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Optimizing Dynamic Resource Allocation

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Outline

- UAV Resource Allocation
  - POMDP Formulation & Non-myopic Belief-state Optimization (NBO)
  - GPU Acceleration
  - Algorithmic advances
- Resource allocation for polyhedral programs & beyond
  - Dynamic dependences (Alphabets)
  - Non-polyhedral iteration spaces (while)
  - Dynamic resources for polyhedral programs
  - CART: Constant Aspect Ratio Tiling

UAV Resource Allocation

- Dynamic constraints
- Uncertain and stochastic
- Spatially varying measurement errors
- Data fusion and geometric synergy
- External factors
  - Obstacles (may also act as occlusions)
  - Wind
  - Aggression & evasion

Non-myopic Dynamic Control

- Problem is inherently dynamic
  - Must exploit feedback
  - Poor control actions at one time will lead to regret in the future
- Non-myopic: cannot just apply control action that optimizes performance at that time instant
- Aligned with DDAS goals

Solution methodology

- Partially Observable Markov Decision Processes (POMDP)
- Solved using approximation method called NBO (nominal belief-state optimization)

GPU Acceleration

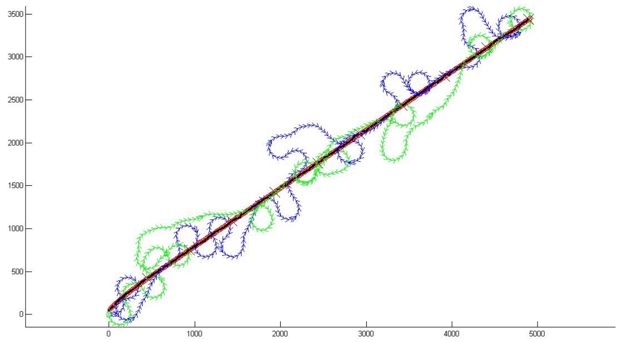
- Initial prototype: Matlab implementation using the fmincom library function.
- Main computational bottleneck: repeated calls to evaluate objfuntrace, the objective function to evaluate candidate solutions
  - 70% time, but in several thousand calls
- Solution: parallelize objfuntrace at fine grain, and also replace fmincom by an alternate coarse grain parallelization:
  - Nelder-Mead
  - Particle Swarm Optimization (PSO)

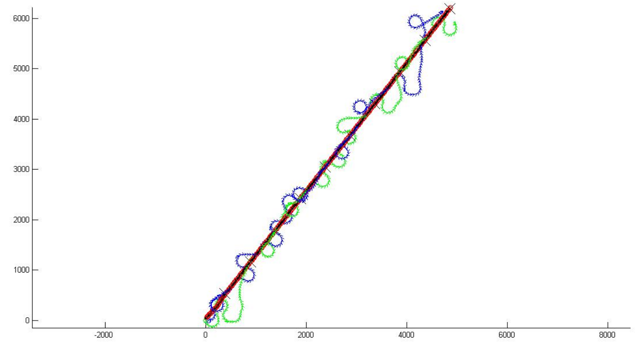
Fine grain parallelization

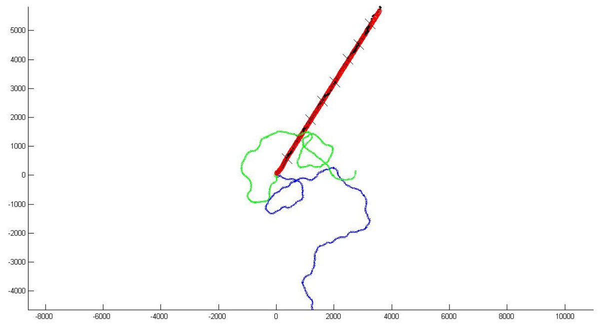
- Individual calls to `objfuntrace` have relatively small matrices and time horizons
- Must parallelize many independent calls to fully exploit GPU functionality
- 6-D iteration space, hand parallelized
  - Memory-parallelism tradeoffs (at all levels)
  - Matlab → C → CUDA (speedup = 2×10^3)
    - Mainly (2+ orders of magnitude) in Matlab → C
      - interpreted vs compiled
      - better memory management
    - 5-10x speedup in C → CUDA

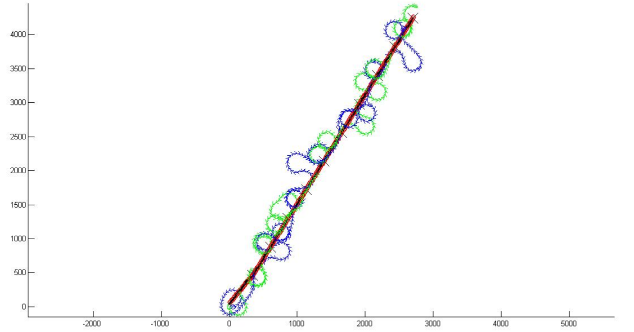
Coarse grain

- Numerical precision: fmincom vs PSO









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Algorithmic advances

- Extension for data association:

Multi-Hypothesis Tracking. Need to modify

- State & State transition law
  - include tracking state
- Observation & observation law: MHT includes false alarms, missed detection, etc.,
  - Use a probabilistic model
- Cost function
  - additional term for target ambiguity
- Belief state
  - Distribution over states (one term is unobservable and updated via Bayes theorem – Kalman filter MHT)

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Dynamic polyhedral programs

- Extend the expressivity:

Alphabets: an extension of the polyhedral equational language Alpha

  - Iterative termination through unbounded polyhedra & fixed-point semantics
  - Non-affine dependences through uninterpreted functions
  - Rework mathematical closure properties

Compiling Alphabets

```
boolean cond(t); //cond will be evaluated at every iteration
    affine counter {N | N>2} over {t|t>0} while cond(t)
    inputs
        float Init{i|0<i<N};
        dep Z {n->j | 0<i<N && 1<=j<=2};
    outputs
        float Y {n|0<n<N};
    let
        Y[i,t] =
        case
            {|t==0}:                     Init[n,0];
            {|t<=n}:                     Y[n,0];
            {|t>n && n==0}:              Y[n,0];
            {|t>n && n>0 && Z[n]==2}:    Y[n,t-n]-1;
            {|t>n && n>0 && Z[n]==1}:    Y[n,t-n]+1;
        esac;
```

Compiling Alphabets

Alpha(bets) is equational/declarative (single assignment). Compiler analyses:

- Scheduling
- Lifetime (memory allocation)

Static scheduling is undecidable
[SQ'89]
fallback strategy: demand-driven evaluation

- Alphabets: unbounded computations ➔ (potentially) unbounded memory

Optimizations

- Memory bound analysis
  - To determine the maximum amount of history that needs to be stored – provably bounded, but may be a function of program size parameters
- Speculative evaluation
  - When the termination condition is monotonic:
    - if cond(t) becomes false for some t, it implies that for any t'>t the condition cond(t') is also false
  - No harm in advancing t by a extra iterations and then correcting as necessary (needs "check-pointing")

Changing target architectures

"JIT" compilation of polyhedral programs:

Maximize static compilation, leave as many "tunable" parameters.

- Challenge: hierarchical & parametric tiling: (polyhedral model meets its Waterloo)

Dynamic Resource Allocation

- Long running computationally intensive multi-core program (mixed memory/compute bound)
- Dynamic changes to operating environment
  - Reduction is cache resources
  - Change to number of available processors
  - Faults (in the future)
- Dynamically modify tile sizes
  - Allows adaptation to both changes
  - May need data remapping to improve locality

Details

Generate code (like checkpoint-restart) to

- Execute periodically
  - Evaluate a control decision to determine cost-benefit of changing tile sizes/ remapping
  - Myopic decision may lead to regret
  - Probabilistic model of the arrival of dynamic changes to machine state
  - Model as a POMDP

Conclusion

- Polyhedral model for affine program analysis – we go beyond that to
  - Dynamic dependences
  - Non-polyhedral iteration spaces
- Optimal control using POMDPs provides a foundation for UAV control
  - Mathematically elegant and rigorous
  - Extensions to target ambiguity