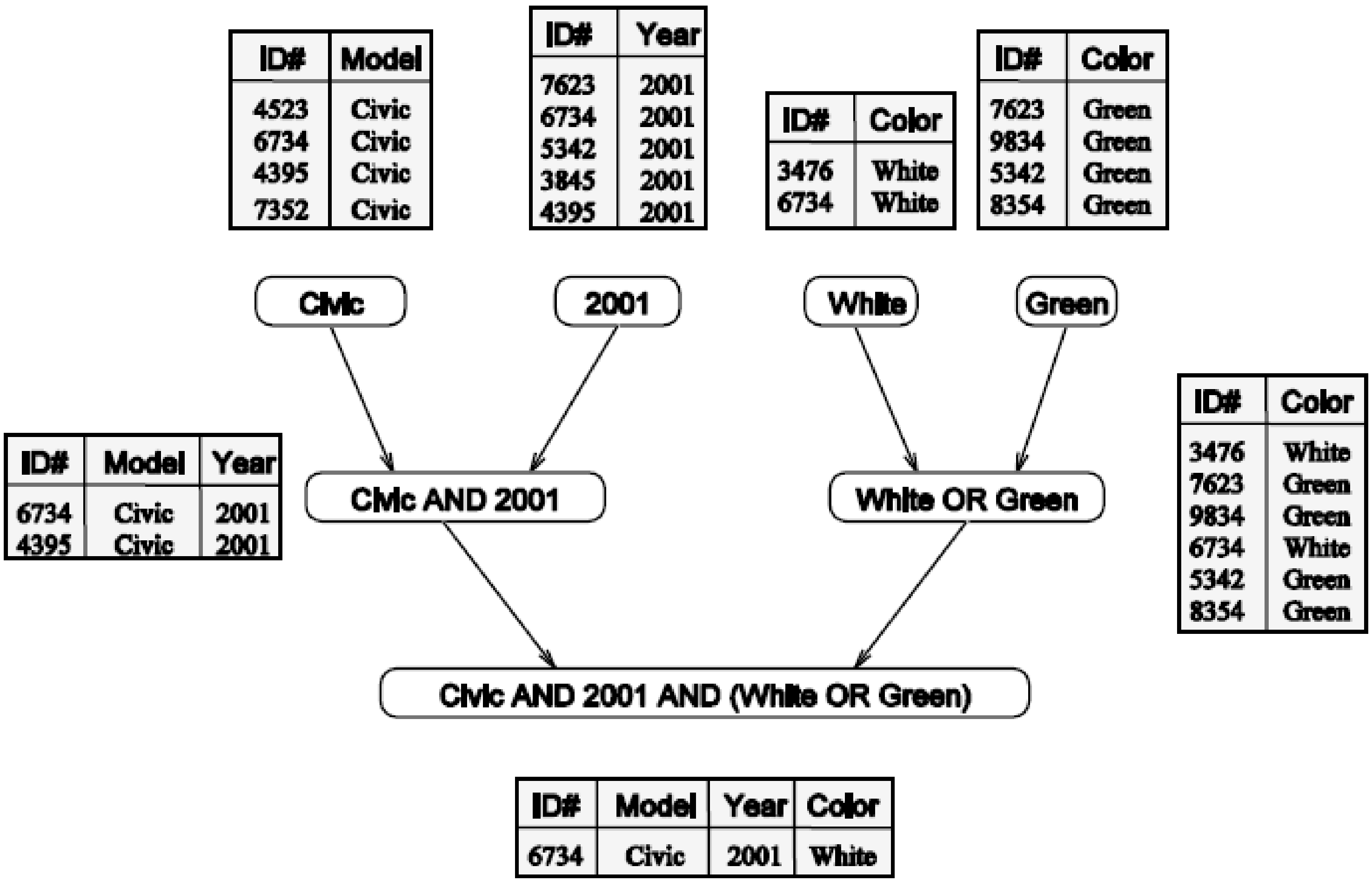
- Executing the query:

Model ="civic" AND Year = "2001" AND (Color = "green" OR Color = "white")

on the following database:

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

- **Task:** create sets of elements that satisfy a (or several) criteria.
- **Edge:** output of one task serves as input to the next



ID#	Model
4523	Civic
6734	Civic
4395	Civic
7352	Civic

ID#	Year
7623	2001
6734	2001
5342	2001
3845	2001
4395	2001

ID#	Color
3476	White
6734	White

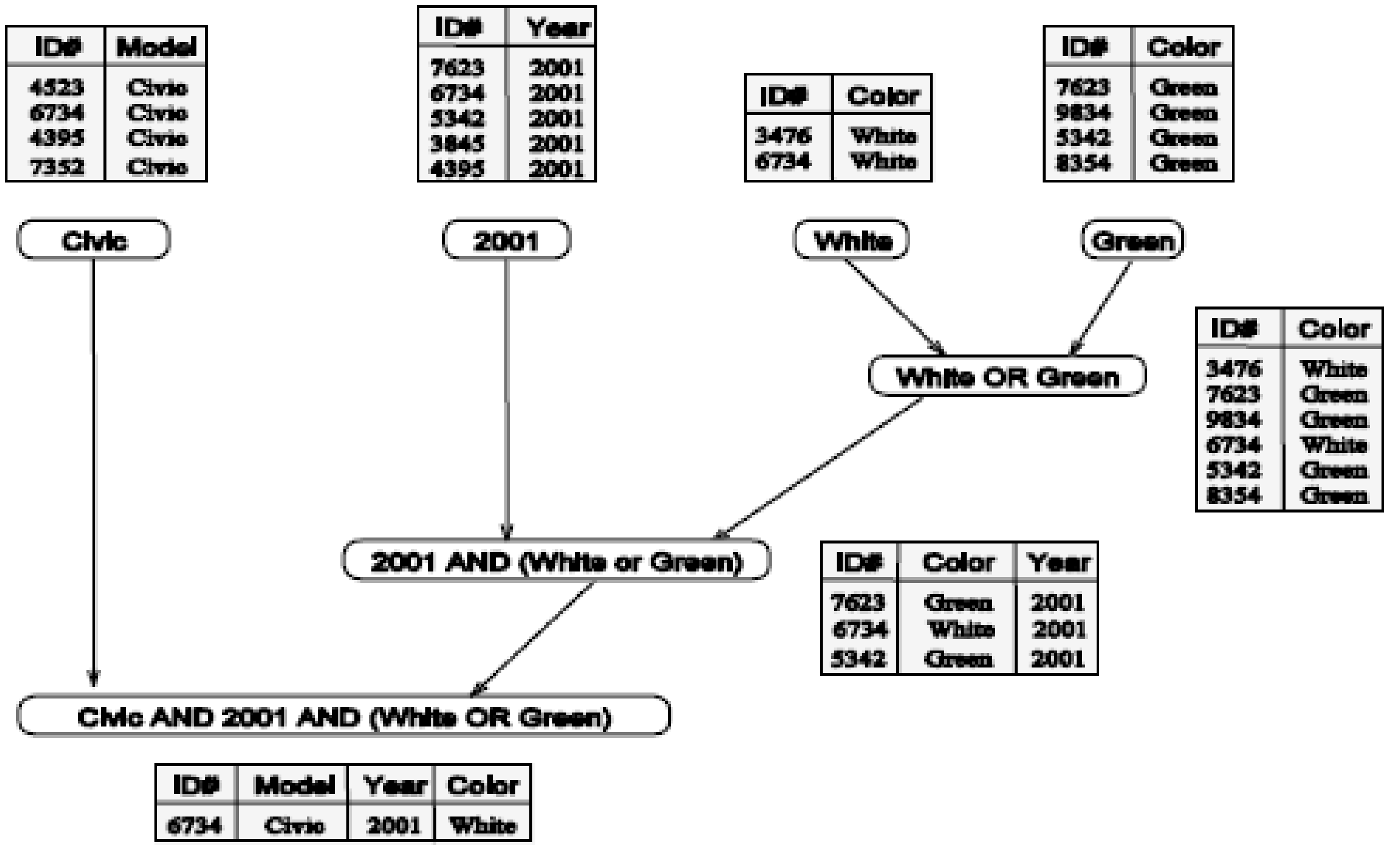
ID#	Color
7623	Green
9834	Green
5342	Green
8354	Green

ID#	Model	Year
6734	Civic	2001
4395	Civic	2001

ID#	Color
3476	White
7623	Green
9834	Green
6734	White
5342	Green
8354	Green

ID#	Model	Year	Color
6734	Civic	2001	White

- An alternate task-dependency graph for query



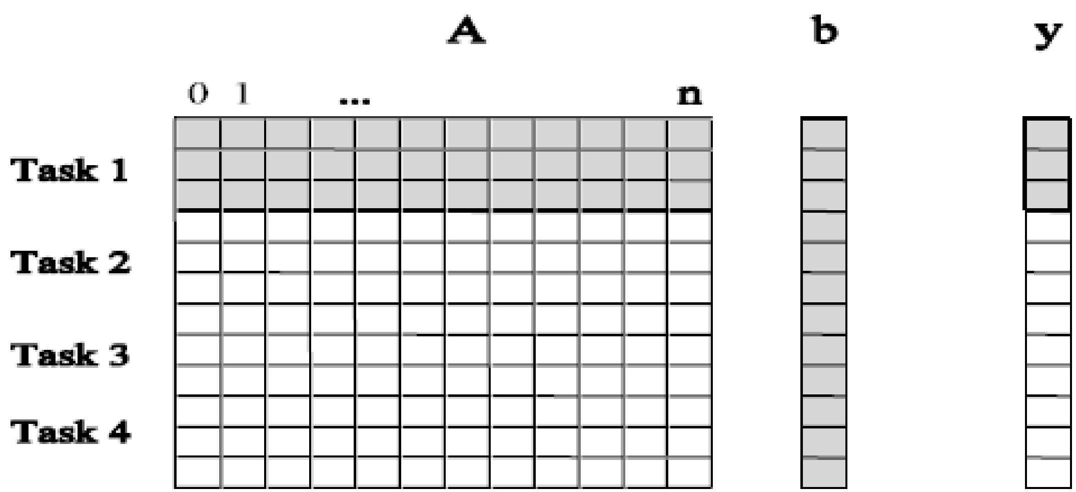
- Different task decomposition leads to different parallelism

Granularity of Task Decomposition

- **Fine-grained** decomposition: large number of small tasks
- **Coarse-grained** decomposition: small number of large tasks

Matrix-vector multiplication example

-- **coarse-grain**: each task computes 3 elements of *y*[]



Degree of Concurrency

- **Degree of Concurrency**: # of tasks that can execute in parallel

  -- **maximum degree of concurrency:** largest # of concurrent tasks at any point of the execution

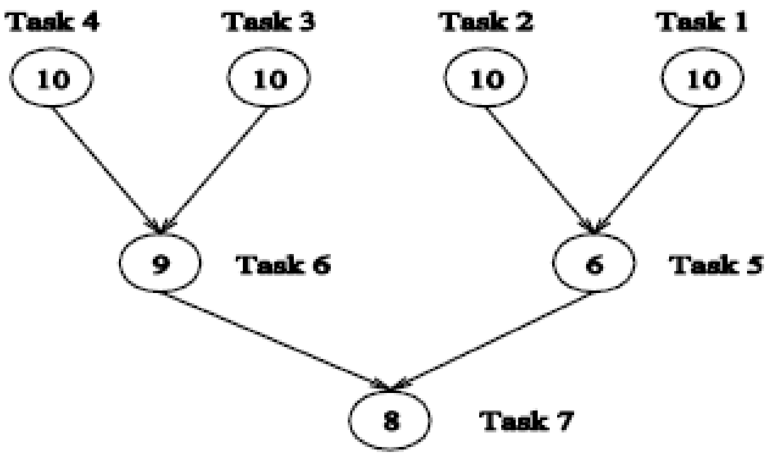
  -- **average degree of concurrency:** average # of tasks that can be executed concurrently
- Degree of Concurrency vs. Task Granularity
  – Inverse relation

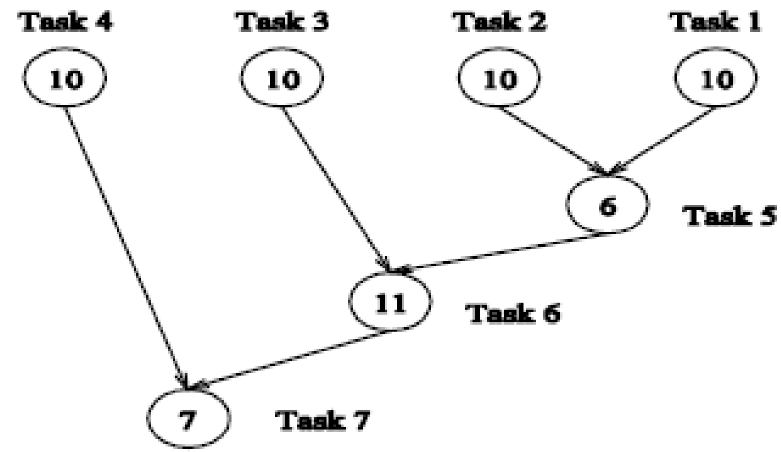
Critical Path of Task Graph

- **Critical path**: The longest directed path between any pair of *start node* (node with no incoming edge) and *finish node* (node with on outgoing edges).
- **Critical path length:** The sum of weights of nodes along critical path.
- **Average degree of concurrency** = total amount of work / critical path length

Example: Critical Path Length

Task-dependency graphs of query processing operation





Left graph:

Critical path length = 27

Average degree of concurrency = 63/27 = 2.33

Right graph:

Critical path length = 34

Average degree of concurrency = 64/34 = 1.88

Limits on Parallelization

- Facts bounds on parallel execution
  - Maximum task granularity is finite
    - Matrix-vector multiplication $O(n^2)$
  - Communication between tasks
- **Speedup** = sequential execution time/parallel execution time
- **Parallel efficiency** = sequential execution time/(parallel execution time × processors used)