Announcements

- HW#8 coming out later today. Due next Wednesday.
- I do will not have office hours tomorrow: moved to 4PM Friday this week only.

Lecture 35: Concurrency, Parallelism, and Distributed Computing

Definitions

- *Sequential Process:* Our subject matter up to now: processes that (ultimately) proceed in *a single sequence* of primitive steps.
- *Concurrent Processing:* The logical or physical division of a process into multiple sequential processes.
- *Parallel Processing:* A variety of concurrent processing characterized by the *simultaneous execution* of sequential processes.
- *Distributed Processing:* A variety of concurrent processing in which the individual processes are physically separated (often using heterogeneous platforms) and communicate through some network structure.

Purposes

We may divide a single program into multiple programs for various reasons:

- *Computation Speed* through operating on separate parts of a problem simultaneously, or through
- *Communication Speed* through putting parts of a computation near the various data they use.
- *Reliability* through having mulitple physical copies of processing or data.
- *Security* through separating sensitive data from untrustworthy users or processors of data.
- *Better Program Structure* through decomposition of a program into logically separate processes.
- *Resource Sharing* through separation of a component that can serve mulitple users.
- *Manageability* through separation (and sharing) of components that may need frequent updates or complex configuration.

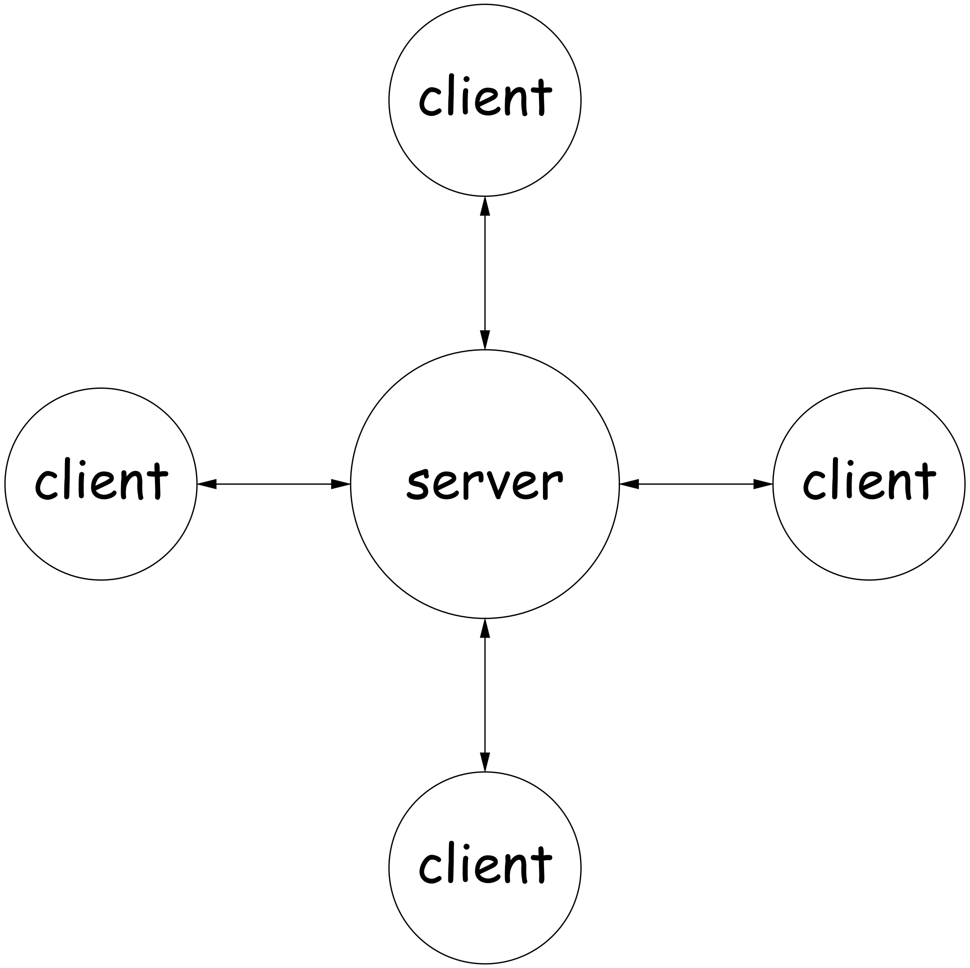
Communicating Sequential Processes

- All forms of concurrent computation can be considered instances of *communicating sequential processes*.
- That is, a bunch of "ordinary" programs that communicate with each other through what is, from their point of view, input and output operations.
- Sometimes the actual communication medium is *shared memory:* input looks like reading a variable and output looks like writing a variable. In both cases, the variable is in memory accessed by multiple computers.
- At other times, communication can involve I/O over a network such as the Internet.
- In principle, either underlying mechanism can be made to look like either access to variables or explicit I/O operations to a programmer.

Distributed Communication

- With sequential programming, we don't think much about the cost of "communicating" with a variable; it happens at some fixed speed that is (we hope) related to the processing speed of our system.
- With distributed computing, the architecture of communication becomes important.
- In particular, costs can become uncertain or heterogeneous:
  - It may take longer for one pair of components to communicate than for another, or
  - The communication time may be unpredictable or load-dependent.

Simple Client-Server Models



- Example: web servers
- Good for providing a service
- Many clients, one server
- Easy server maintenance.
- Single point of failure
- Problems with scaling

Variations: on to the cloud

- Google and other providers modify this model with redundancy in many ways.
- For example, *DNS load balancing* (DNS = *Domain Name System*) allows us to specify multiple servers.
- Requests from clients go to different servers that all have copies of relevant information.
- Put enough servers in one place, you have a *server farm*. Put servers in lots of places, and we have a *cloud*.

Communication Protocols

- One characteristic of modern distributed systems is that they are conglomerations of products from many sources.
- Web browers are a kind of universal client, but there are numerous kinds of browsers and many potential servers (and clouds of servers).
- So there must be some agreement on how they talk to each other.
- The *IP Protocol* is an agreement for specifying destinations, packaging messages, and delivering those messages.
- On top of this, the *transmission control protocol (TCP)* handles issues like persistent telephone-like connections and congestion control.
- The DNS handles conversions between names (inst.eecs.berkeley.edu) and IP addresses (128.32.42.199).
- The *HyperText Transfer Protocol* handles transfer of requests and responses from web servers.

Example: HTTP

- When you click on a link, such as

  `http://inst.eecs.berkeley.edu/~cs61a/lectures,`

  your browser:

  - Consults the DNS to find out where to look for `inst.eecs.berkeley.edu`.
  - Sends a message to port 80 at that address:

    ```
    GET ~cs61a/lectures HTTP 1.1
    ```

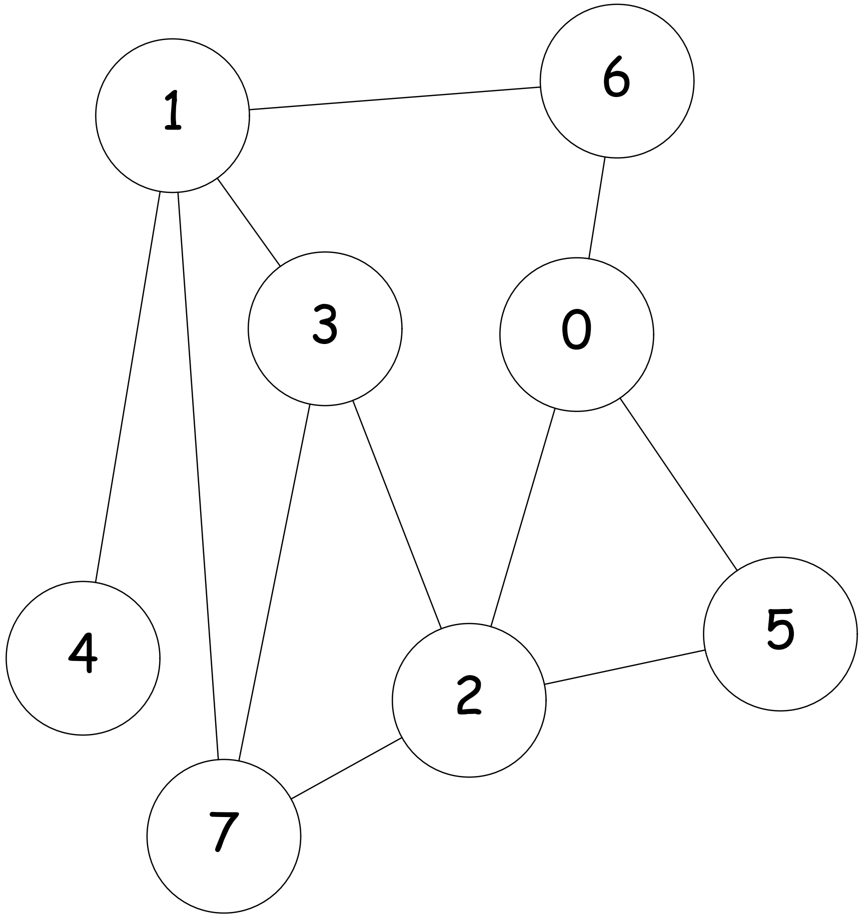
  - The program listening there (the web server) then responds with

    ```
    HTTP/1.1 200 OK
    Content-Type: text/html
    Content-Length: 1354

    <html> ... text of web page
    ```

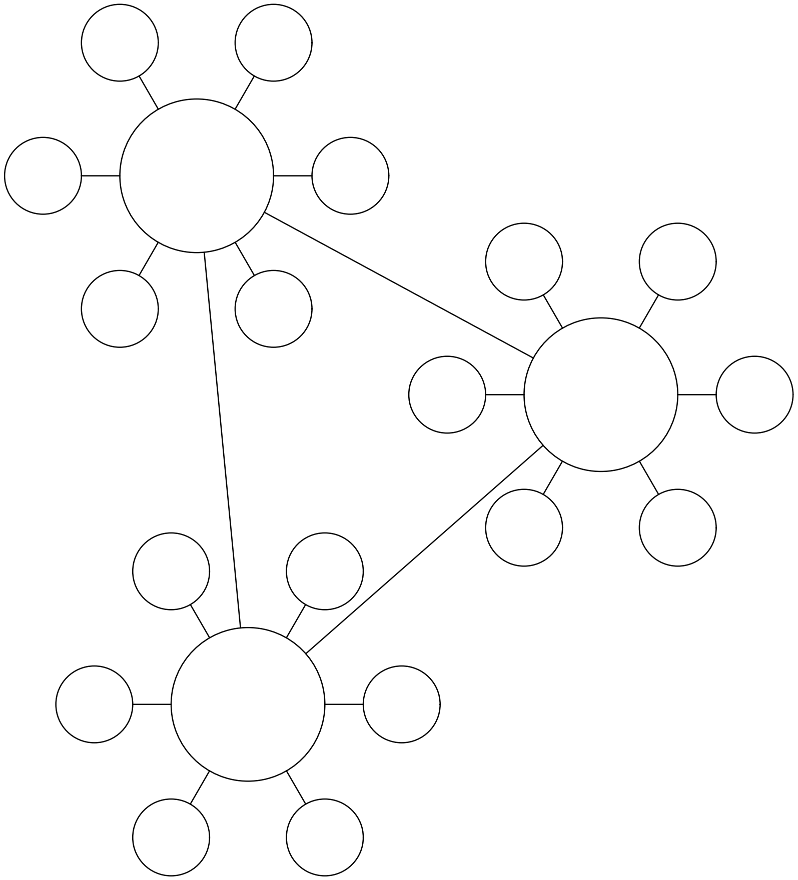
- Protocol has other messages: for example, POST is often used to send data in forms from your browser. The data follows the POST message and other headers.

Peer-to-Peer Communication



- No central point of failure; clients talk to each other.
- Can route around network failures.
- Computation and memory shared.
- Can grow or shrink as needed.
- Used for file-sharing applications, botnets (!).
- But, deciding routes, avoiding congestion, can be tricky.
- (E.g., Simple scheme, broadcasting all communications to everyone, requires N^2 communication resource. Not practical.
- Maintaining consistency of copies requires work.
- Security issues.

Clustering



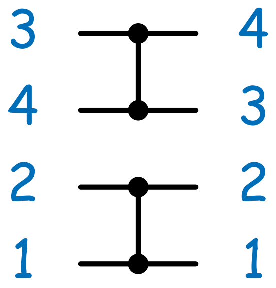
- A peer-to-peer network of “supernodes,” each serving as a server for a bunch of clients.
- Allows scaling; could be nested to more levels.
- Examples: Skype, network time service.

Parallelism

- Moore's law ("Transistors per chip doubles every N years"), where N is roughly 2 (about $5,000,000\times$ increase since 1971).
- Similar rule applied to processor speeds until around 2004.
- Speeds have flattened: further increases to be obtained through *parallel processing* (witness: multicore/manycore processors).
- With distributed processing, issues involve interfaces, reliability, communication issues.
- With other parallel computing, where the aim is performance, issues involve synchronization, balancing loads among processors, and, yes, "data choreography" and communication costs.

Example of Parallelism: Sorting

- Sorting a list presents obvious opportunities for parallelization.
- Can illustrate various methods diagrammatically using *comparators* as an elementary unit:



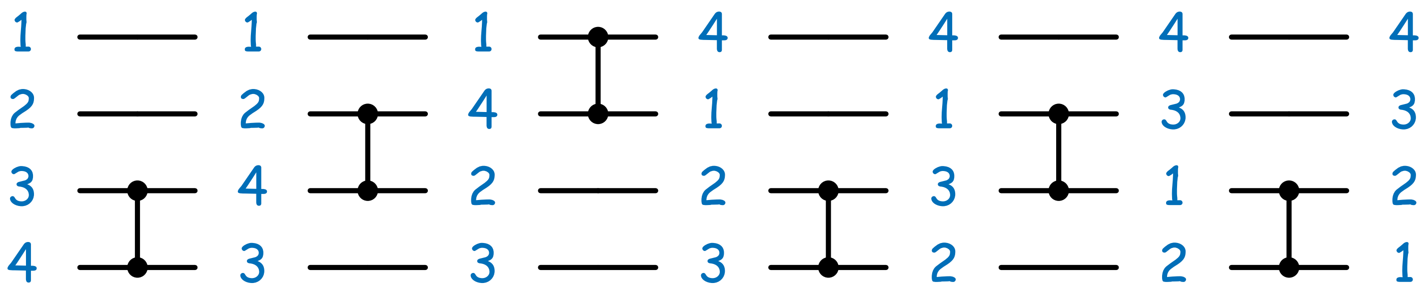
- Each vertical bar represents a *comparator*—a comparison operation or hardware to carry it out—and each horizontal line carries a data item from the list.
- A comparator compares two data items coming from the left, swapping them if the lower one is larger than the upper one.
- Comparators can be grouped into operations that may happen simultaneously; they are always grouped if stacked vertically as in the diagram.

Sequential sorting

- One way to sort a list of items into ascending order goes like this:

```
for i in range(len(L) - 1):
    for j in range(i, len(L) - 1):
        if L[j] > L[j + 1]:
            L[j], L[j+1] = L[j+1], L[j]
```

- In general, there will be $\Theta($? $)$ steps.
- Diagrammatically (read bottom to top):



- Each comparator is a separate operation in time.
- Many comparators operate on distinct data, but unfortunately, there is an overlap between the operations in adjacent columns.

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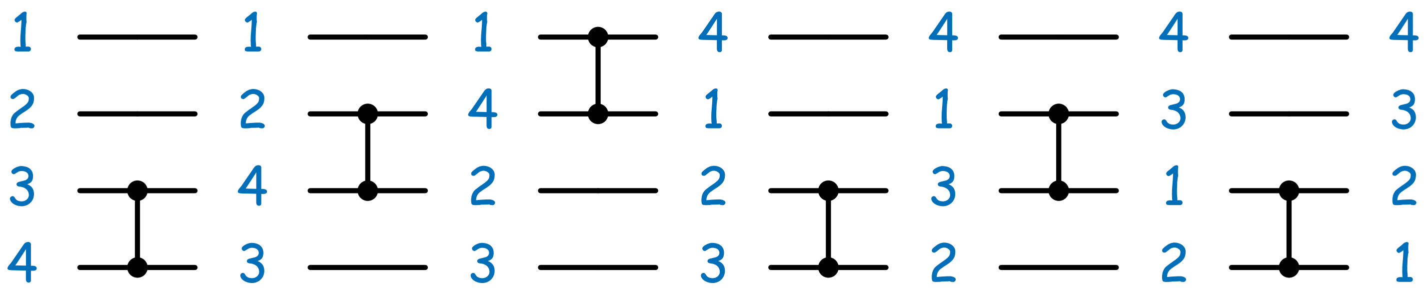
```

- In general, there will be $\Theta(N^2)$ steps.
- Diagrammatically (read bottom to top):



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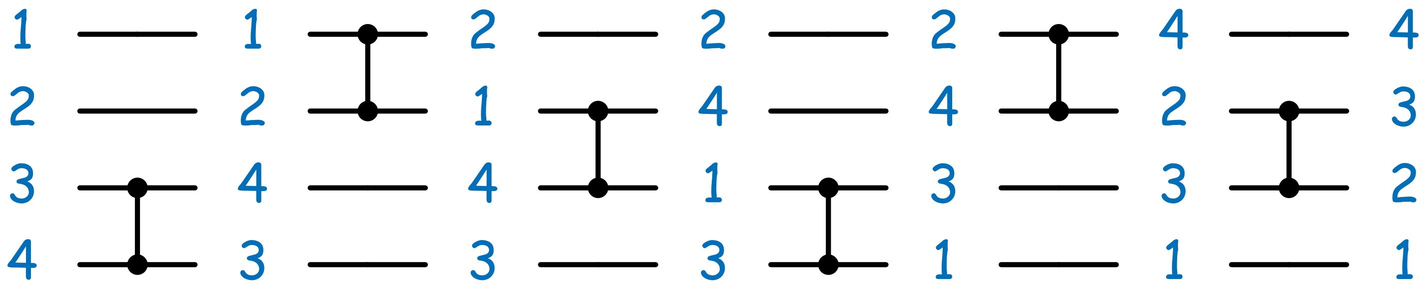
A Reorganization

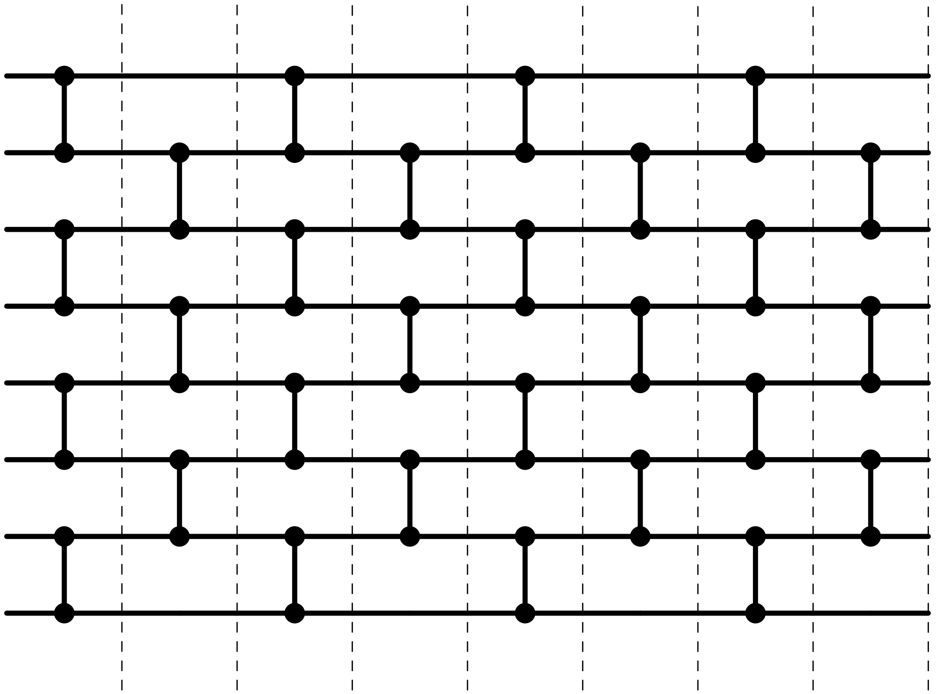
- It's not obvious, but we can accomplish the same final result with a different order of swaps:

```
for c in range(len(L) // 2):
    # Swap even/odd pairs
    for j in range(0, len(L) - 1, 2):
        if L[j] > L[j + 1]: L[j], L[j+1] = L[j+1], L[j]
    # Swap odd/even pairs
    for j in range(1, len(L) - 1, 2):
        if L[j] > L[j + 1]: L[j], L[j+1] = L[j+1], L[j]
```

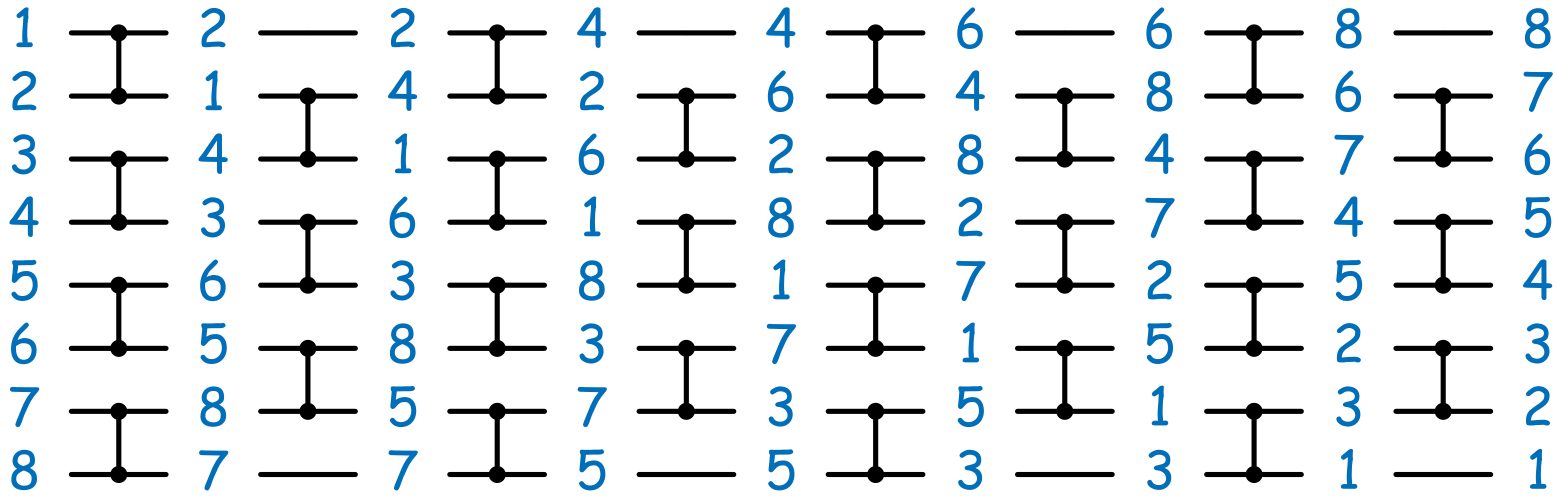


Odd-Even Transposition Sorter

- Now suppose we repeatedly scrunch together adjacent columns of non-overlapping operations:



Odd-Even Sort Example



- What would have been 28 separate sequential operations (in general about $N(N-1)/2$) becomes 8 (N) *parallel operations*.
- If they can be carried out in parallel, we have sped things up by a factor proportional to N.