Real Time and Clocks

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Real time and clocks

- Lamport showed that if we care about event ordering, the best option is to use logical clocks
- But suppose we care about real time?
  - How well can clocks be synchronized?
  - To what extent can the operating system help us build applications that are sensitive to time?

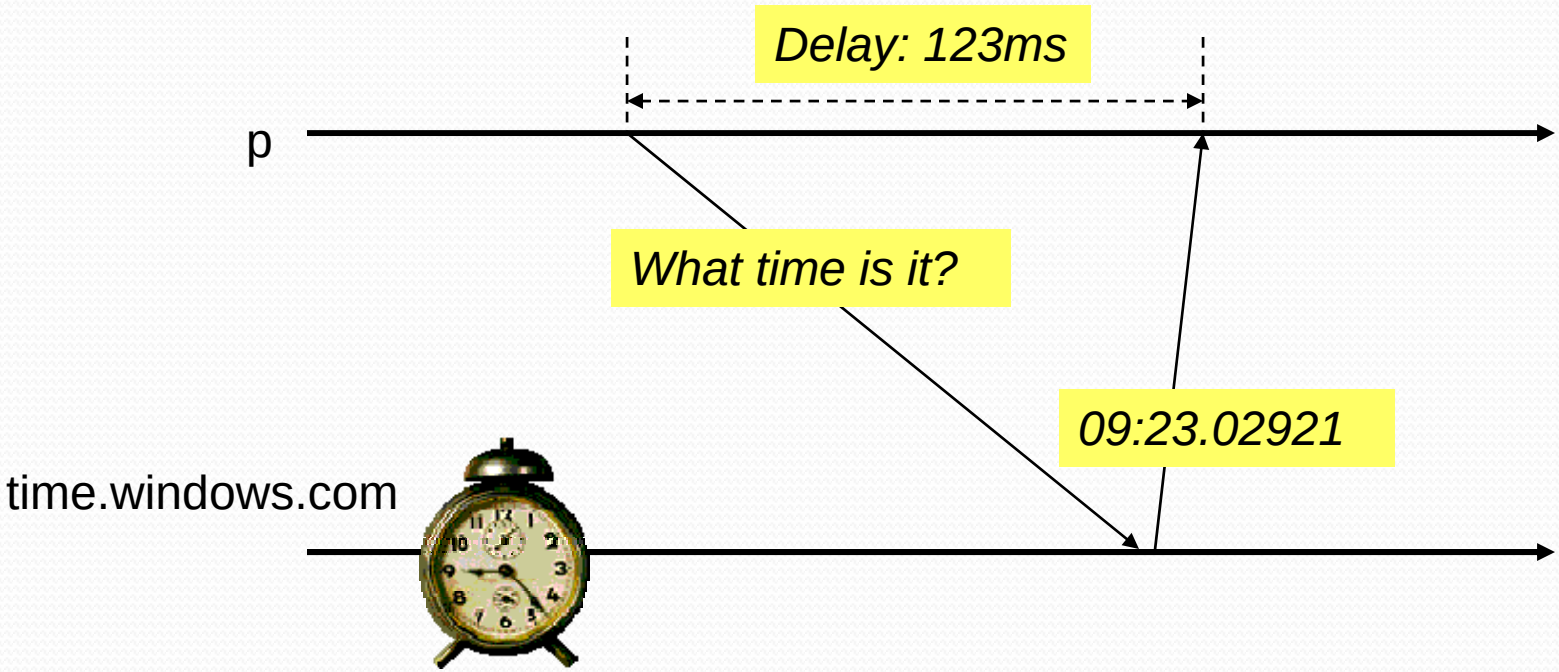
Introducing “wall clock time”

- There are several options
  - “Extend” a logical clock or vector clock with the clock time and use it to break ties
    - Makes meaningful statements like “B and D were concurrent, although B occurred first”
    - But unless clocks are closely synchronized such statements could be erroneous!
  - We use a clock synchronization algorithm to reconcile differences between clocks on various computers in the network

Synchronizing clocks

- Without help, clocks will often differ by many milliseconds
  - Problem is that when a machine downloads time from a network clock it can't be sure what the delay was
  - This is because the "uplink" and "downlink" delays are often very different in a network
- Outright failures of clocks are rare…

Synchronizing clocks

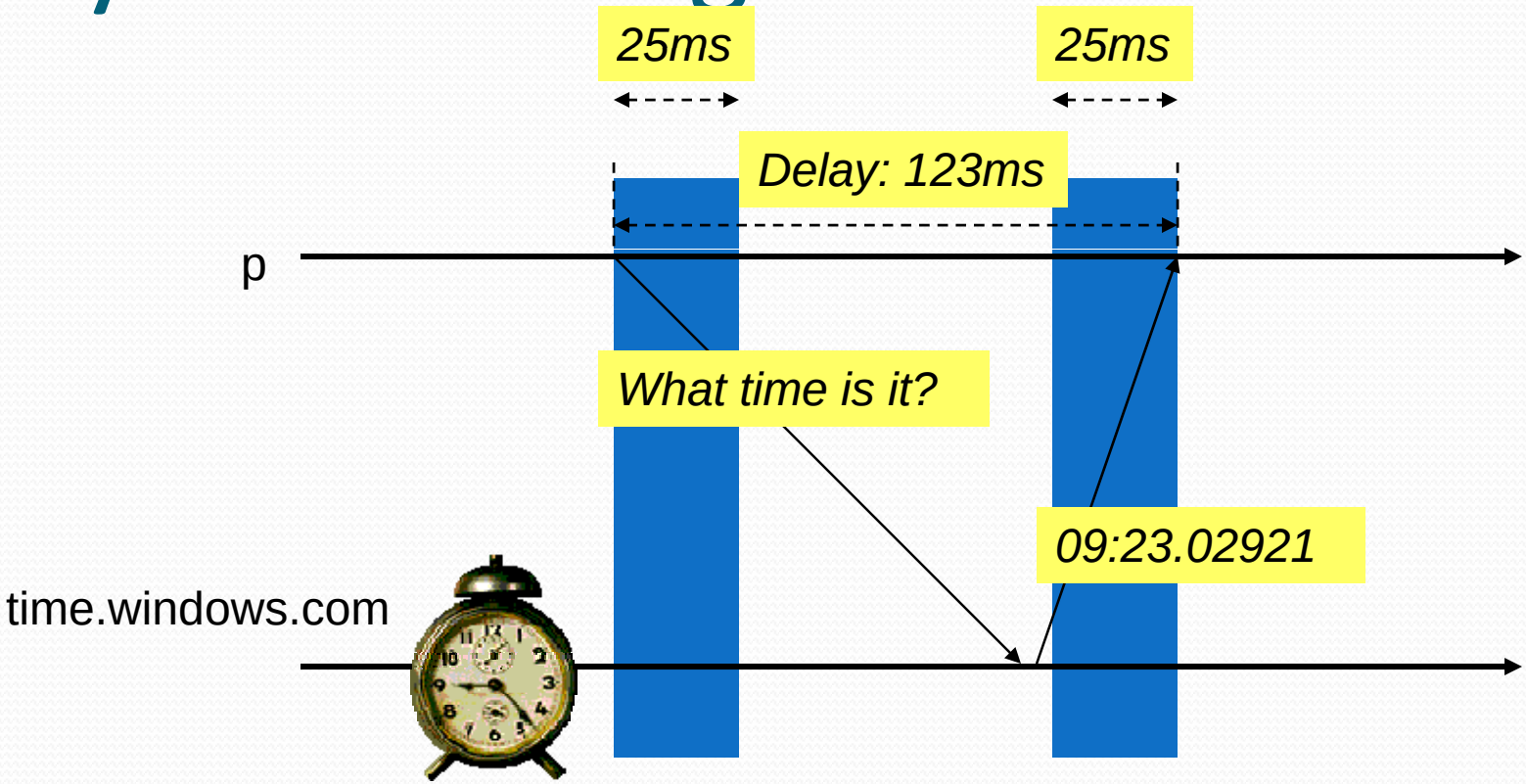


- *Suppose p synchronizes with time.windows.com and notes that 123 ms elapsed while the protocol was running… what time is it now?*

Synchronizing clocks

- Options?
  - P could guess that the delay was evenly split, but this is rarely the case in WAN settings (downlink speeds are higher)
  - P could ignore the delay
  - P could factor in only “known” delay
    - For example, suppose the link takes at least 25ms in each direction…

Synchronizing clocks



- *Suppose p synchronizes with time.windows.com and notes that 123 ms elapsed while the protocol was running… what time is it now?*

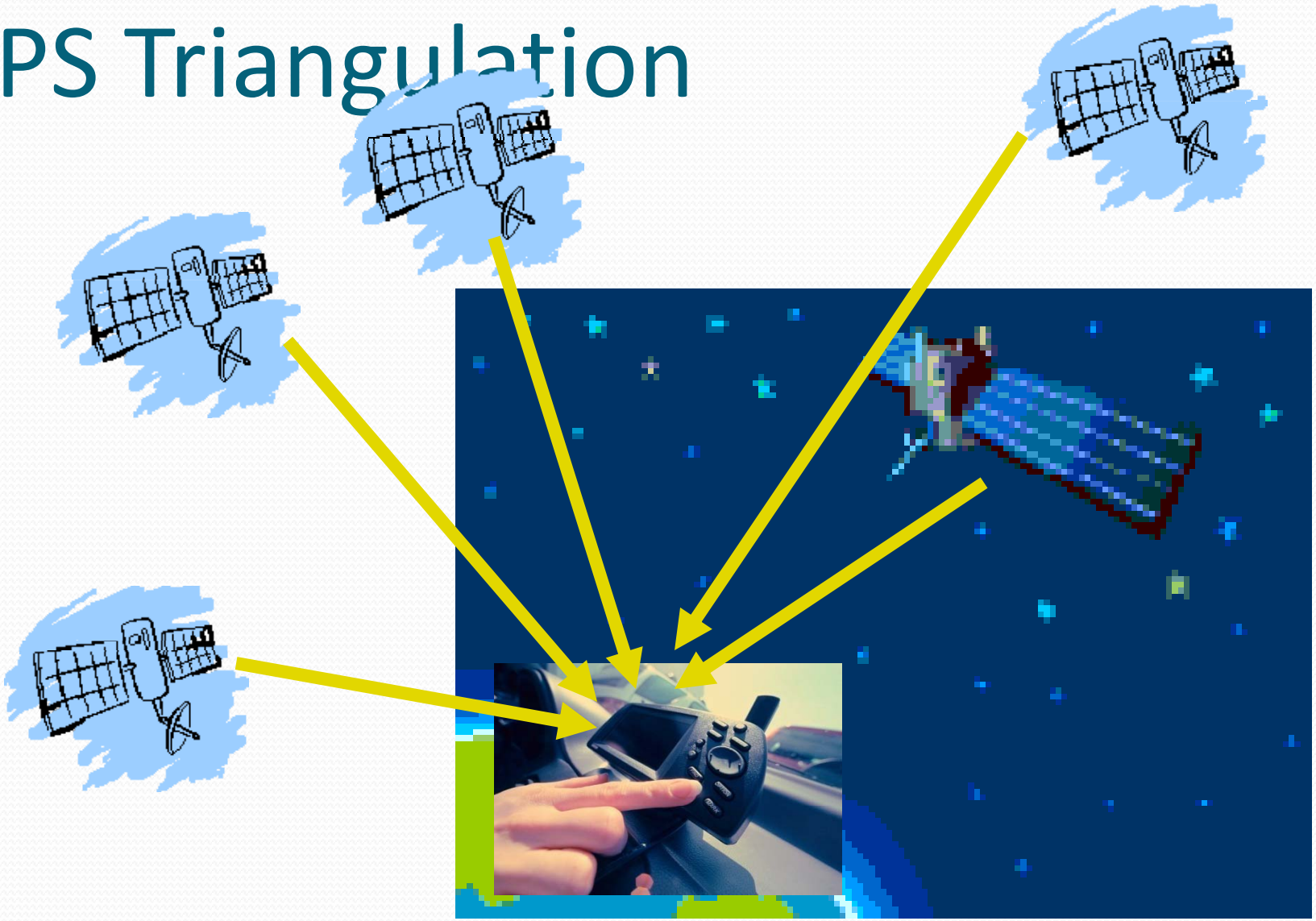
Synchronizing clocks

- In general can't do better than uncertainty in the link delay from the time source down to p
  - Take the measured delay
  - Subtract the "certain" component
  - We are left with the uncertainty
- Actual time can't get more accurate than this uncertainty!

What about GPS?

- GPS has a network of satellites that send out the time, with microsecond precision
- Each radio receiver captures several signals and compares the time of arrival
- This allows them to triangulate to determine position

GPS Triangulation



Issues in GPS triangulation

- Depends on very accurate model of satellite position
  - In practice, variations in gravity cause satellite to move while in orbit
- Assumes signal was received “directly”
  - Urban “canyons” with reflection an issue
- DOD encrypts low-order bits

GPS as a time source

- Need to estimate time for signals to transit through the atmosphere
  - This isn't hard because the orbit of the satellites is well known
  - Must correct for issues such as those just mentioned
- Accurate to +/- 25ms without corrections
- Can achieve +/1 1us accuracy with correction algorithm, if enough satellites are visible

Consequences?

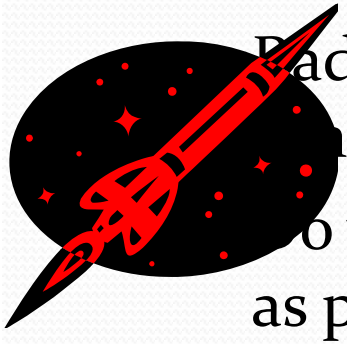
- With a cheap GPS receiver, 25ms accuracy, which is large compared to time for exchanging messages
  - 10,000 msgs/second on modern platforms
  - … hence .1ms "data rates"
  - Moreover, clocks on cheap machines have 10ms accuracy
- But with expensive GPS, we could timestamp as many as 100,000 msgs/second

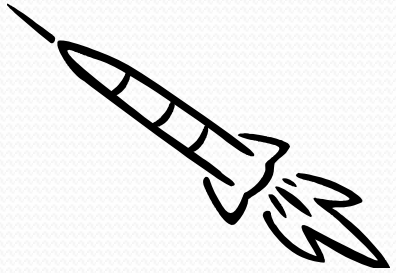
Accuracy and Precision

- *Accuracy* is a measure of how close a clock is to "true" time
- *Precision* is a measure of how close a set of clocks are to one-another
  - Both are often expressed in terms of a window and a drift rate

Thought question

- We are building an anti-missile system
- Radar tells the interceptor where it should be and what course to get there
- So we want the radar and interceptor to be as accurate as possible, or as precise as possible?





Thought question

- We want them to agree on the time but it isn't important whether they are accurate with respect to "true" time
  - "Precision" matters more than "accuracy"
  - Although for this, a GPS time source would be the way to go
    - Might achieve higher precision than we can with an "internal" synchronization protocol!

Real systems?

- Typically, some “master clock” owner periodically broadcasts the time
- Processes then update their clocks
  - But they can drift between updates
  - Hence we generally treat time as having fairly low accuracy
  - Often precision will be poor compared to message round-trip times

Clock synchronization

- To optimize for precision we can
  - Set all clocks from a GPS source or some other time "broadcast" source
    - Limited by uncertainty in downlink times
  - Or run a protocol between the machines
    - Many have been reported in the literature
    - Precision limited by uncertainty in message delays
    - Some can even overcome arbitrary failures in a subset of the machines!

Adjusting clocks: Not easy!

- Suppose the current time is 10:00.00pm
  - Now we discover we're wrong
  - It's actually 9:59.57pm!
- Options:
  - Set the clock back by 3 seconds…
    - But what will this do to timers?
    - Implies a need for a "global time warp"
  - Introduce an artificial time drift
    - E.g. make clock run slowly for a little while

Real systems

- Many adjust time “abruptly”
  - Time could seem to freeze for a while, until the clock is accurate (e.g. if it was fast)
  - Or might jump backwards or forwards with no warning to applications
- This causes many real systems to use relative time: “now + XYZ”
  - But measuring relative time is hard

Some advantages of real time

- Instant common knowledge
  - “At noon, switch from warmup mode to operational mode”
  - No messages are needed
  - Action can be more accurate that would be possible (due to speed of light) with message agreement protocols!

Some advantages of real time

- The outside world cares about time
  - Aircraft attitude control is a “real time” process
  - People and cars and planes move at speeds that are measured in time
  - Physical processes often involve coordinated actions in time

Disadvantages of real time

- On Monday, we saw that causal time is a better way to understand event relationships in actual systems
  - Real time can be deceptive
  - Causality can be tracked… and is closer to what really mattered!
- For example, a causal snapshot is “safe” but an instantaneous one might be confusing

Internal uses of time

- Most systems use time for expiration
  - Security credentials are only valid for a limited period, then keys are updated
  - IP addresses are “leased” and must be refreshed before they time out
  - DNS entries have a TTL value
  - Many file systems use time to figure out whether one file is fresher than another

The “endless rebuild problem”

- Suppose you run Make on a system that has a clock running slow
  - File xyz is “older” than xyz.cs, so we recompile xyz…
  - … creating a new file, which we timestamp
  - … and store
- The new one may STILL be “older” than xyz.cs!

Implications?

- In a robust distributed system, we may need trustworthy sources of time!
  - Time services that can't be corrupted and won't run slow or fast
  - Synchronization that really works
  - Algorithms that won't malfunction if clocks are off by some limited amount

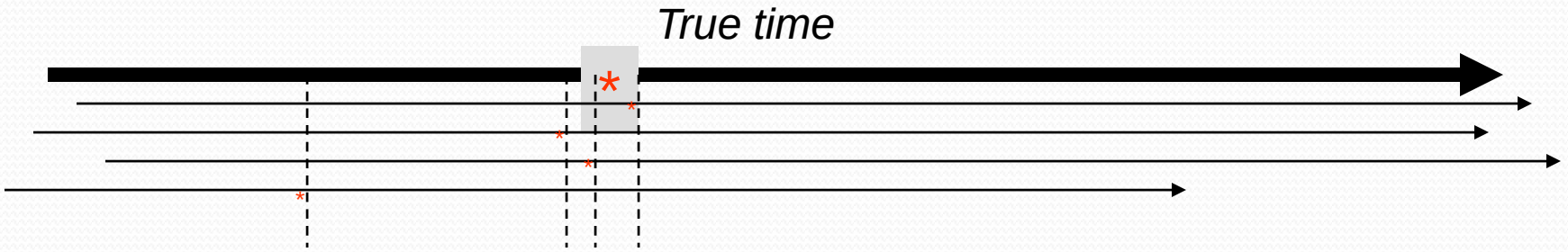
Fault-tolerant clock sync

- Assume that we have 5 machines with GPS units
- Each senses the time independently
- Challenge: how to achieve optimal precision and accuracy?

Srikanth and Toueg

- You can't achieve both at once
  - To achieve the best precision you lose some accuracy, and vice versa
- Problem is ultimately similar to Byzantine Agreement
  - We looked at this once, assuming signatures
  - Similar approach can be used for clocks

Combining “sensor” inputs



- “Shout at 10:00.00”

Combining “sensor” inputs

- Basic approach
  - Assume that no more than k out of n fail
    - Depending on assumptions, k is usually bounded to be less than n/3
  - Discard outliers
  - Take mean of resulting values
- Attacking such a clock?
  - Try and be “as far away as possible” without getting discarded

How do real clocks fail?

- Bits can stick
  - This gives clocks that “jump around”
- The whole clock can get stuck, perhaps erratically
- Clock can miscount and hence drift (backwards) rapidly

Using real-time

- Consider using a real-time operating system, clock synchronization algorithm, and to design protocols that exploit time
- Example: MARS system uses pairs of redundant processors to perform actions fault-tolerantly and meet deadlines. Has been applied in process control systems. (Another example: Delta-4)

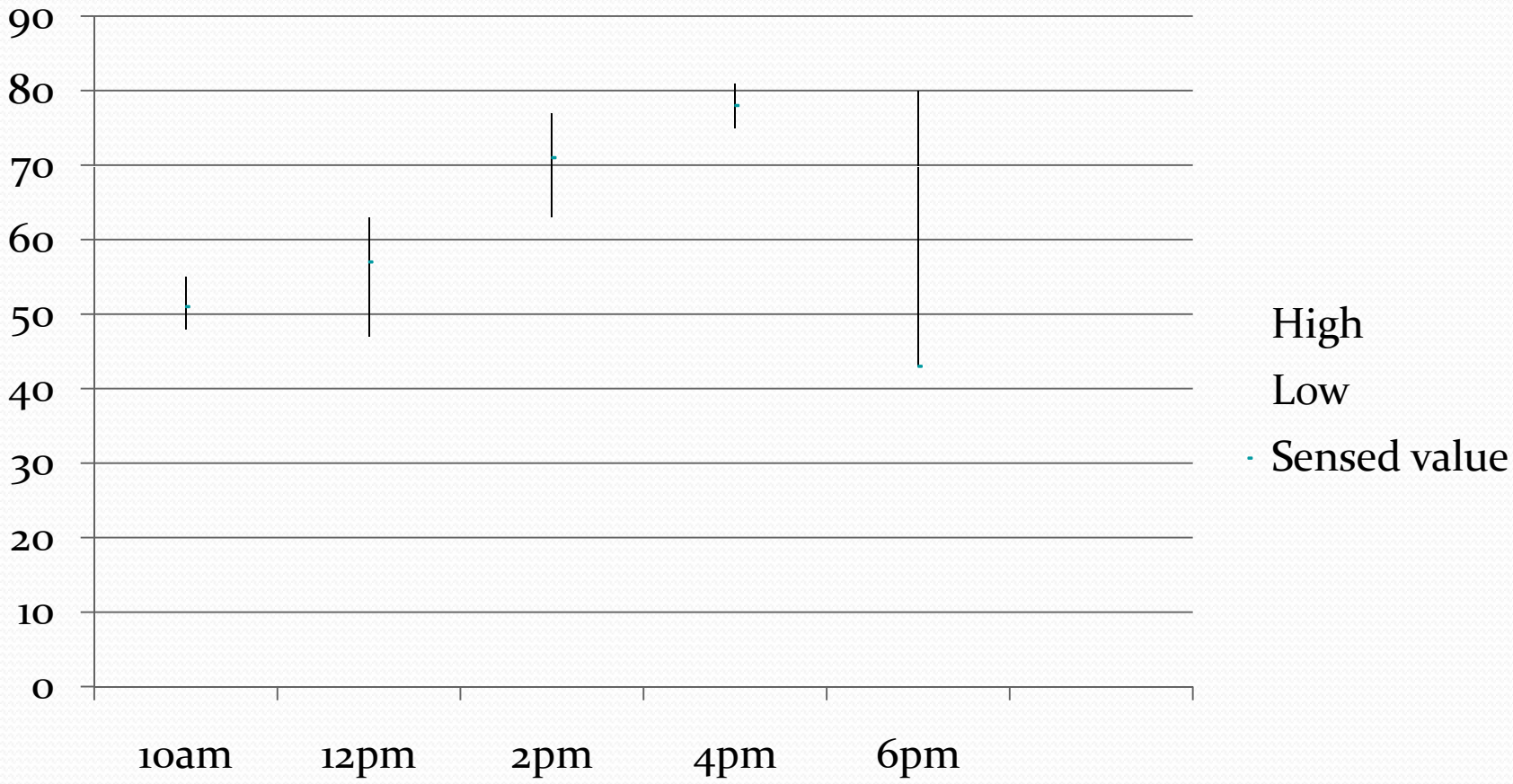
Using time with sensors

- Many distributed systems monitor something in the outside world
  - They use "sensors" to capture data such as temperature, video images, etc. Often data comes with build-in precision limits
  - Then label these with time
- We've seen that time comes with imprecision too
- How does this impact applications that "sense" things?

Time with sensors

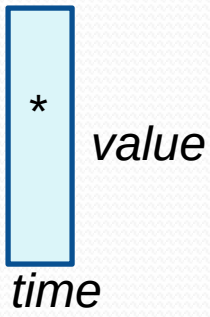
- Suppose that an application tracks temperature in Ithaca
  - At 10:00am, 52 degree F
  - At noon, 68 degrees F
  - At 2:00pm, 74 degrees F
  - At 6:00 pm 58 degrees F
- And temperature is +/- 2 degrees

Temperatures



Do we really know the value?

- The 12pm value was really within a "bounding box"
  - The value was between, say, 63 and 67 with a "best estimate" of 65
  - But the *time* was also in a range of possible times
    - Perhaps, between 11:59 and 12:01
- So we should think of the sensor value as a box

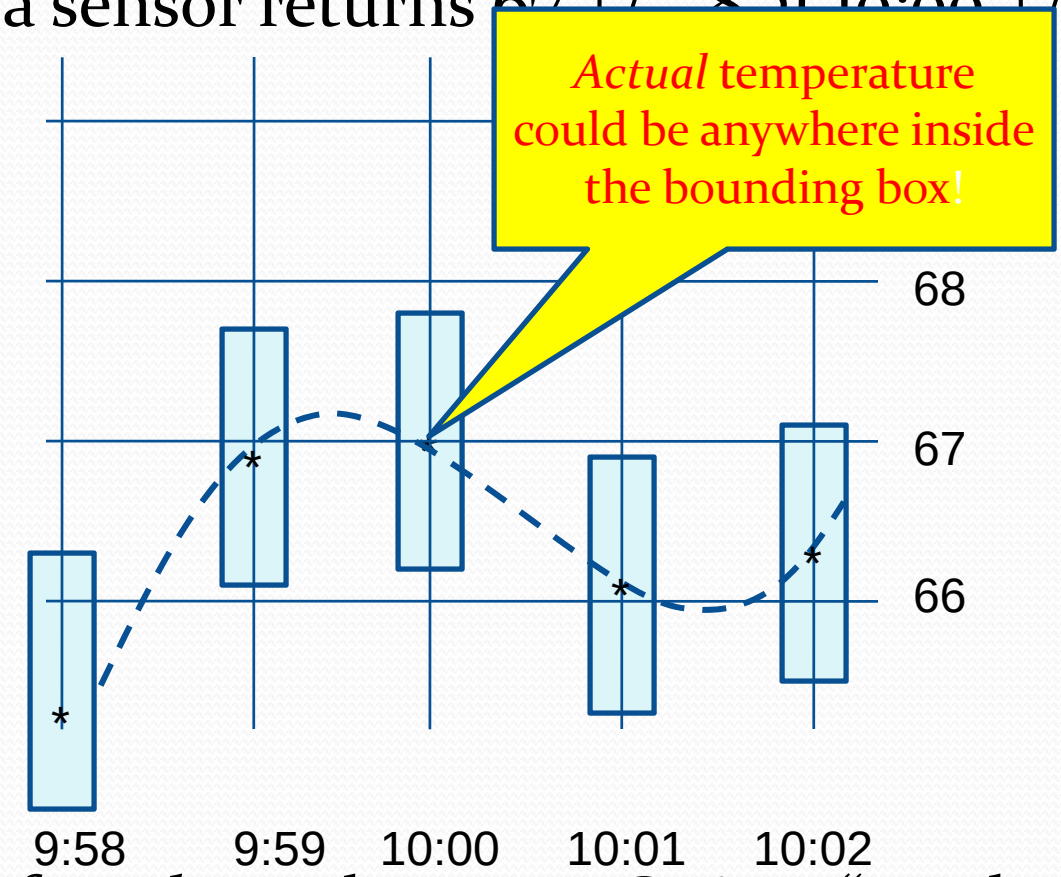


Does this matter?

- Suppose that we are supposed to *only activate the assembly line once all the furnaces have reached operating temperature*
- Or *vent the reactor vessel if the pressure goes over 100 lbs per square inch*
- How would we translate these rules to work with sensors that return values in “boxes”?

“Maybe” versus “Definitely”

- Suppose a sensor returns 67 +/- 8 at 10:00 +/- 10 secs



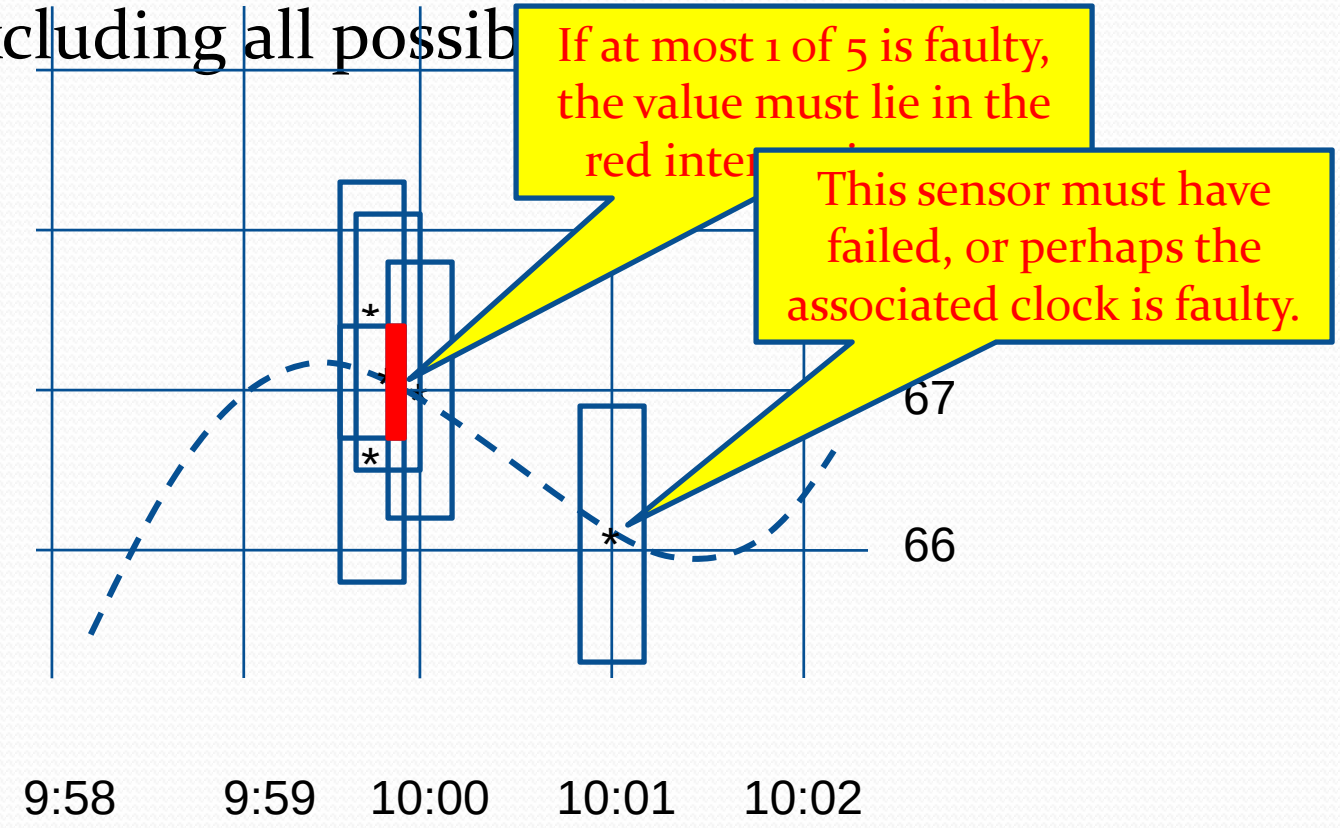
- Was it *definitely* 68 degrees? Or just “maybe”?

Wood and Marzullo

- Looked at issues of clock and sensor synchronization
- Developed fault-tolerance mechanisms for estimating data values and synchronizing clocks
- Showed how to deal with imprecision
  - You needed to tell them which behavior you wanted
  - Then they interpreted the question relative to the "bounding box" for the sensor

Overcoming errors

- If we have *n* readings and at most *k* are faulty, intersect boxes (excluding all possib



Back to our questions

- *Only activate the assembly line once all the furnaces have [definitely] reached operating temperature*
  - We want to know that the temperature is *definitely* high enough. *Entire bounding box* must be above the threshold temperature to be safe, since any point in the box is a "possibility" for the current temperature
- *Vent the reactor vessel if the pressure [may be] over 100 lbs per square inch*
  - Trigger vent if *any portion of the box* is over threshold, because (perhaps) the vessel has reached that pressure.

Other issues to consider

- *Source* of imprecision is often the operating system
  - Scheduling delays
  - Paging
  - Contention for resources (locking)
- To overcome these problems it can be helpful to use a *real time operating system* in addition to using clock synchronization or sensor synchronization protocols
- By reducing uncertainty these "shrink the box"

Summary

- On Monday we saw that events in a system are best understood in terms of the logical progression of time
- Now we've looked at real (clock) time, which is one form of sensor, and also other kinds of sensor inputs
- Imprecise measurements force us to think in terms of bounding boxes with values in the box
  - We can use this to overcome errors
  - And we can also intepret queries over sensors and time in ways that explicitly cope with imprecision