HACMS kickoff meeting: TA3

Technical Area 3: Control Software

John Rushby

Computer Science Laboratory
SRI International
Menlo Park, CA

Overview

- Assured sensor fusion using interval representations
- Synthetic sensors
- Controller synthesis with a safety envelope

Sensor Fusion

- Flawed sensor fusion (in the presence of faults) is a major source of accidents and incidents in commercial aircraft
  - Airbus A330 accident, Learmonth, 2008: 3 AOA sensors
  - Boeing 777 upset, Perth, 2005: 7 accelerometers
- Because of its difficulty, sometimes prefer not to use all available information
  - 737 crash, Schipol, 2009: single radar altimeter
- Rich opportunity for attackers: RQ-170 Sentinel over Iran
- So our first step is assured sensor fusion in the presence of faults and attacks

Communicating a Single Sensor Sample

- Traditional Approach: send a single number
  - Indicates best estimate, but not its quality

- Instead, send an interval
  - Nonfaulty sensor guarantees true value is in this range
  - Width of interval indicates quality
  - Embellishment: interval is a function of time since sample
  - Possibly a use-by time also

Fusing Multiple Point Samples

Traditional Approach (e.g., with 3 samples)

Fusing for a single value:

Mid-value select when 3, average when 2

Eliminating faulty samples:

Reject if not within 15% of the others

Problems: thumps and bad values, and worse

Experience: X29

- Three sources of air data: a nose probe and two side probes
- Selection algorithm used the data from the nose probe, provided it was within some threshold of the data from both side probes
- The threshold was large to accommodate position errors in certain flight modes
- Belated discovery: if nose probe failed to zero at low speed, it would still be within the threshold of correct readings, causing the aircraft to become unstable and "depart"
- 162 flights had been at risk
- Recent methods use more complex selection algorithms
- Take the dynamics into account
- Generally validated by Matlab simulations

Fusing Multiple Interval Samples

Theorem: true value must be in overlap of nonfaulty intervals

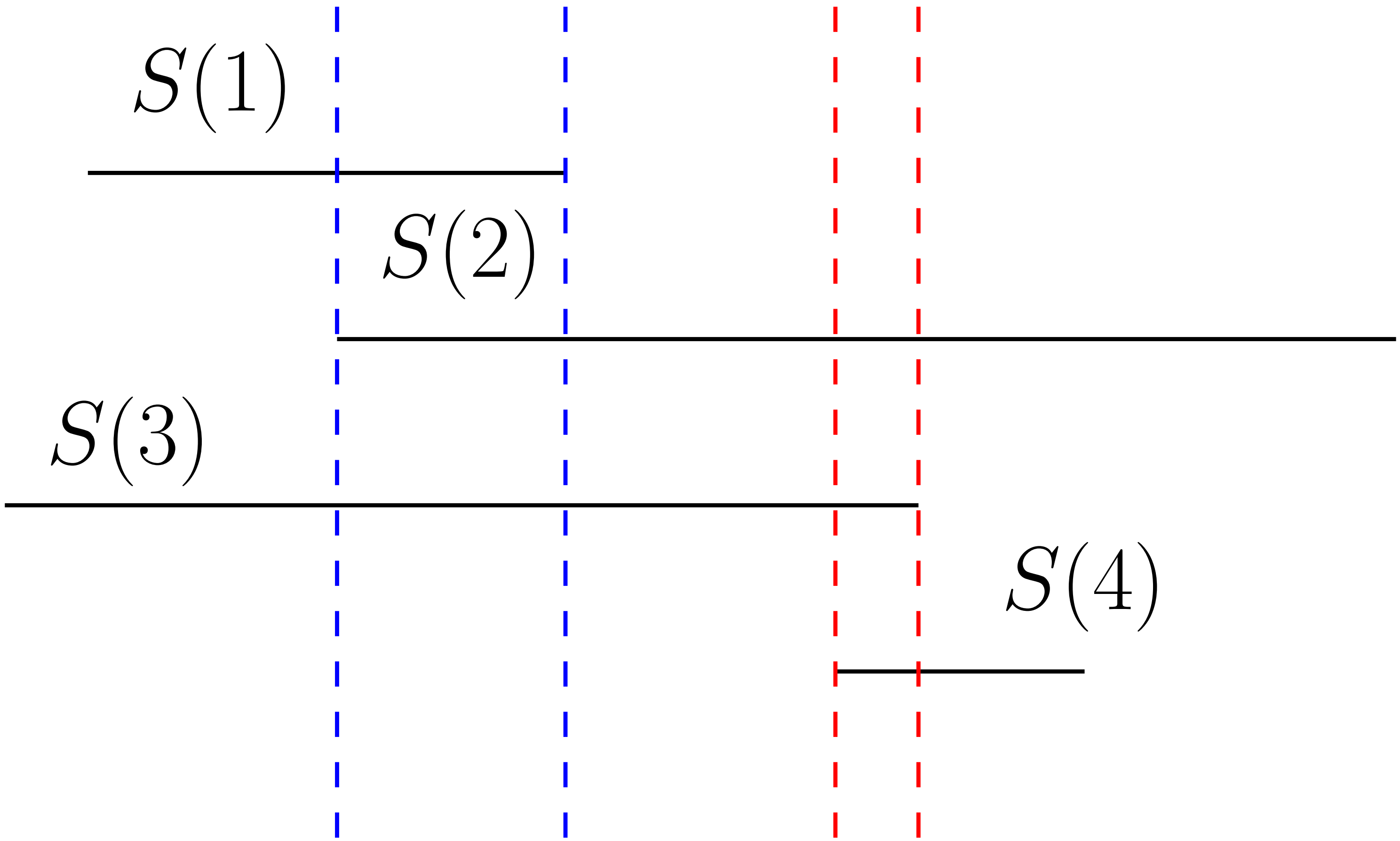
Calculating consensus interval: to tolerate f faults in n, choose interval that contains all overlaps of $n-f$;

i.e., from least value contained in $n-f$ intervals to largest value contained in $n-f$ (Marzullo)

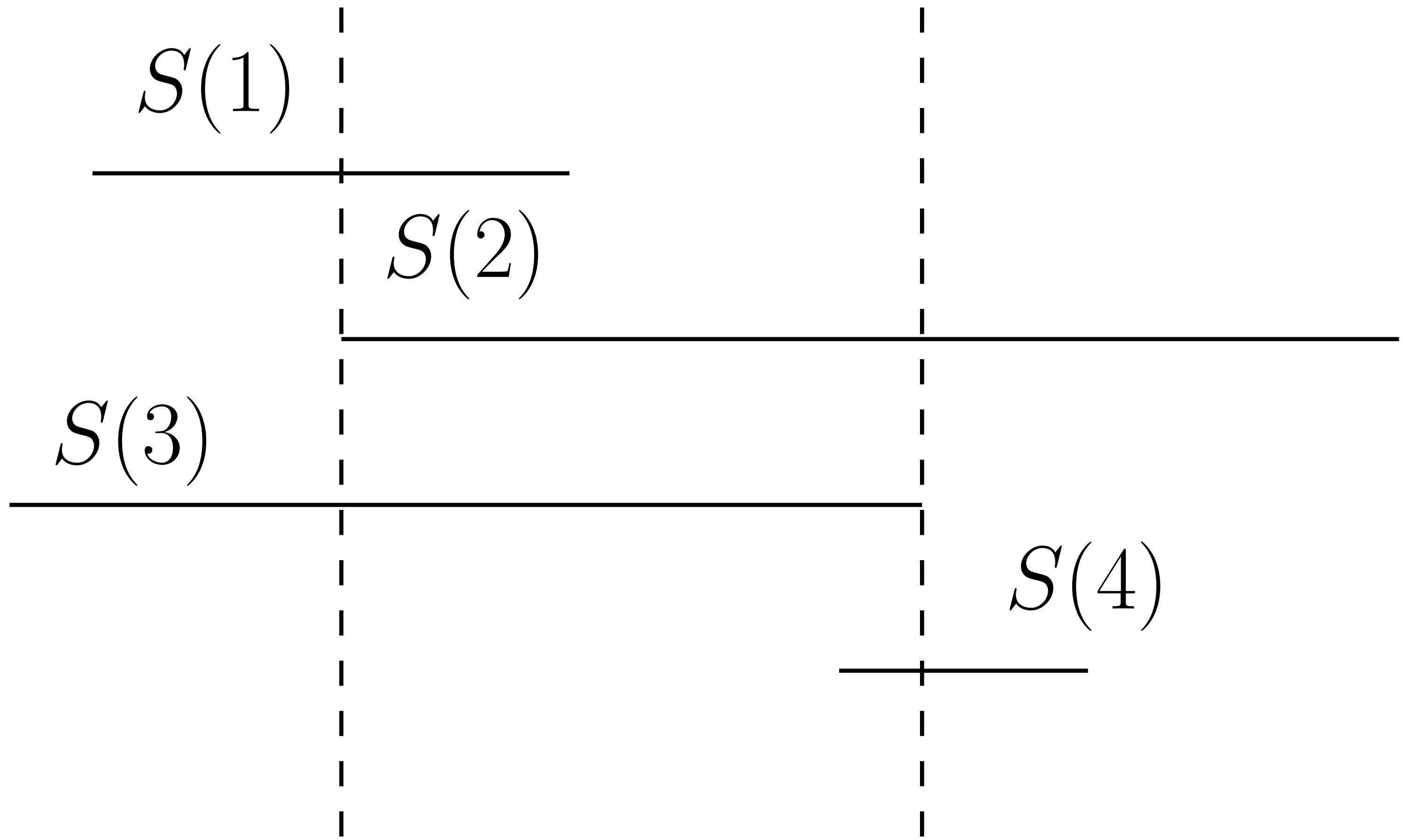
An interesting small exercise in formal verification (finite sets, predicate subtypes, dependent types)

Eliminating faulty samples: separate problem, not needed for fusing, but any sample disjoint from the consensus interval must be faulty

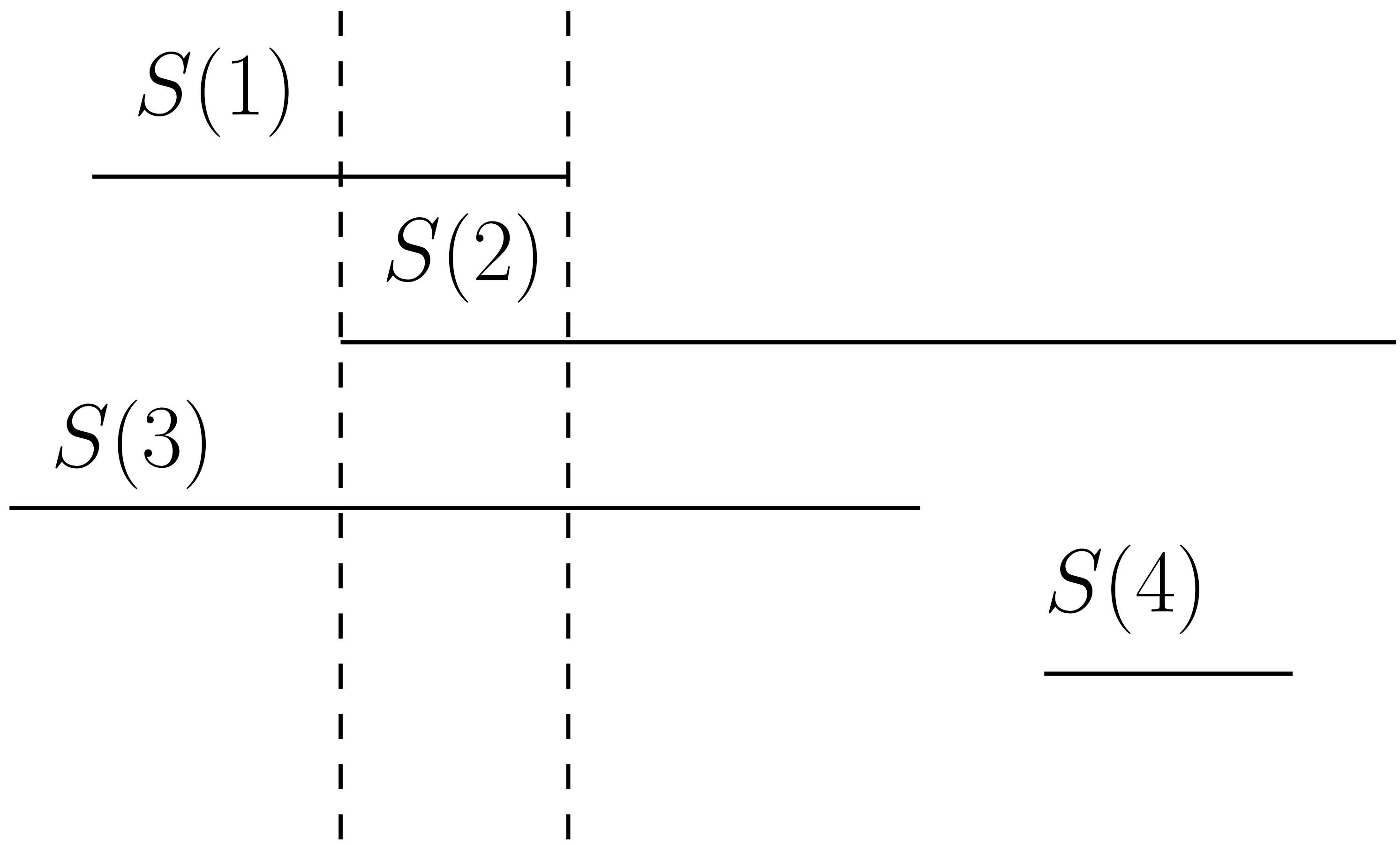
True Value In Overlap Of Nonfaulty Intervals



Marzullo's Fusion Interval



Marzullo's Fusion Interval: Fails Lipschitz Condition

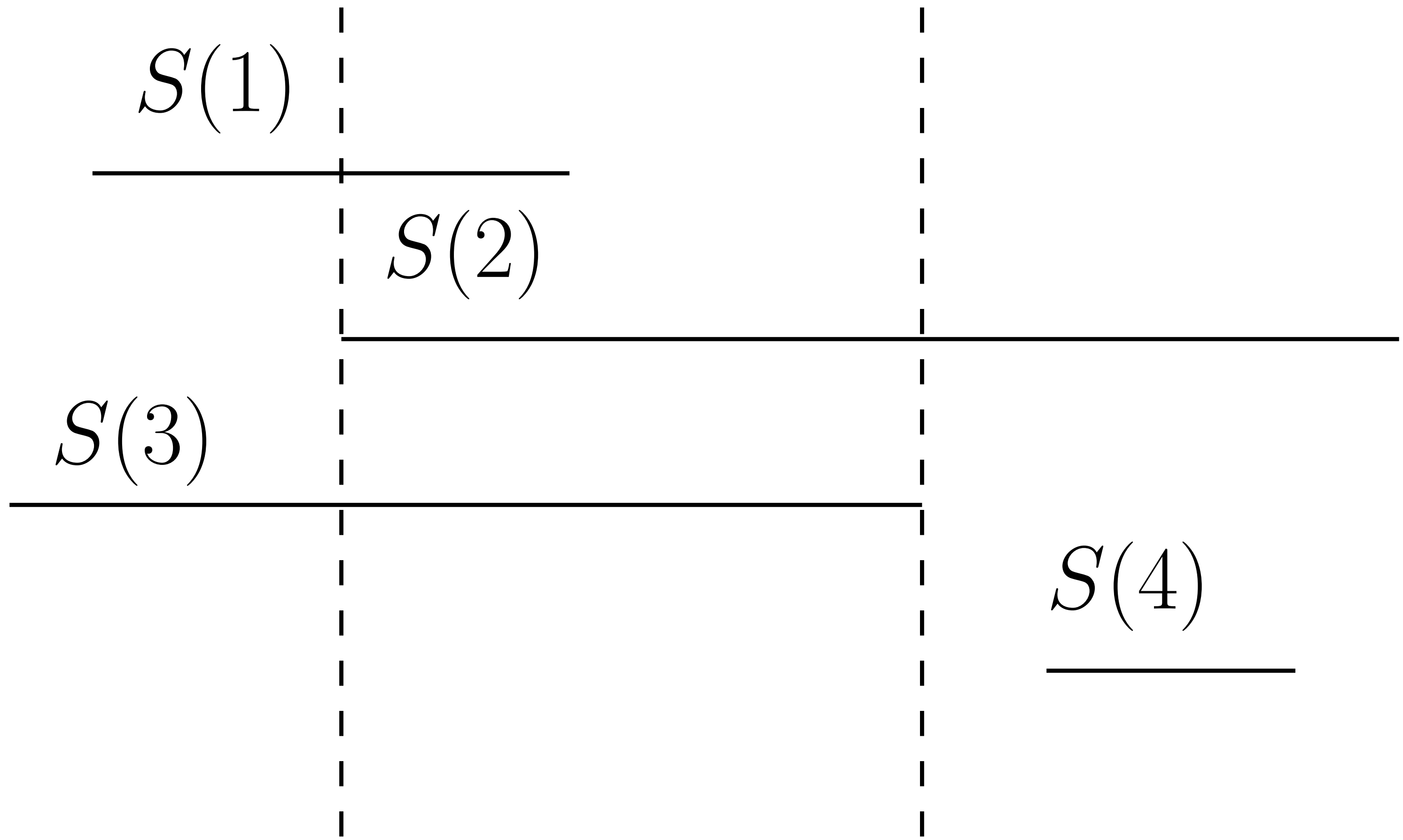


Schmid's Fusion Interval

- Choose interval from $f+1$'st largest lower bound to $f+1$'st smallest upper bound

- Optimal among selections that satisfy Lipschitz Condition

Schmid's Fusion Interval



Synthetic Sensors

- Once we can safely fuse sensors, we can use many of them
- Even imprecise sensors can add value
- Make use of all available information: synthesize new sensors
- e.g., estimate distance from engine performance and time as well as from wheel sensors
- Estimate fuel/power remaining by similar means
- Radio call signs may suggest whether you are over Afghanistan or Iran

Safe Control

- We now have a lot of sensor information
- Reliably fused
- And dependable monitors for safety violations (from TA2)
- Wish to synthesize controllers to keep within safe region
- In the context of hybrid systems

Controller Synthesis With A Safety Envelope

- Synthesize a safety envelope
  - Invariants are a good start
  - Linear systems: left eigenvectors of the A matrix
  - Others: template methods using EF solving (from TA2)
- Then do certificate-based controller verification and synthesis
  - i.e., controller synthesis for a safety objective—in contrast to that for more traditional objectives (stability etc.)
  - Controller uses mode switches to keep plant within safety envelope
  - More EF solving, searching for witnesses such as invariant, Lyapunov function
- Need a DSL to specify this, including distinction between plant and controller, time-triggered interaction, etc.
  - Will extend HybridSAL (to HybridSAL-X) for this

Plan

- Develop HybridSAL-X and its toolset, including safety envelope and certificate-based controller verification and synthesis
  - Ashish Tiwari

- And methods and tools for synthetic sensors and assured fusion using intervals
  - Shankar