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Kestrel Institute

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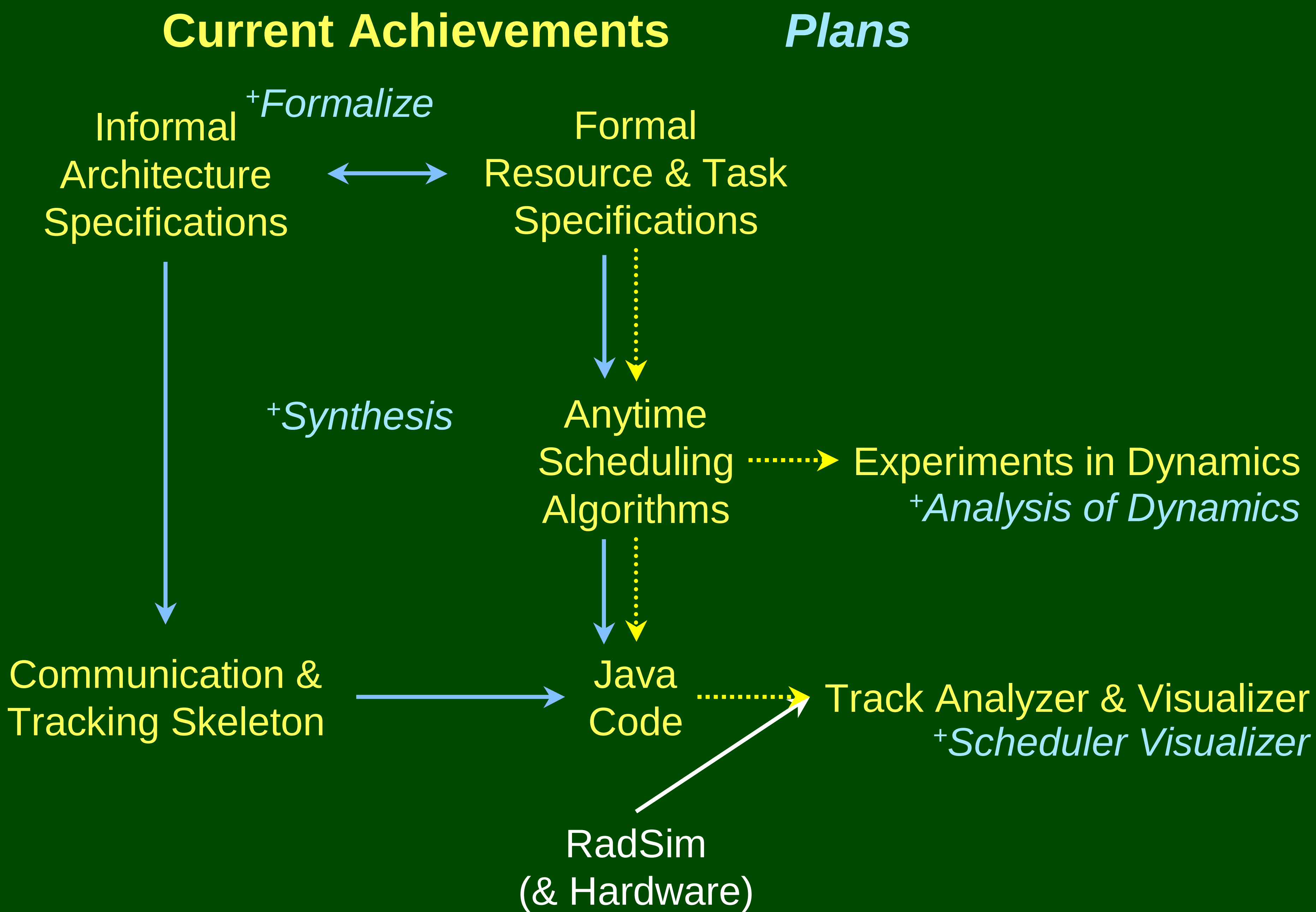
ANTs PI Meeting, Charleston, SC, 28-30 November 2000

Outline

- Status
- Anytime scheduler with anytime graph coloring
- Results using simulator
- Comments on challenge problem

Status


Current Achievements
Plans
Informal Architecture Specifications
+Formalize
Formal Resource & Task Specifications
+Synthesis
Anytime Scheduling Algorithms
Experiments in Dynamics
+Analysis of Dynamics
Communication & Tracking Skeleton
Java Code
Track Analyzer & Visualizer
+Scheduler Visualizer
RadSim
(& Hardware)

Distributed, Anytime Rescheduling

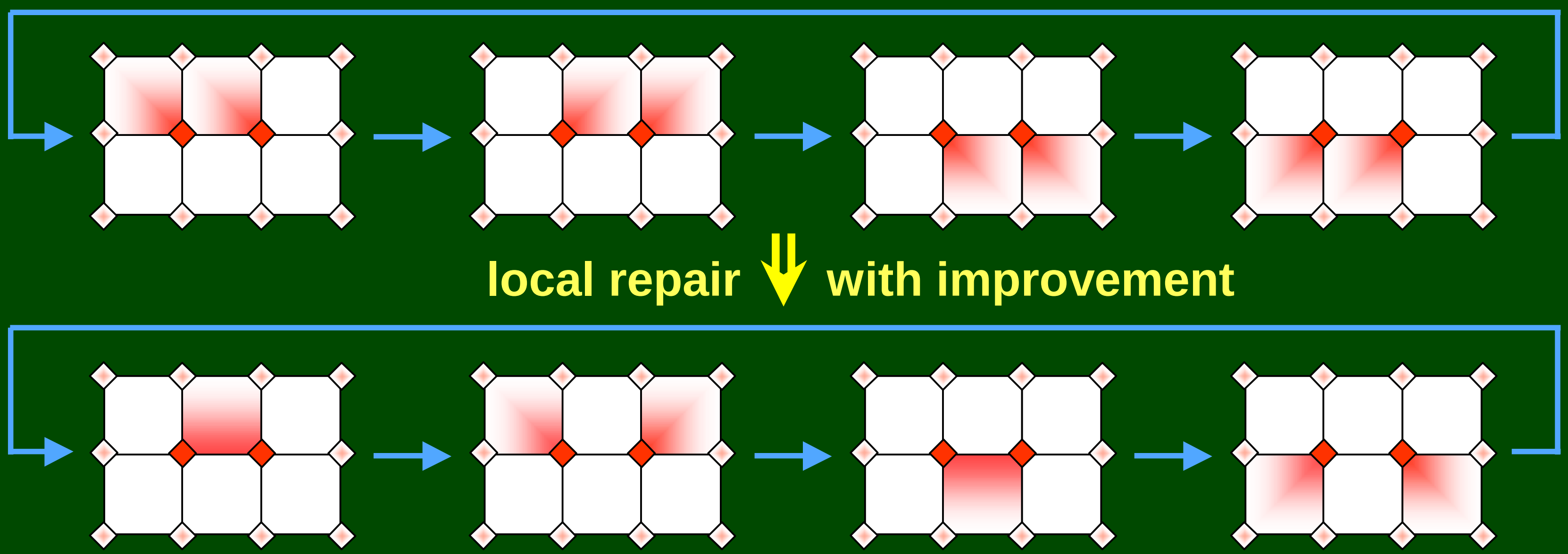
- An algorithm for scheduling radar nodes
  - meet mission objectives (track targets)
  - reduce resource consumption
- Operational requirements
  - scaleable: complexity independent of number of nodes
  - distributed: tolerant of communication latency
  - real-time: responds quickly enough to track targets effectively
  - robust: degrades gracefully as, e.g., communication or hardware fails
  - incremental: schedules ongoing, dynamic tasks

Distributed, Local Repair Algorithm

- Define a distributed set of scheduling processes
  - each scheduling process is responsible for some set of local resources
  - schedules for two resources are in conflict if they together cause a constraint violation
- Define neighborhoods
  - two resources are neighbors if they interact
    - e.g., there is some constraint that relates the two resources
- Define *local* quality metric on schedules
  - e.g., number of conflicts at a node
    - requires neighbors to inform each other about schedules

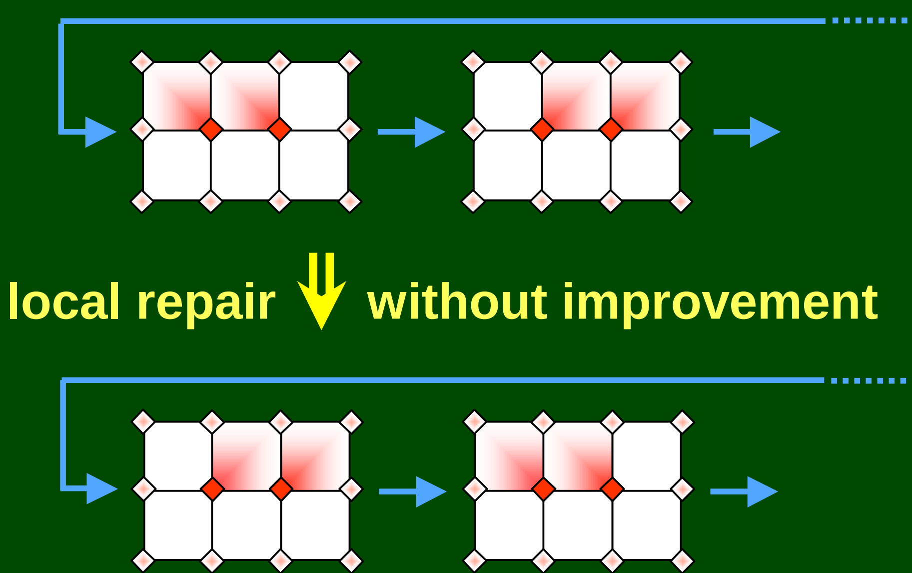
Distributed, Local Repair Algorithm (cont.)

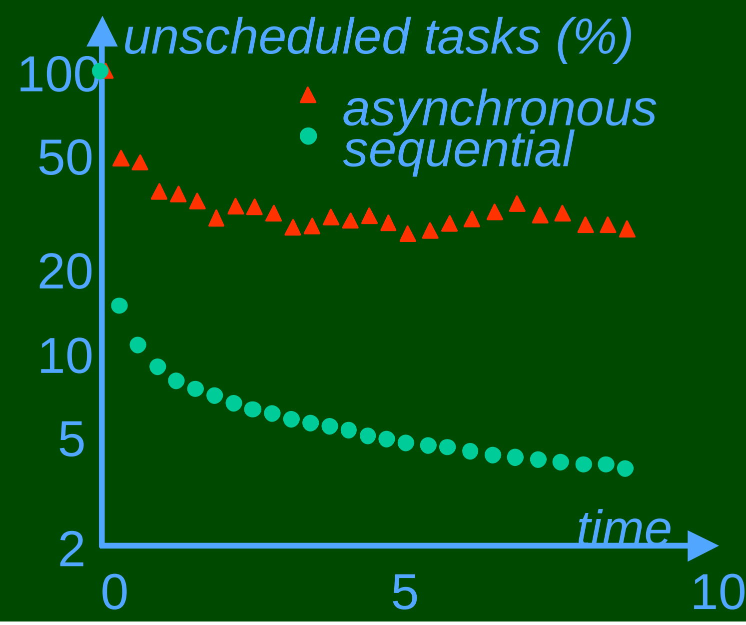
- Each scheduling process follows an iterative procedure:
  - it locally optimizes its own schedule with respect to its neighbors' schedules
    - e.g., to accommodate new taks & to reduce its conflicts with its neighbors
  - and then informs its neighbors of its new schedule



Communication Latency/Synchronization

- Each scheduling process optimizes its schedule wrt its neighbors’ schedules
  - optimization is based on information at hand
  - neighbors may have changed schedules
  - an optimization wrt neighbors’ old schedules may be a degradation wrt actual *current* schedules
  - result is poor convergence
- Need to synchronize update & exchange of schedules





Totally Sequential Synchronization?

- Extreme case: totally sequential operation across system
  - ensures every change is made with up-to-date information
  - $\Rightarrow$ no change produces a worse schedule
- BUT, sequential operation is not scaleable
  - at any given time, only **one** scheduling process throughout the entire system may update its schedule
  - (and communicate the new schedule to its neighbors)
- Complexity $\propto$ number of nodes

Graph Coloring for Synchronization

- Use graph coloring to achieve sufficient synchronization
  - nodes of the (undirected) graph are scheduling processes
  - two graph nodes have a connecting edge if they interact
  - color the nodes so that no two nodes of the same color have an edge between them
- At any given time, only one color is “active”
  - all of the scheduling processes of that color may update
  - all other scheduling processes must wait

$\Rightarrow$ Interacting processes (neighbors) cannot change schedules simultaneously

- Require number of colors << number of nodes
  - number of colors = number of nodes $\Rightarrow$ sequential operation
  - number of colors = 1 $\Rightarrow$ totally parallel operation

Graph Coloring: Complexity of Scheduling

- Number of scheduling processes: N
- Minimum number of colors required: C_{min}
- N/C_{min} scheduling processes can be active simultaneously
  - high degree of parallelism

$\Rightarrow$ Complexity independent of size of system

- C_{min} depends on “interaction topology”
  - at most C_{min} scheduling processes directly interact
  - non-local task structures/constraints give high C_{min}
    - truly global constraints cause C_{min} to be equal to N
    - indicative of (theoretically) non-scaleable deployment platform

Distributed, Anytime Graph Coloring

- How to compute a coloring in a distributed environment?
- Apply similar local repair process to graph coloring:
  - a color conflict occurs when two neighboring scheduling processes have the same color
  - each process repeatedly selects that color which (currently) minimizes its conflicts with its neighbors
- Need to address convergence of coloring
  - at each stage, use whatever coloring is available to synchronize coloring process
  - even an imperfect coloring reduces the probability of simultaneous changes offsetting each other
- Coloring and scheduling proceed simultaneously
  - an imperfect coloring may also be beneficial for the scheduling process

Requirements Met?

- Scaleable? Constant complexity
  - complexity is independent of number of nodes
- Distributed? Convergence is achieved via coloring
  - a high latency will still slow down the processes
  - it dictates the cycle time
- Real-time? A schedule is always available
  - provides real-time **framework**
  - time bounds affect the quality of schedules
- Robust? Each scheduling process operates on information available
  - missing information will degrade schedules due to unresolved resource conflicts
  - but some results will still be available
- Incremental? Continually reschedules

Analysis

- To date, analysis is of tracking results
  - – outstanding objective: analysis of scheduling
- Example track

  Ground truth: times, position vectors, velocity vectors

  $G = [\, t_i \times \vec{g}_i \times \vec{u}_i, \; i=1..\,]$

  Tracker output: times, position vectors, velocity vectors

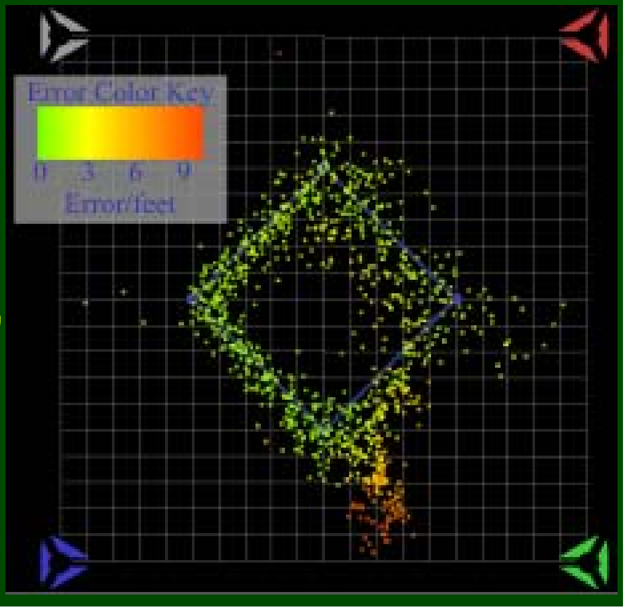
  $R = [\, t_k \times \vec{p}_k \times \vec{v}_k, \; k=1..n_R \,]$

  Error vectors (in position)

  $\vec{e}_k = \vec{p}_k - \text{interpolate}(G, t_k), \; k=1..n_R$

  Display color ~ $|\vec{e}_k|$

  green good - red bad
- High-error points due to target being "lost"
  - – time required to reacquire



Track Display

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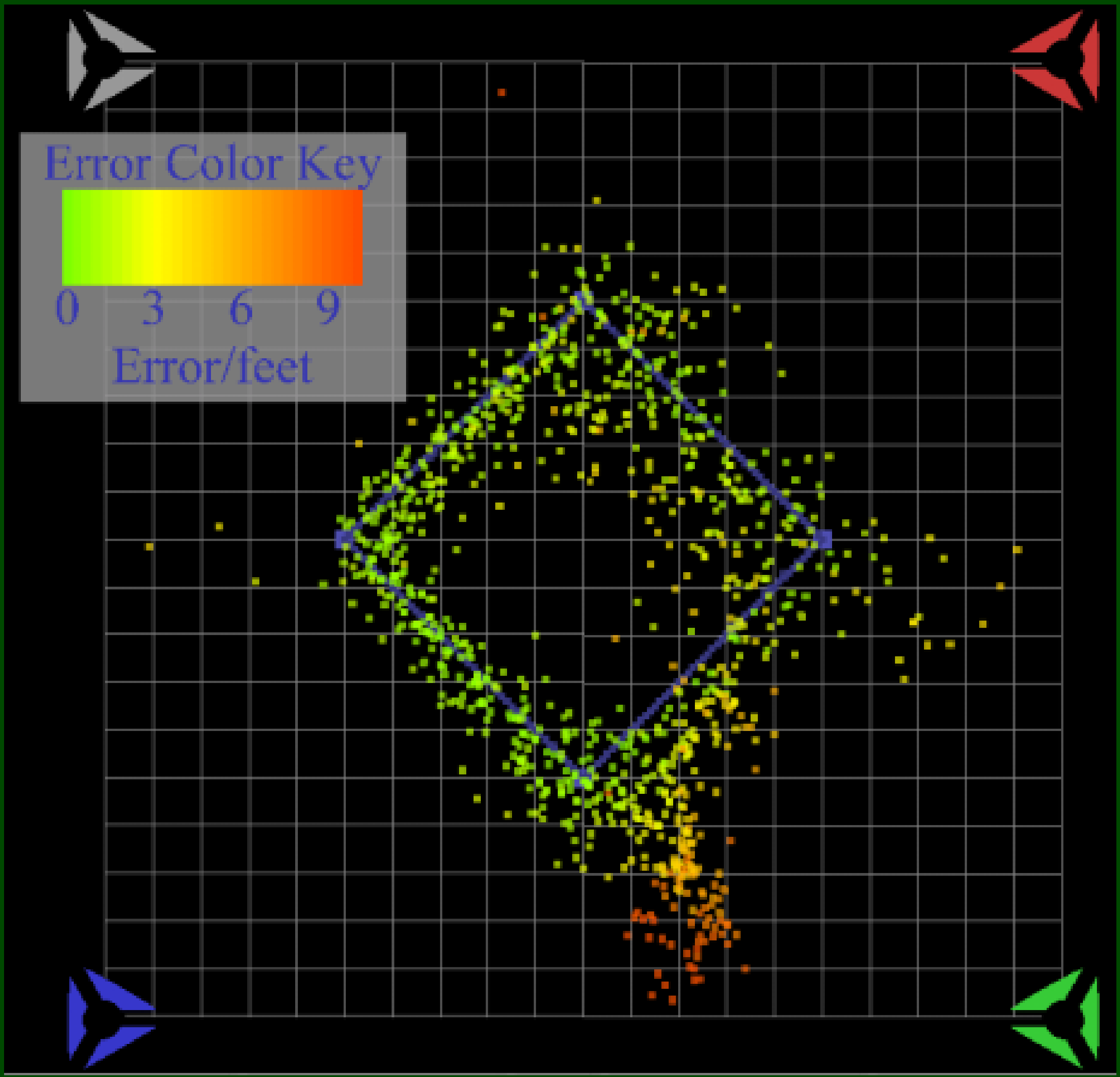
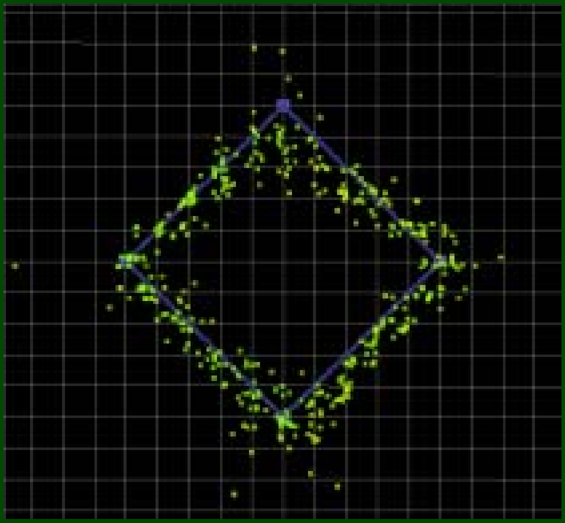


RadSim Example



Analysis: Overall Performance

- Representative results *using simulator*

R.M.S. = $\sqrt{(\sum|\vec{e}_k|^2/n_R)}$, k=1..$n_R$

= 3.09 feet

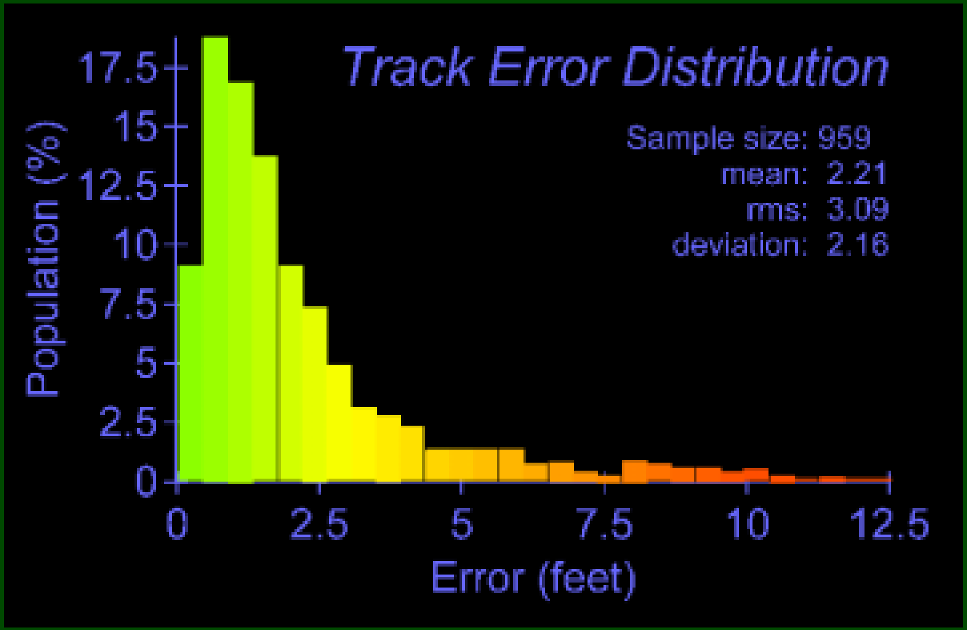
Average beam usage

= total beam seconds/(3 × number of nodes × simulation duration)

= 27%

Communication usage

= 0.9 messages per second per node

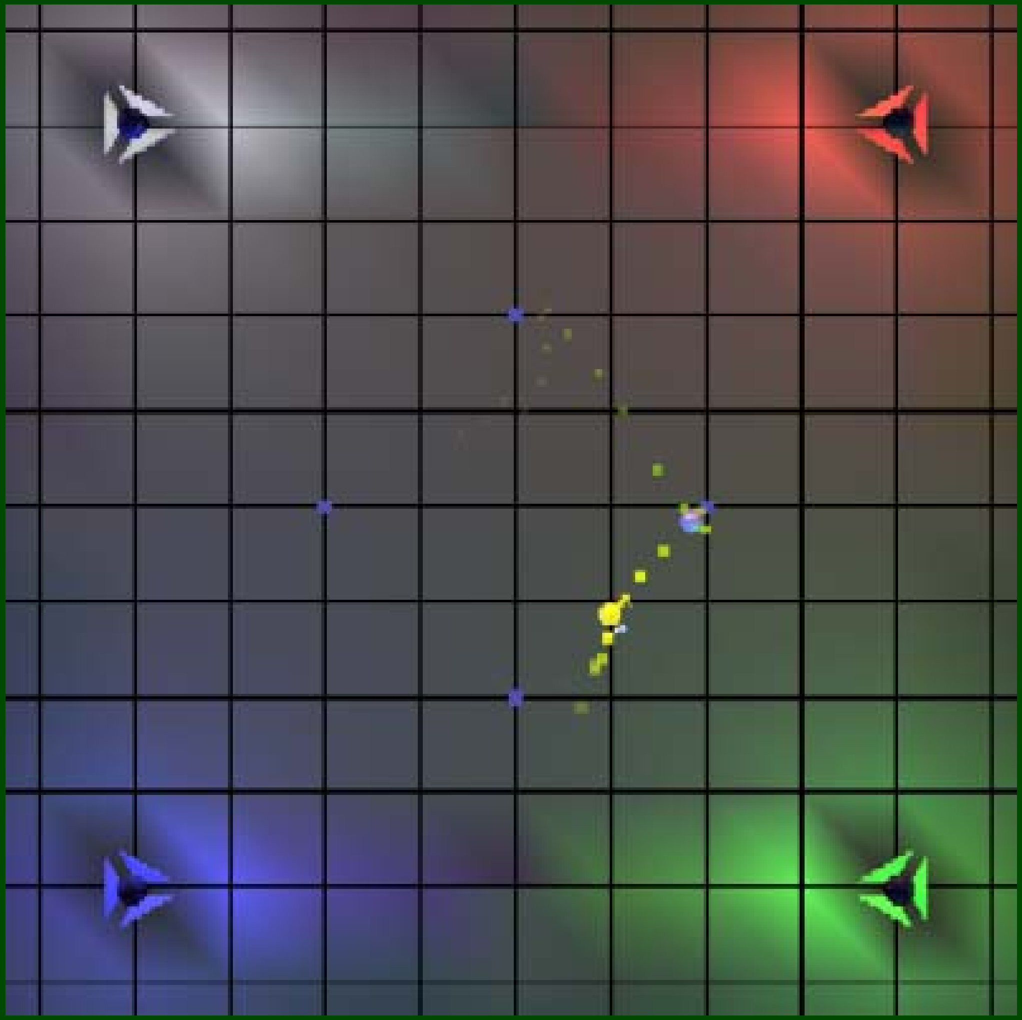


Analysis: Track Animation

- Shows ground truth path
- Shows track positions
  - sliding/fading window over actual track positions
  - linear interpolation between positions (with velocity)
  - color coded to show error (linear interpolation)
- Shows tracker's *a priori* prediction of target path segment
- Shows radar beam usage
- Implemented in VRML 2.0 for convenience
  - allows control of animation speed, direction
  - pre-defined and user-controlled viewpoints
  - maybe move to Java3D or X3D

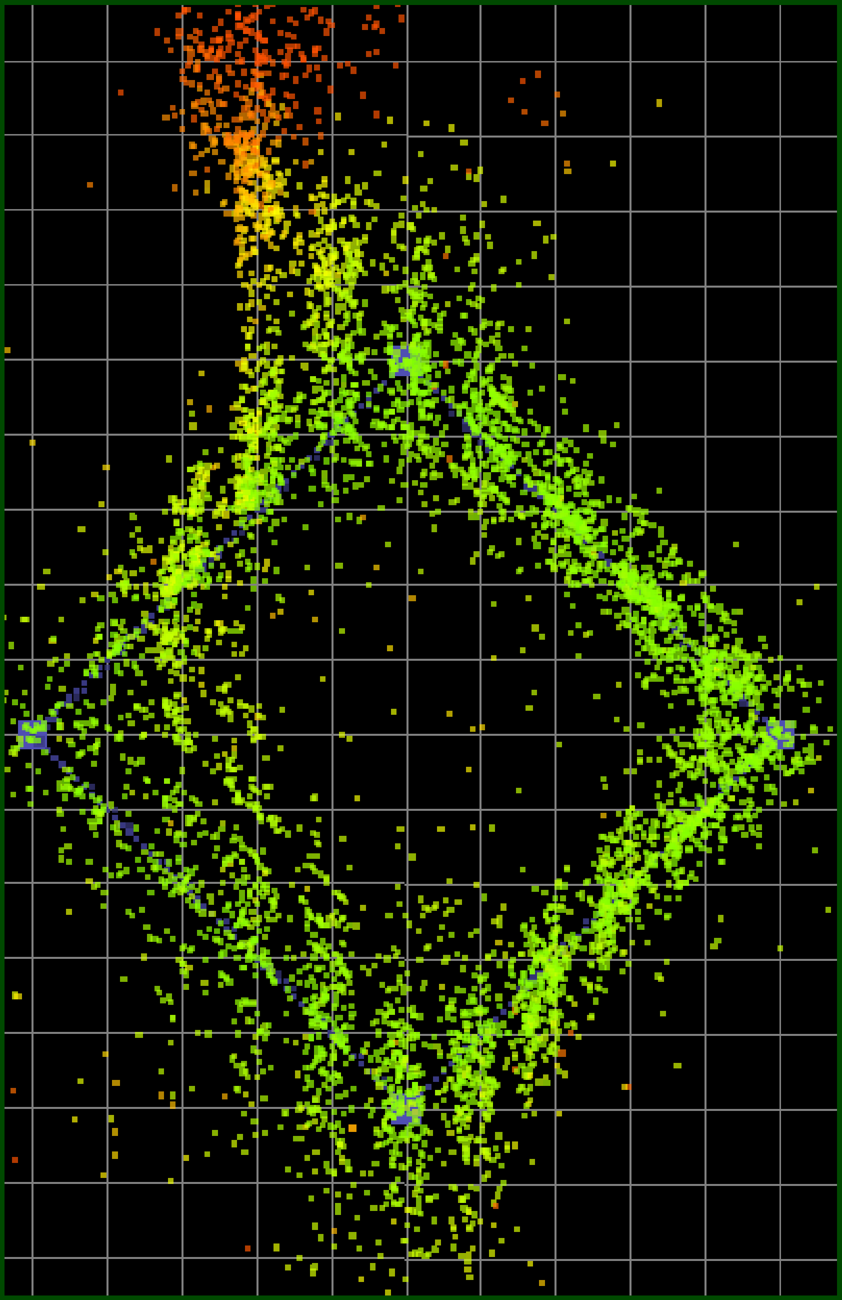
Track Animation: Movie

- 90 second pre-rendered movie shown here
- Approximately 5x normal speed



Analysis: Tracker Grid

- Larger sample size
  - 6000 track points
- Grid artifact
  - Track positions show correlation with 1 foot × 1 foot grid used by tracker to compute target locations that best match radar measurements



Comments on Challenge Problem Error Metric

- Error metric discussed on mailing list
  - shortest distance to ground-truth path
    $\sqrt{(\sum \text{distance}(G, \vec{p}_k)^2/n_R)}$, $k=1..n_R$
- Error metric we used
  - interpolate ground-truth path using track point's time coordinate
    $\sqrt{(\sum |\vec{p}_k - \text{interpolate}(G, t_k)|^2/n_R)}$, $k=1..n_R$
- Neither metric takes into account the number of track points
  - a track having just one measurement may score highly
- Proposal: interpolate both ground and track positions to n_I points evenly spaced over duration of simulation
  - approximated path integral
    $\sqrt{(\sum |\text{interpolate}(R, t_j) - \text{interpolate}(G, t_j)|^2/ n_I)}$, $j=1..n_I$
    $t_j = j \times (\text{simulation duration})/n_I$

Summary

- Have produced a slice from specification to code
  - need to refine the specifications
  - and tie them to code using synthesis
- Performance of tracker & scheduler seems reasonable
  - need to try larger systems with multiple targets
- Need further experiments to analyze scheduler performance
  - synthesize family of implementations for experimentation

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References

- VRML 2.0 (a.k.a. VRML 97) http://www.vrml.org/
  - open, standardized, plain text format for 3D scene description
  - animation described using key frame techniques
    - e.g., time-position coordinates
    - CPU/system speed determines quality of animation (frame rate)
  - VRML scene can be viewed using any compliant viewer
    - e.g., plugins for Netscape and Internet Explorer
  - good 3D graphics card needed for reasonable frame rate (>8 fps)
  - never quite reached critical mass, but some stalwarts remain (e.g., Parallel Graphics, Blaxxun)
- X3D http://www.web3d.org/x3d.html
  - open format being developed as replacement for VRML 2.0
- Java3D http://www.j3d.org/
  - open API for 3D scene construction & viewing in Java
  - VRML scene can be viewed using stand-alone applications or objects/applets embedded in web pages