

Distributed Software Development
Problem Solving I

Chris Brooks

Department of Computer Science
University of San Francisco

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20-2: Distributed Problem Solving

- The preliminary portion of the course focused on techniques for achieving properties or states in distributed systems.
 - Causal delivery, mutual exclusion, etc.
- Now, we turn to the question of how to solve problems in a distributed fashion, assuming that we have implemented some of these properties.

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20-3: Problem environments

- One dimension along which we can characterize distributed problem solving is according to the degree of autonomy or self-interestedness of the participants.
- How much can a protocol assume about the behavior and motives of the participants?

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20-4: Centrally controlled environments

- At one extreme, all processes in a system are controlled by a single individual or organization.
 - Beowulf cluster
 - Parallel computer
 - Intranet
- This allows us to make fairly restrictive assumptions about the behavior of system processes.
 - NFS, parallel computation (e.g. conjugate gradient)

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20-5: Cooperative processes

- We'll also think about processes that are controlled by separate individuals, but assumed to be cooperative.
 - SETI@Home, distributed.net
 - Meeting scheduling
 - TCP (originally)
- In this case, we can assume that processes will act benevolently, but that they will be heterogenous.

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20-6: Non-cooperative processes

- We'll also need to think about non-cooperative systems, in which each process is self-interested.
 - Not necessarily malevolent, just concerned only about its own performance.
- This will require a different set of assumptions about how our protocol should work.
 - Resource allocation, auctions, some scheduling problems, file-sharing

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20-7: TCP: an illustration

- TCP is an example of a protocol that was designed to work in a cooperative environment.
- Recall that TCP is built on top of UDP
 - UDP provides packet-oriented delivery.
- TCP provides reliable in-order delivery on top of UDP.
- Sender A sends a packet to receiver B.
- B returns an acknowledgment that the packet was received.
- If A does not receive an ACK before a timer expires, the packet is resent.

20-8: TCP: an illustration

- To improve transmission efficiency, TCP uses a concept called *sliding windows*.
 - The sender has a “window” of size n . It sends all packets within that window.
 - As the lowest-numbered packet in the window is acknowledged, the window “slides” upward, and more packets are sent.
- This improves transmission rates - the goal is for the network to be completely saturated.

20-9: TCP: an illustration

- The problem is how to deal with congestion.
 - Packets may be dropped by the receiver, or by intermediate hosts.
 - When should the sender resend?
 - Too slow → inefficiency
 - Too quickly → oversaturation is worsened.
- TCP uses an adaptive retransmission policy.
 - As connection performance changes, so does timeout duration.

20-10: TCP: an illustration

- The TCP congestion algorithm does the following (loosely):
 - When a packet is lost, halve the window size and double timeout.
 - If all packets in a window are transmitted successfully, increase window size by 1.
- There are lots of details in the implementation of this that I'm glossing over.
- The key point is this: This protocol works wonderfully, *as long as everyone else also uses it*.
 - Designed to minimize congestion over the entire Internet.

20-11: TCP: an illustration

- In the early days of the Internet, this was not a problem.
 - Small number of users, fewer bandwidth-saturating apps.
- Parallel download of images from web pages was the first concern.
- Later, non-TCP protocols (RTSP, proprietary schemes) implemented their own congestion control algorithms.
- These applications are not necessarily tuned to any sort of global optimum.

20-12: Tragedy of the Commons

- This is an example of a problem known as *tragedy of the commons*.
 - Cost of using a resource is not borne equally by the beneficiaries of that resource.
- Leads to overuse.
- Shared resources, such as networks, tend to be vulnerable to this problem.
- Game theory provides some ideas for dealing with this dilemma.

20-13: Distributing a Problem

- We'll also need to think about how well a problem can be partitioned.
- Typically, a problem is distributed by dividing it into subproblems.
- Each node or process works on its own subproblem.
- Processes may need to communicate with each other.
- A center or coordinator is responsible for doling out subproblems and collecting results.

20-14: Problem Coupling

- We can characterize distributed problems by the degree of interaction that is required between nodes.
- Tightly coupled: nodes must communicate frequently in order to solve subproblems.
- Loosely coupled: Subproblems are relatively independent of each other.
- "Medium coupled": Some interaction must take place.

20-15: Tightly Coupled Problems

- Tightly coupled problems require each node to communicate with other nodes very frequently in order to solve its subproblem.
- Fast, low-latency communication is essential.
- These are the sorts of problems you studied in Prof. Pacheco's Parallel and Distributed Computing class.
 - Inverting a matrix.
 - Solving a system of linear equations
 - Fourier transform

20-16: Tightly Coupled Problems

- Tightly coupled problems typically have a great deal of data dependency between subproblems.
 - Nodes must frequently share partial results in order to proceed.
- This means that tightly coupled problems are best solved in a parallel computer or a LAN.
- All nodes should have roughly the same computing power.
 - A slow process can act as a bottleneck.

20-17: Loosely coupled problems

- At the other end of the spectrum are loosely coupled problems.
- The center can divide up a problem and allow processes to work independently on subproblems.
- Nice for settings in which communication is slow, or nodes may run at different speeds
- Examples:
 - distributed.net
 - SETI@Home

20-18: distributed.net

- A distributed project set up to test the security of symmetric-key encryption algorithms.
- A problem is chosen to solve
- Each node is assigned a subset of the keyspace.
- Node try their subset of the keys and return results to a central server.
- No interaction with other nodes is required.

20-19: Symmetric-key encryption: a brief digression

- Symmetric key encryption (or secret-key encryption) uses one key to encrypt and decrypt a message.
 - As opposed to public-key encryption, which uses pairs of keys.
- A series of bit shifts and ANDs with a key are used to conceal a message.
- Secret-key encryption is “more secure” than public key encryption in the sense that a shorter key is needed to provide the same level of security.

20-20: Symmetric-key encryption: a brief digression

- Two well-known algorithms: DES, RC5.
 - DES was developed by the government in the 50s
 - RC5 was developed at RSA labs in the 90s.
- The only *known* way to defeat them is through exhaustive search of all keys.
- DES keyspace is $2^{keysize}$
- 56-bit secret-key algorithm has a keyspace of $2^{56} = 72$ quadrillion keys.

20-21: distributed.net

- History:
 - 1997: RC5-56 is cracked: 212 days, 34 quadrillion keys searched. (47% of keyspace)
 - 2002: RC5-64 is cracked: 1757 days, over 1.16×10^{19} keys (63%) of keyspace searched. (270 GKeys/sec at completion)
 - RC5-72 is ongoing. (how long will this take at current speeds?)
- Other problems:
 - DES
 - Factoring
 - Golomb rulers

20-22: How does it work?

- The keyspace is broken into set of blocks.
- A master keyserver tracks all blocks:
 - Which are unprocessed
 - Which are currently being processed
 - Which are done.
- It communicates with a set of *proxy keyservers*

20-23: How does it work?

- Proxies serve as a layer between clients and servers.
- Proxies request a block of keys, which are then handed out to clients on demand.
 - Avoids server bottleneck.
 - Round-robin DNS provides fault-tolerance; if one proxy fails, client uses the next available.
- When a client is done processing a block, it returns it to the server.
- Blocks that are unreturned after 90 days are reassigned.

20-24: Grid computing vs. Public resource computing

- distributed.net is an example of what's sometimes referred to as *public resource computing*
 - Unused computing resources are added into an application dynamically
 - Focus is on easily integrating large numbers of clients into an application.
- *Grid computing* is a similar concept
 - Applications can discover and use resources dynamically as they become available.
 - Difference is one of degree: grid computing tends to focus more on interactions between national-lab-level computing facilities.
 - Focus is on access control and rights, management of identity, automated service description, etc.

20-25: SETI@Home

- SETI stands for Search for Extraterrestrial Intelligence
- Radio telescopes listen for transmissions from outer space
 - SETI@Home uses signals captured by a telescope in Puerto Rico
 - Either intended or unintended transmissions
- Radio telescopes produce a vast amount of continuously-occurring data.
 - Approximately 35GB/day
- Standard SETI programs can only examine the data superficially
- By dividing the data into small pieces, it can be distributed to clients worldwide for processing.

20-26: SETI@Home

- Data is captured by the telescope onto 35 GB magnetic tapes, then mailed to Berkeley.
- It is then broken into 0.25 MB chunks.
- Each chunk represents about 107 seconds of data in a 10kHz range of the electromagnetic spectrum.
- As with distributed.net, each chunk can be processed completely independently of the others.

20-27: SETI@Home

- FFTs are used to extract signals at specific frequencies
- Doppler effects are removed. (this is the computationally intensive part)
- Looks for signals with a Gaussian shape (weaker, then strong, then weak again)
 - Since the telescope is fixed and the Earth rotates, a signal will 'move across it' in about 12 seconds.
 - Earth-based transmissions will have a constant amplitude.
- Also looks for pulsed signals.

20-28: The SETI@Home architecture

- Once data arrives at Berkeley, a *splitter* program preprocesses it and divides it into workunits (or chunks).
- These are then stored in a database.
- Clients interact with a data server that distributes workunits.
- The client may then disconnect and work on the data for as long as necessary.
- Results are then returned from the client to the server.

20-29: The SETI@Home architecture

- Data is distributed redundantly (the same block is sent to several clients).
 - This provides fault tolerance.
- Results are returned to the server, where they are written to a file, then processed and entered into a database.
- Once a workunit has enough results, it is considered complete and the results are aggregated.

20-30: The distributed search problem

- SETI@Home and distributed.net are both examples of *distributed search*
 - Exhaustively examine a huge search space.
- This sort of problem has many characteristics that make it appealing for large-scale distributed computing
 - All compute nodes are independent of each other.
 - No bottlenecks at client
 - No need for client-client communication
 - Failure of a compute node is easily tolerated.
 - Redundant computation of results is not a problem.
 - Clients can be stopped and restarted without problem.

20-31: Folding@Home

- Folding@Home is a similar project that aims to simulate the protein folding process.
 - Goal: understand how individual proteins bind together into larger structures.
- Simulating a process that may take microseconds can take months
- Folding@Home allows many clients to work on the problem in parallel.
- Architecturally very similar to SETI@Home.

20-32: Folding@Home

- Unlike SETI@Home, a single simulation of a protein fold can't be easily subdivided.
 - Simulating a series of dependent events
- Folding@Home takes advantage of the statistical nature of protein folding
 - Results are not deterministic
 - Processes change from state to state periodically
- Insight: run many simulations simultaneously. When one changes state, change all the others.
- Only infrequent communication with clients is needed.

20-33: BOINC

- BOINC (Berkeley Open Infrastructure for Network Computing) is a generalization of the SETI@Home project
 - Rosetta@Home - protein structure
 - Einstein@Home - search for pulsars
 - Climateprediction.net - Eco-simulations
 - Predictor@Home - studies protein-related diseases.
- All of these problems can be expressed in the framework used by SETI@Home.
 - Problem is decomposed into work units.
 - Scheduling servers hand out work units to clients and handle reports of completed results.
 - Data servers handle upload of actual data.

20-34: BOINC

- Given this basic model for doing distributed computing, the problem becomes one of translating your problem into the BOINC framework.
 - Parallelize your algorithm if possible
 - Identify existing serial implementations for pieces of your problem
 - Identify appropriately-sized workunits
 - Can (should) multiple clients work on the same workunit?
 - Do clients need to generate data?

20-35: "Medium-coupled" problems

- The BOINC model works great for highly parallel problems
- A large class of problems exist between the extrema of matrix inversion and SETI@home/BOINC.
- Typically, the problem can be somewhat decomposed, but some communication or synchronization between computing nodes is needed.
 - Scheduling problems
 - Dynamic programming problems
 - Planning problems
- Next week, we'll look at a particular well-studied example: distributed constraint satisfaction.

20-36: Summary

- Distributed problem solving requires an awareness of:
 - Distribution of control
 - How a problem can be decomposed
- Tightly-coupled problems are best attacked in environments with synchronous, low-latency communication and homogenous processors.
- Loosely-coupled problems (distributed.net, SETI@home) are appropriate for heterogeneous environments with asynchronous, sporadic communication.