National Aeronautics and Space Administration

Parallel Monotonic Basin Hopping for Low Thrust Trajectory Optimization

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Summary

- What's the Problem?
- What is Monotonic Basin Hopping?
- What is Parallel Monotonic Basin Hopping?
- Small Example
- Medium Example
- Large Example
- Conclusion

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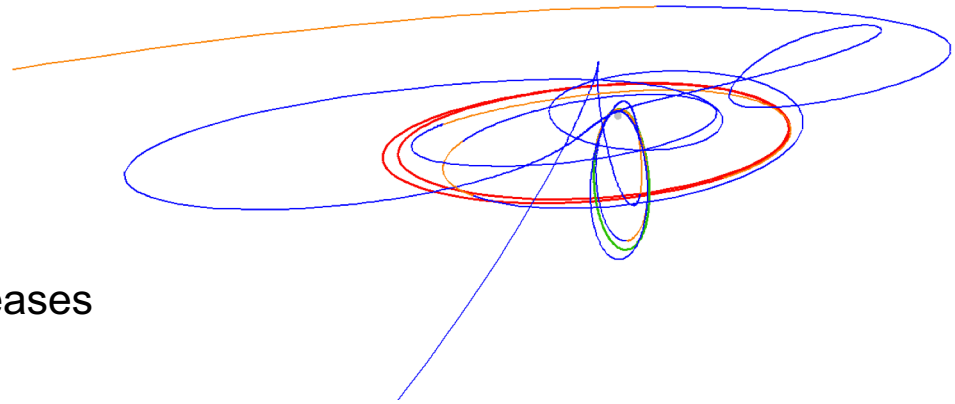
What's the Problem?

- **Low thrust trajectory optimization can be tricky:**
  - Many locally optimal solutions
  - Non-intuitive solutions
  - Long integrated finite burns
  - Full ephemeris models
  - Tedious to design by hand
  - This gets worse as complexity increases



- **Questions Arise:**
  - Do I really have to locate a feasible solution "by hand"?
  - Is there a more optimal solution nearby?
  - Can this somehow be done while I'm out to lunch or home for the night?

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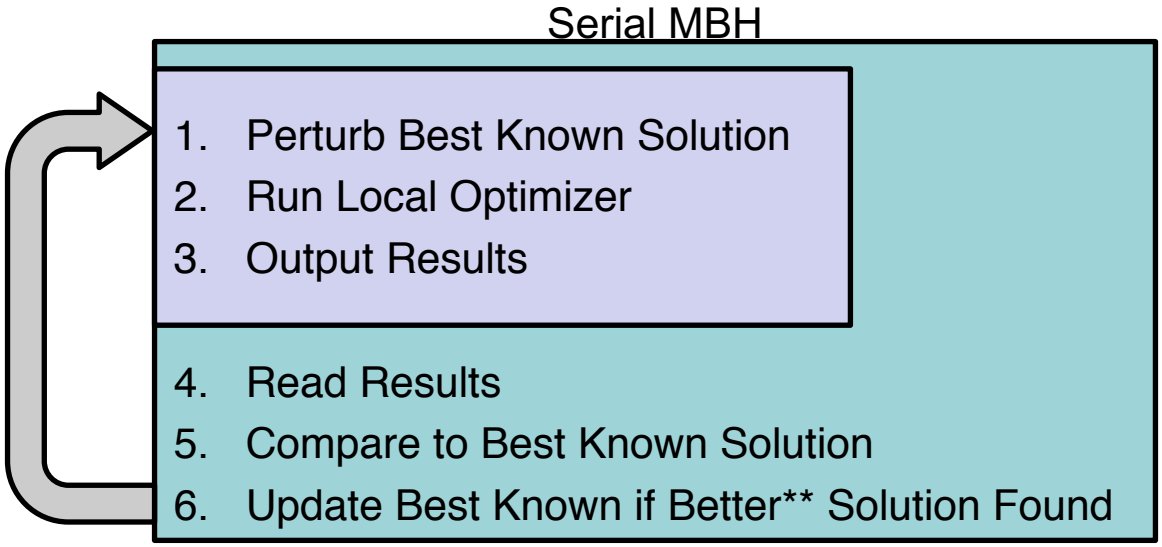
Serial Monotonic Basin Hopping (MBH)

- **Stochastic Global Optimization Meta-algorithm**
- **Robust, Automated**
- **Notable example: Evolutionary Mission Trajectory Generator (EMTG)**



**Better solution can be more optimal OR more feasible

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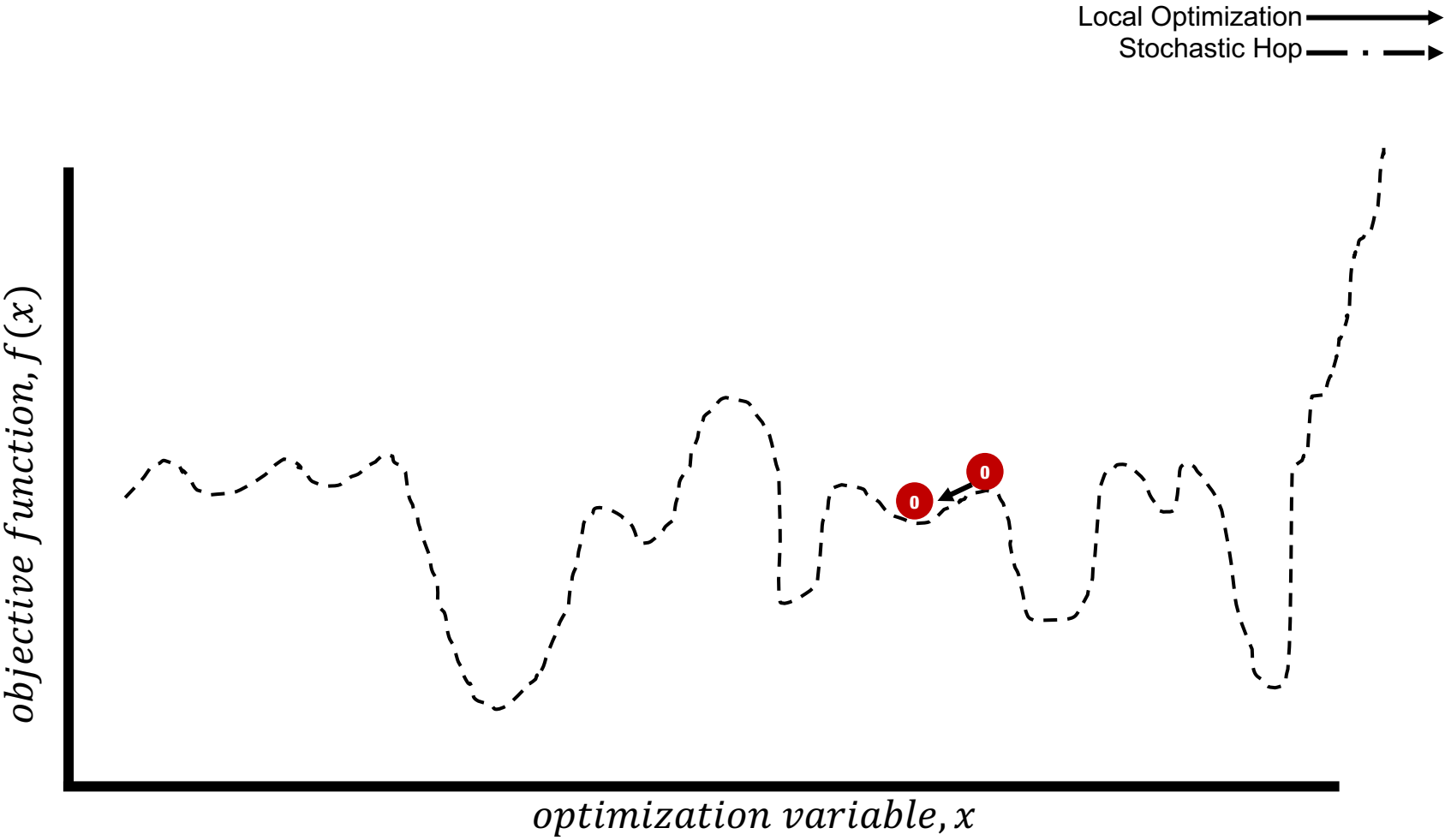

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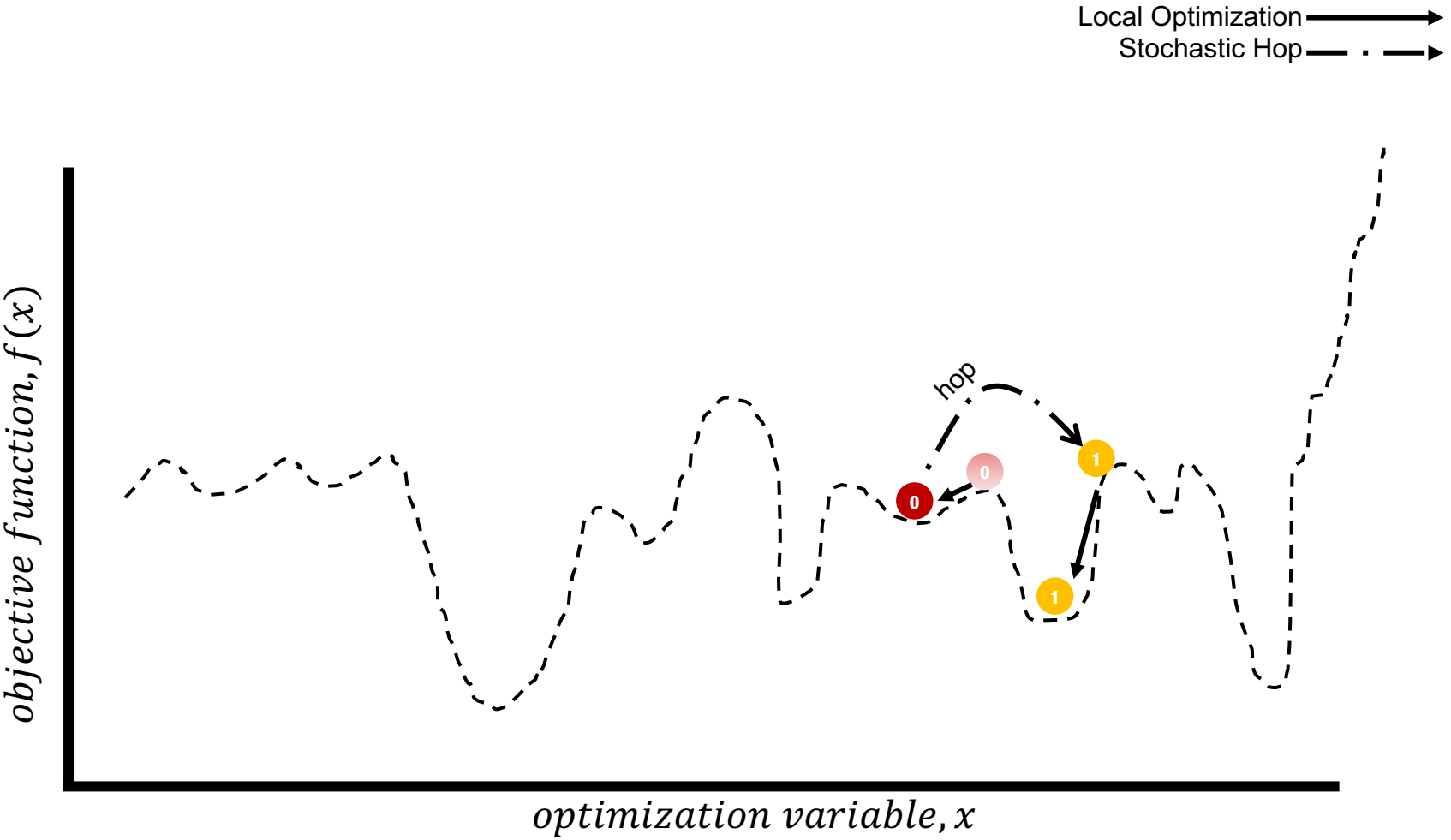

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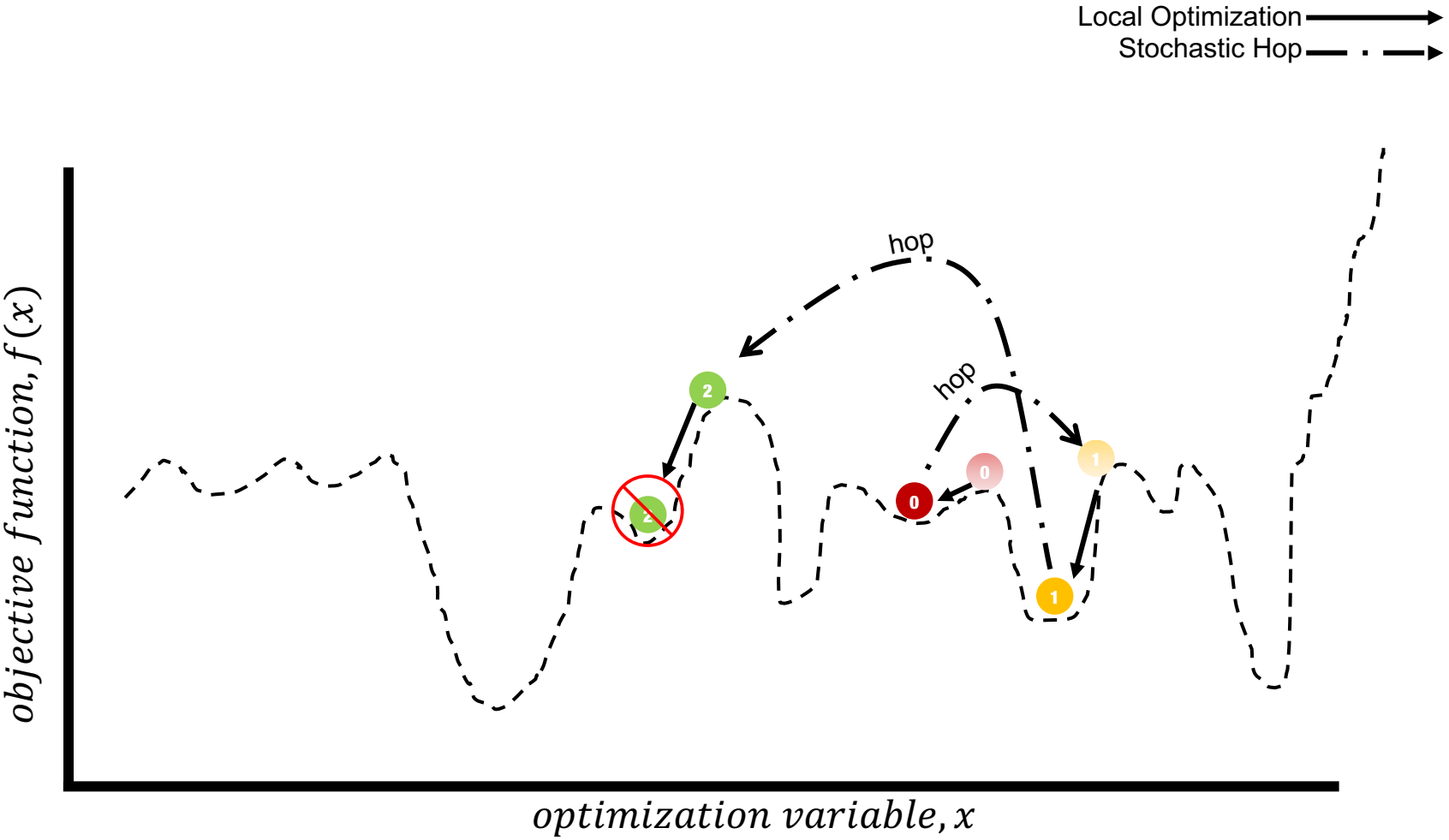

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Parallel Monotonic Basin Hopping (PMBH)

- **Why Parallel MBH?**
  1. Some low-thrust trajectory optimization problems are too complex for serial MBH to reliably find solutions in reasonable time
  2. Computation resources are relatively inexpensive

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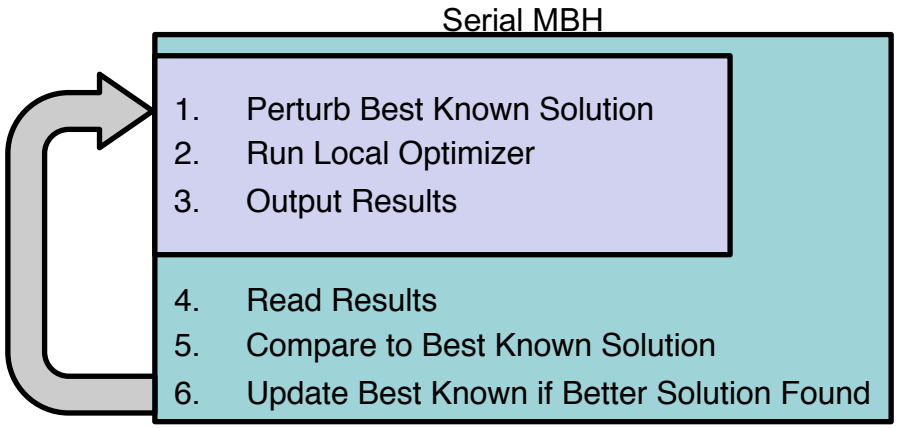

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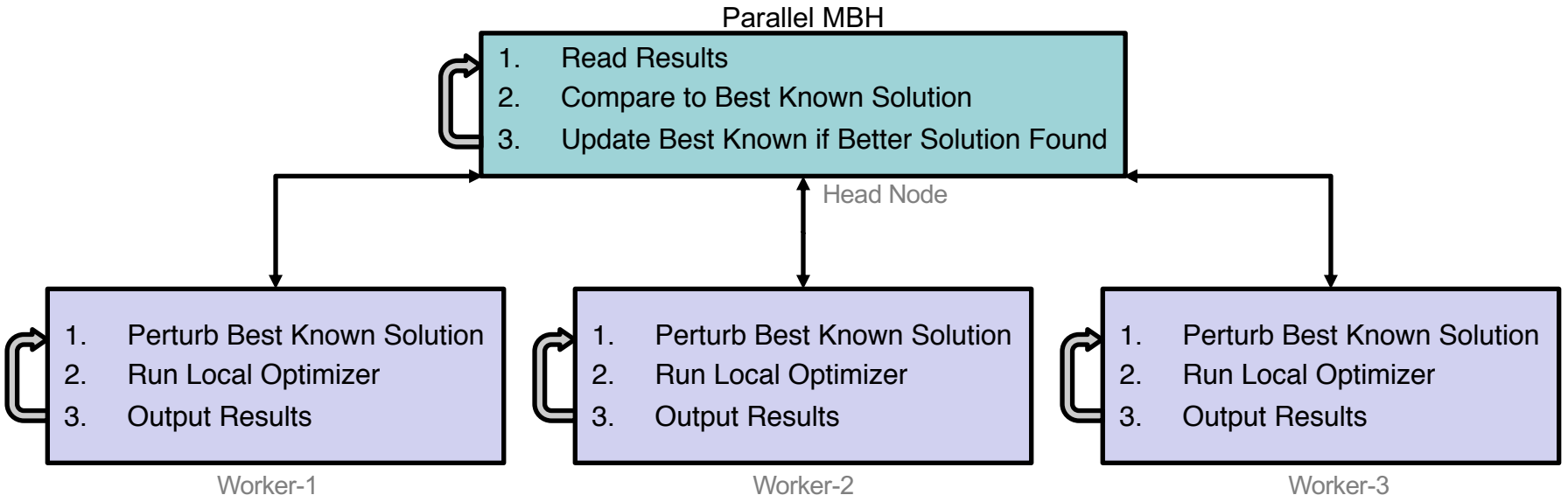

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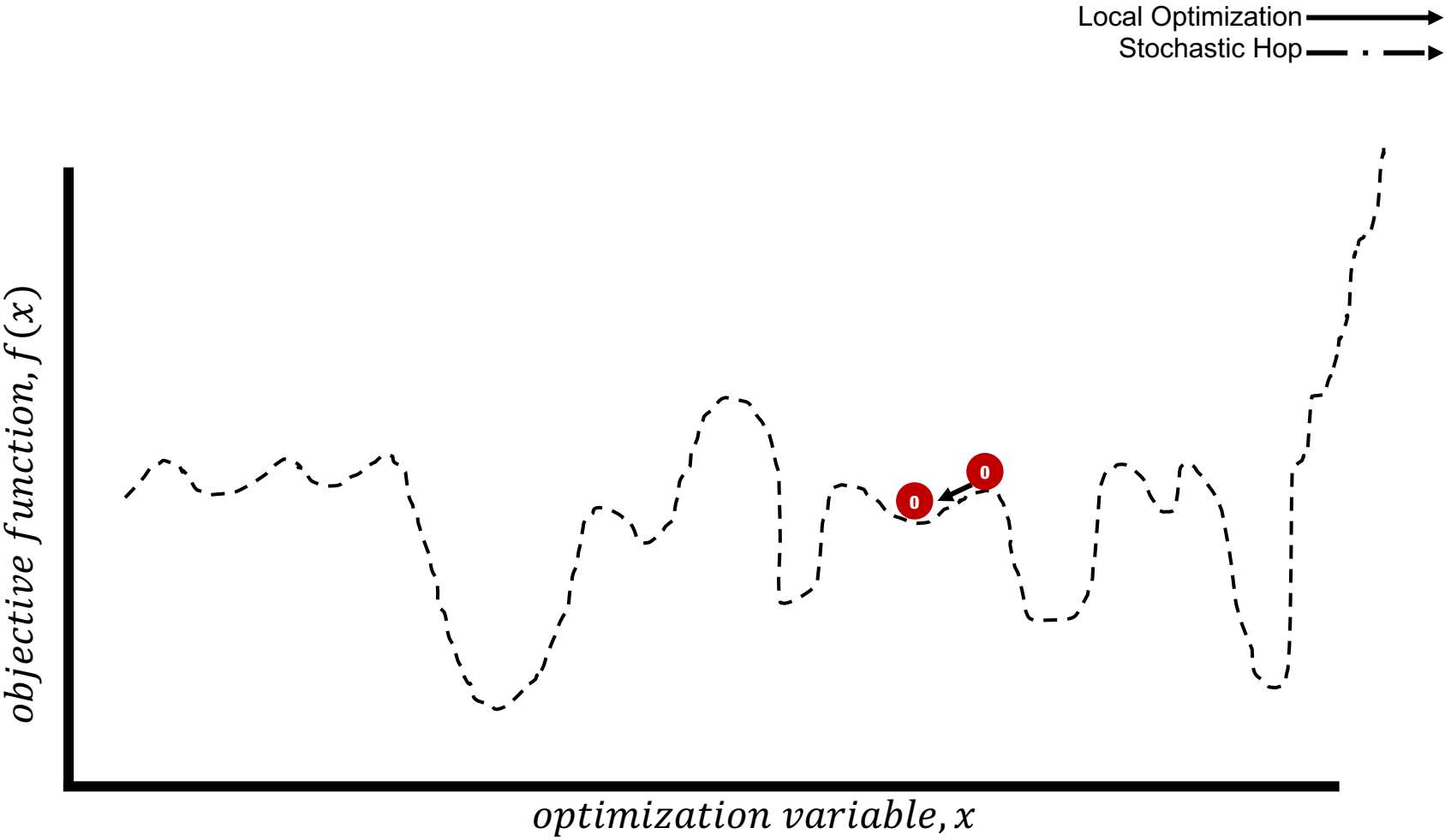

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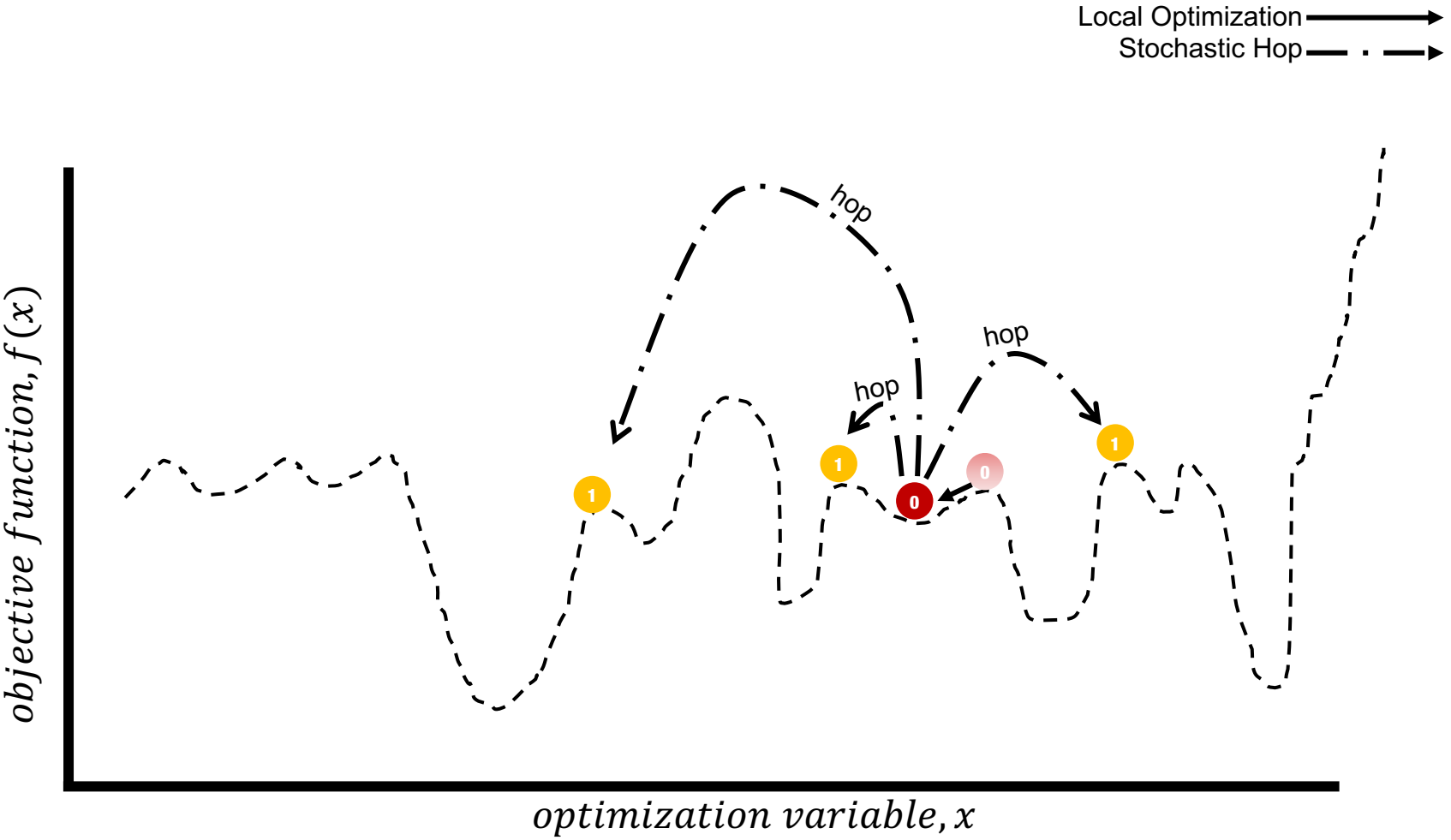

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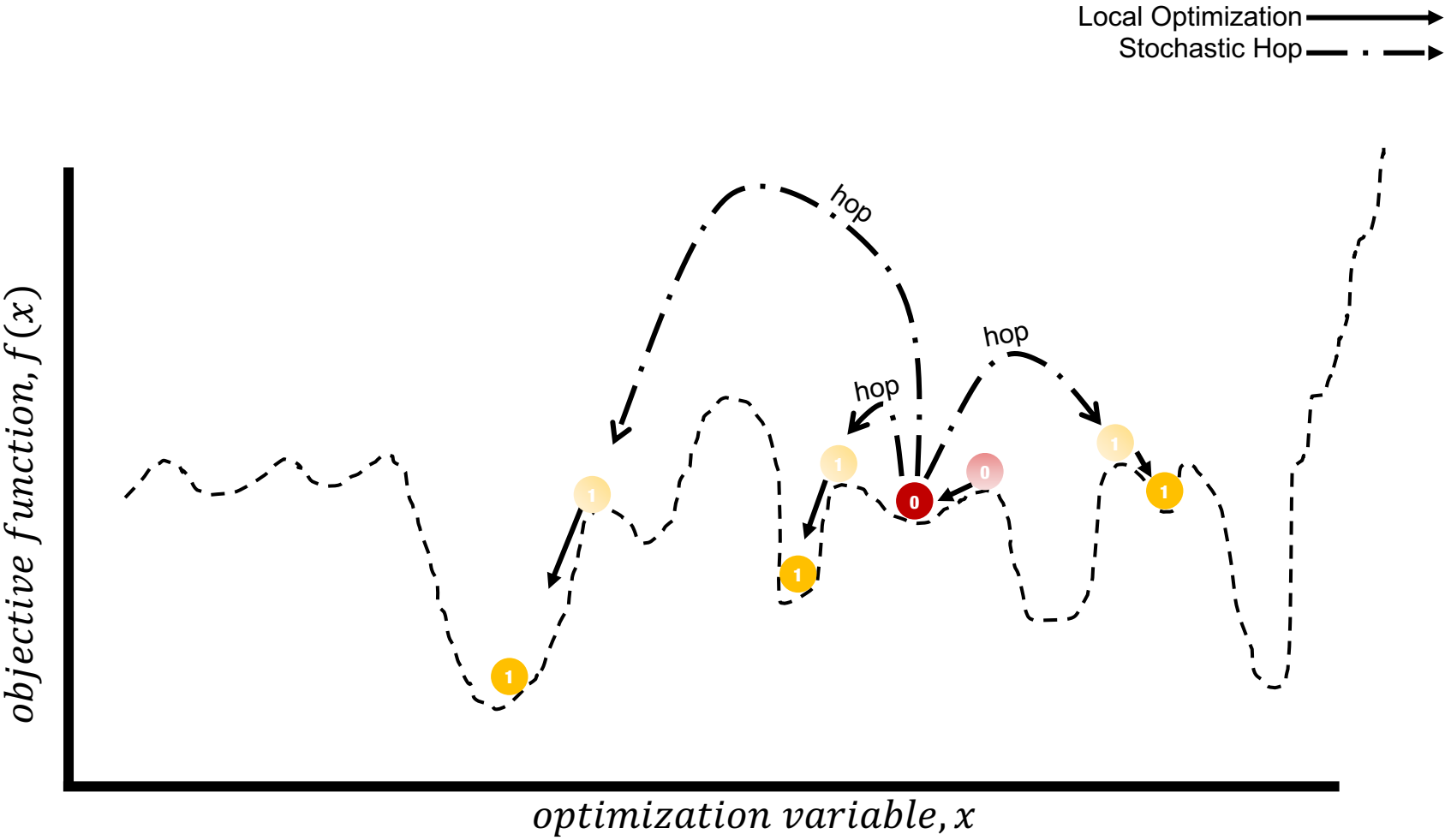

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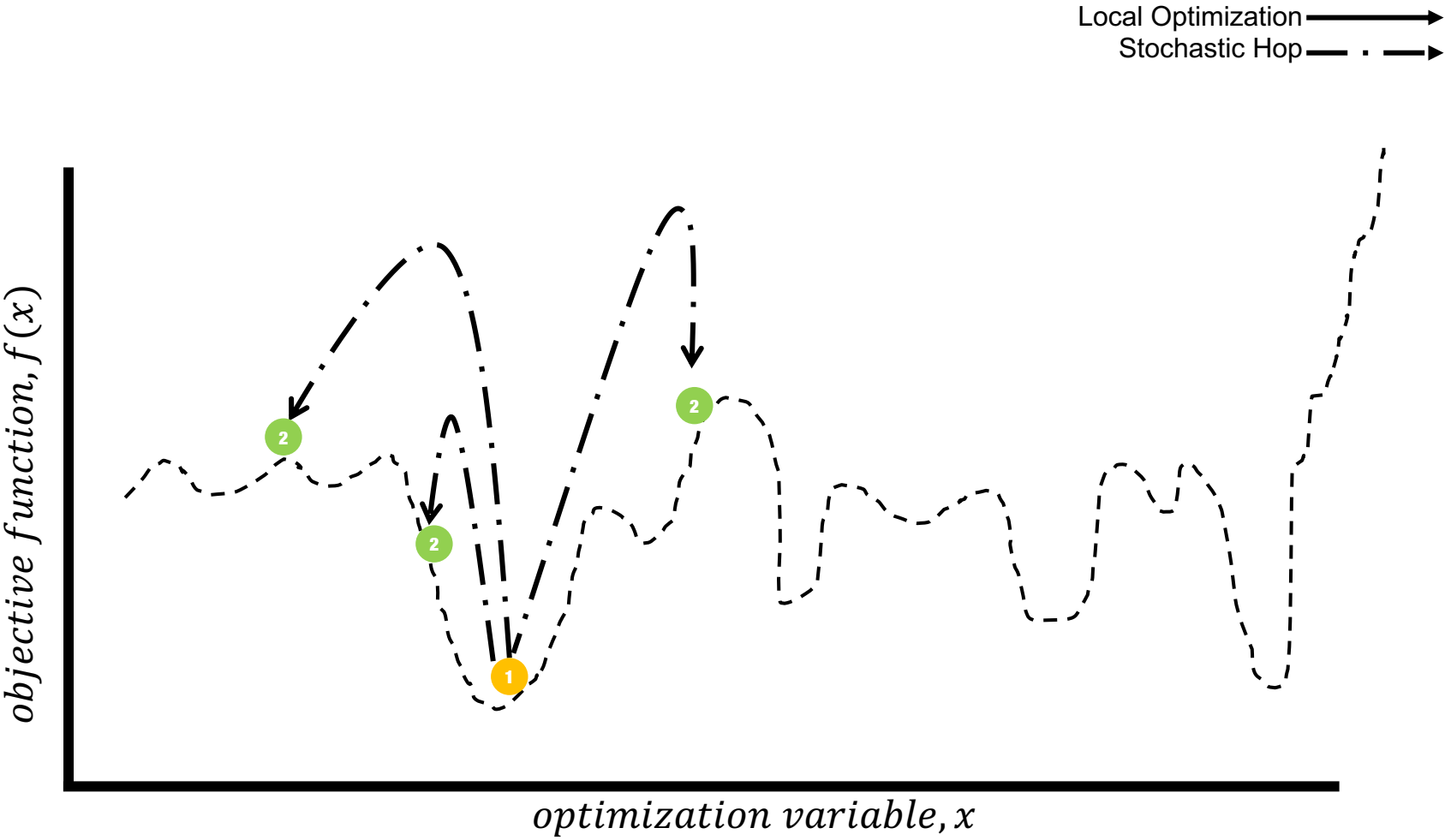

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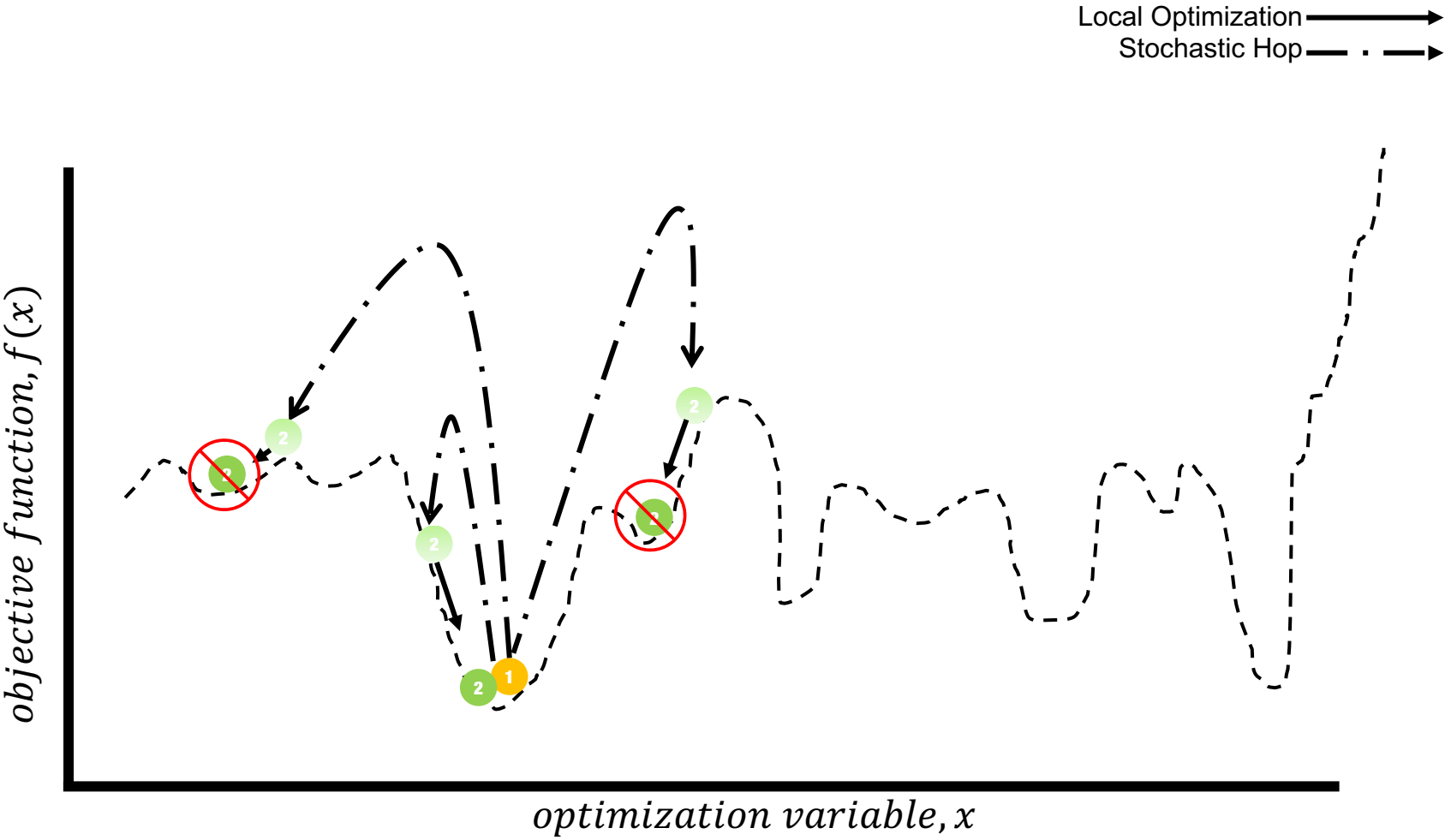

PMBH Implementation

- **MBH Scripts: Python**
  - Easy to interface with Copernicus
  - Easy to implement in parallel
  - Speed isn't important as most time is spent elsewhere

- **Mission Design Tool: Copernicus**
  - Developed at NASA Johnson Space Center
  - Primary mission design tool used at NASA GRC
  - Enables the formulation of arbitrarily complex trajectories

- **Local Optimization: SNOPT**
  - Built into Copernicus
  - Most of the computational time is spent here

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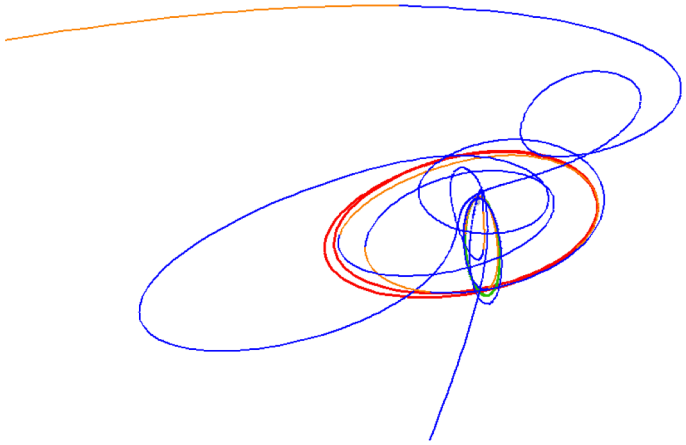
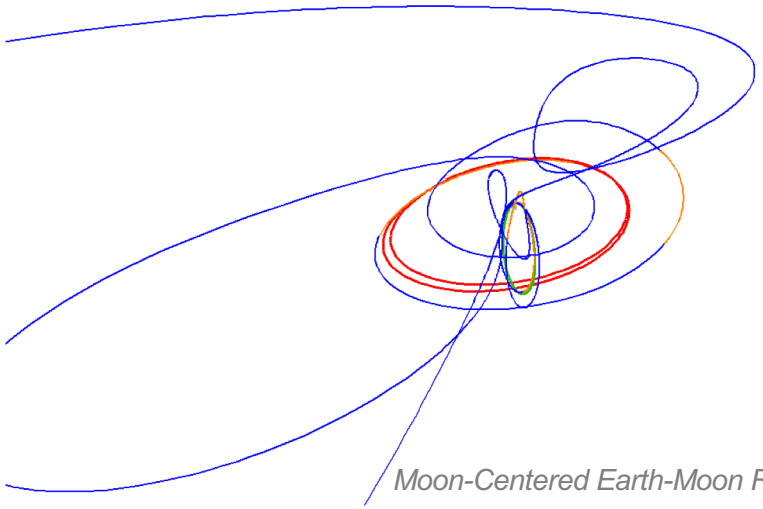
Small Example Problem

- **Low Thrust Solar Electric Propulsion Transfer**
- **Near Rectilinear Halo Orbit (NRHO) > Lunar Distant Retrograde Orbit**
- **Fully Integrated, Time Varying Finite Burns**
- **150-Day Duration**
- **Minimum Propellant Mass**
- **Serial MBH vs. 27-core PMBH (20 trials each)**

Initial Solution

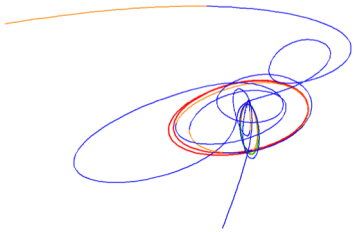


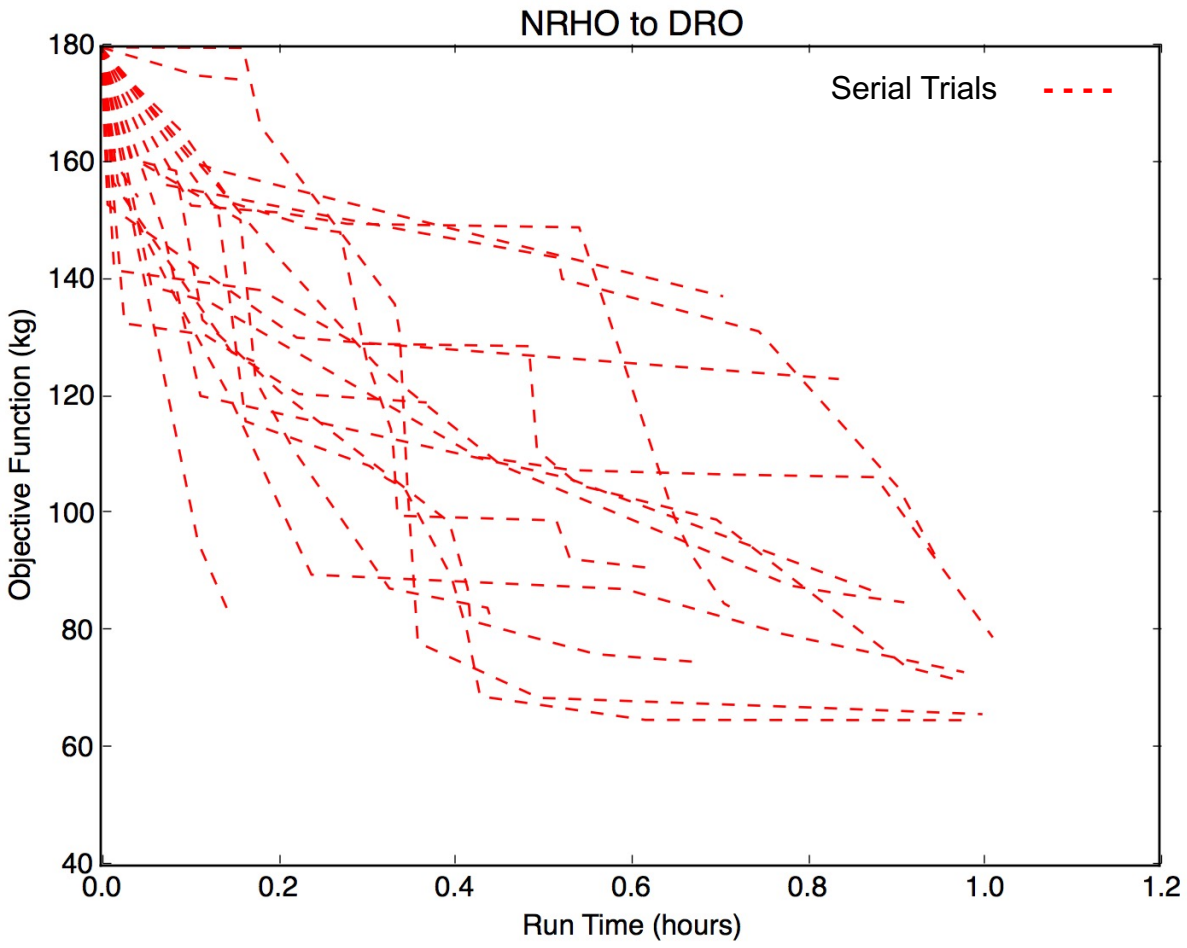
Final Solution



Moon-Centered Earth-Moon Rotating Frame

Small Example Results





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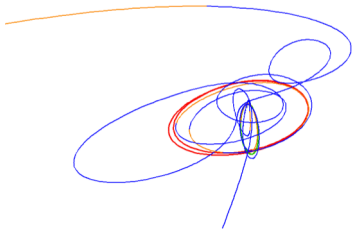

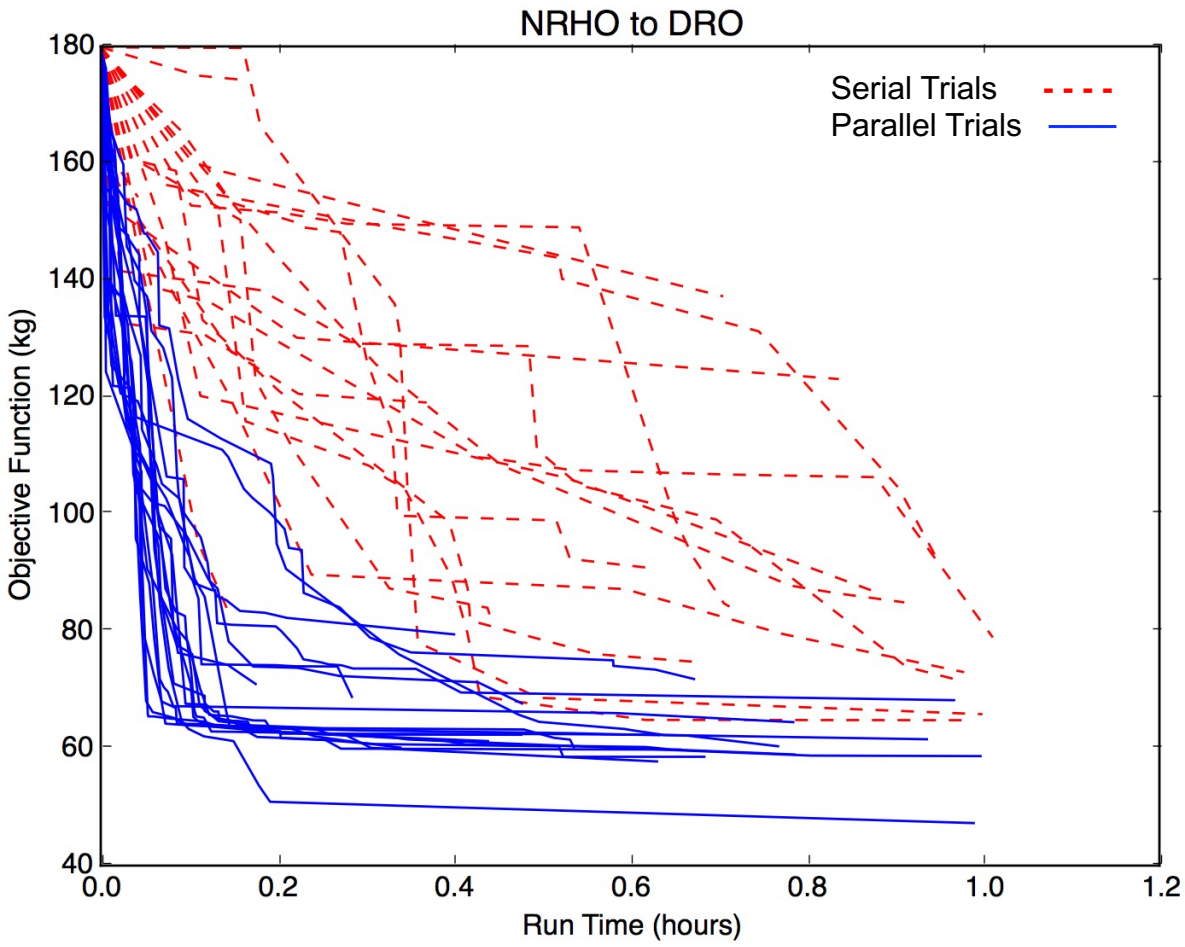

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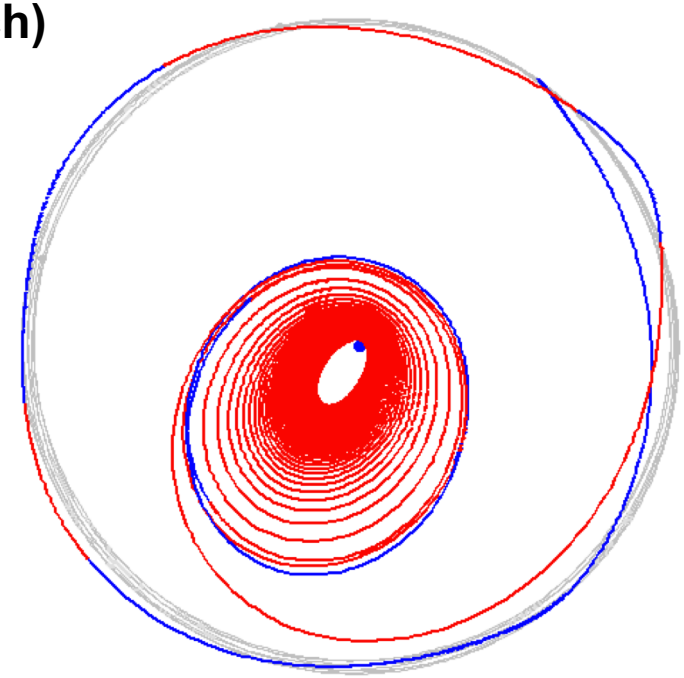
Medium Example Problem

- Low Thrust Solar Electric Propulsion Transfer
- High Earth Orbit > NRHO
- Fully Integrated, Time Varying Finite Burns
- 100+ Day Low Thrust Spiral
- Minimum Propellant Mass
- Serial MBH vs. 27-core PMBH (20 trials each)



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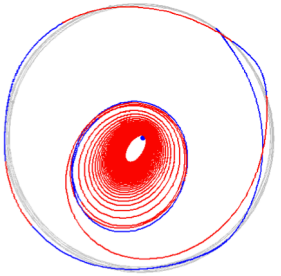

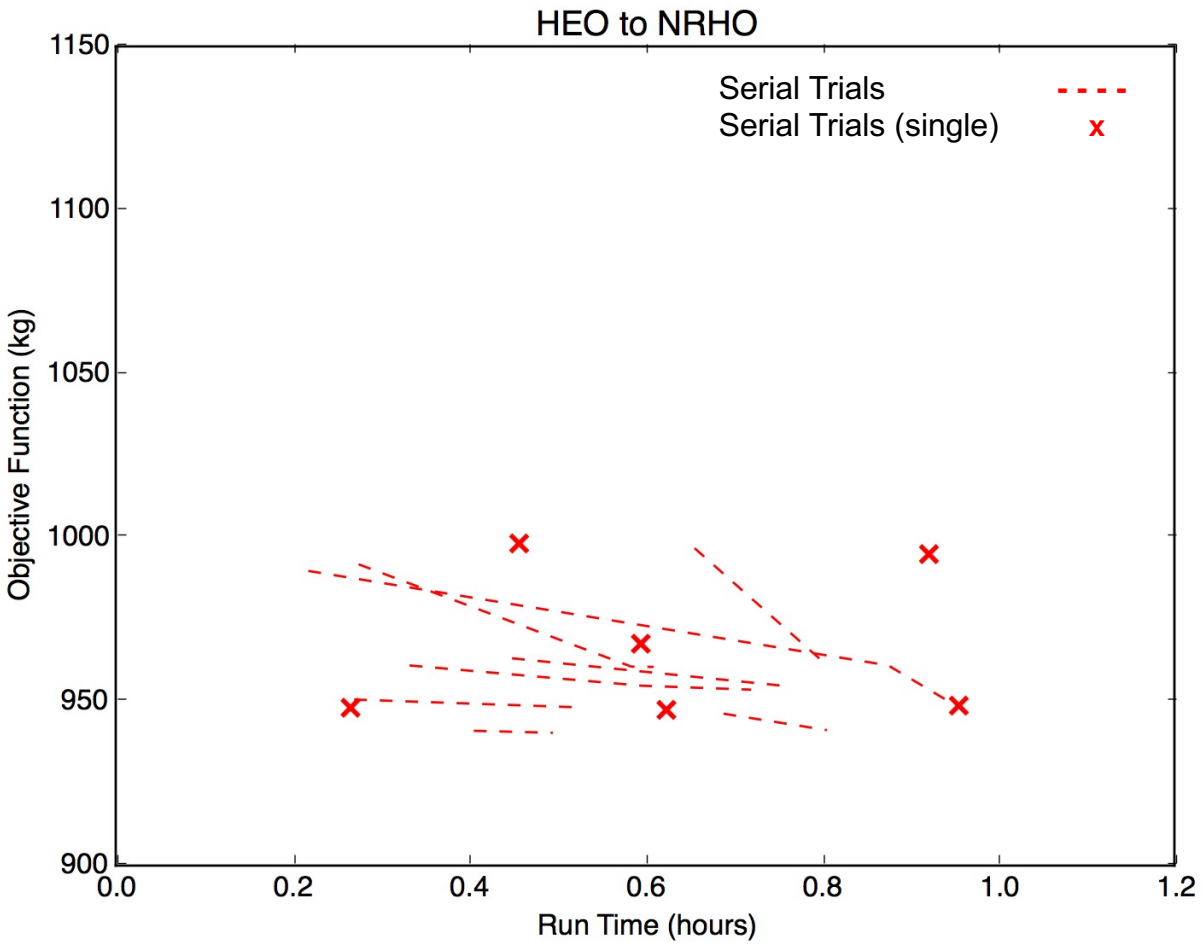

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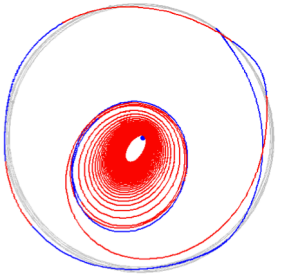

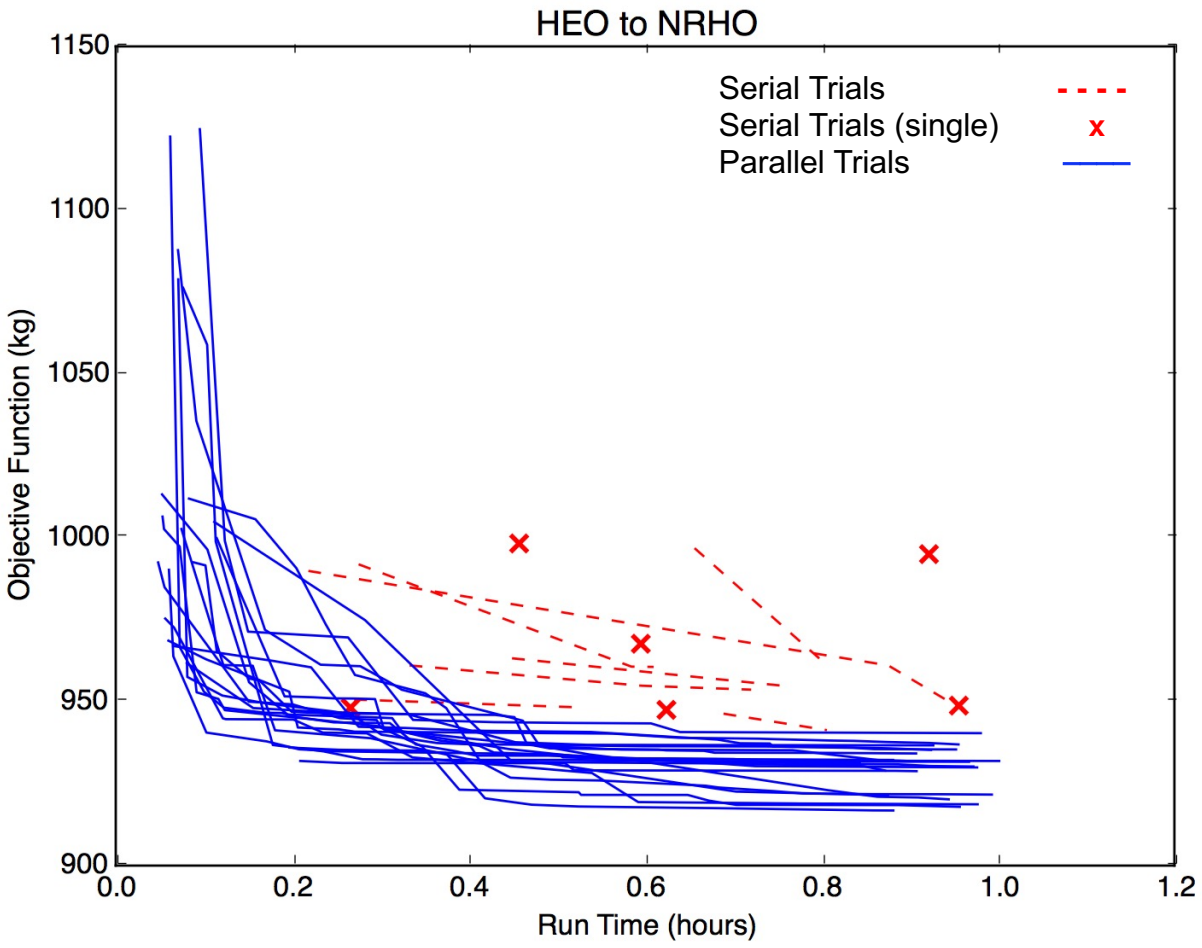

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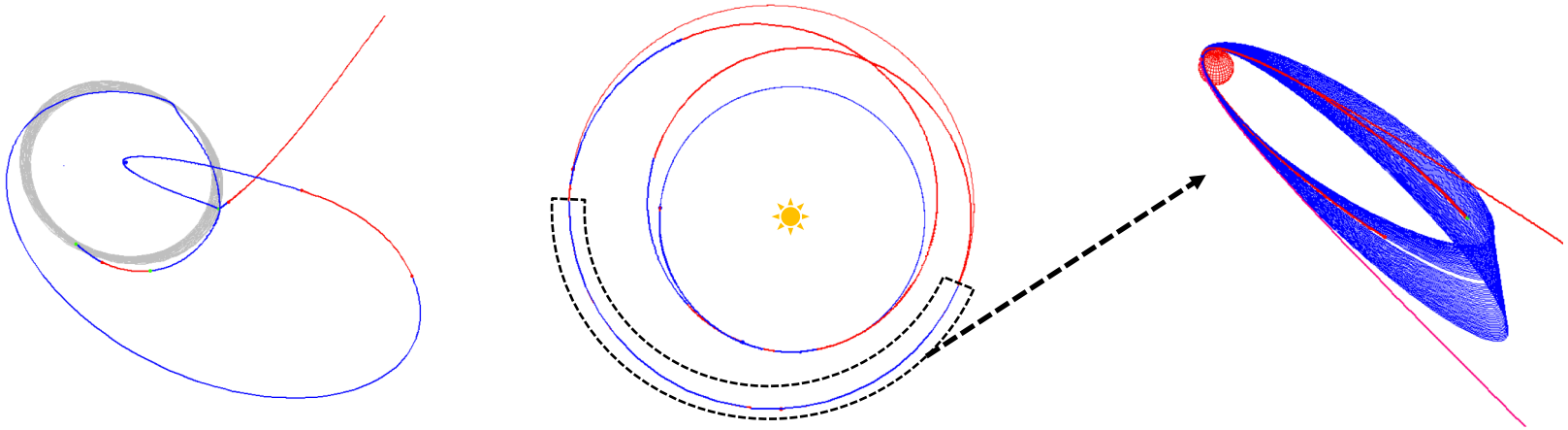
Large Example Problem

- **Hybrid (SEP + Chemical) Round Trip Mars Mission**
  - Chemical for Earth Departure, Mars Arrival, Mars Departure – SEP otherwise
- **NRHO > LGA Escape > High Mars Orbit > Earth**
- **Fully Integrated, Time Varying Finite Burns**
- **1100+ Day Mission Optimized End-to-End**
- **Minimum NRHO Departure Mass**
- **Serial MBH vs. 27-core PMBH (10 trials each)**

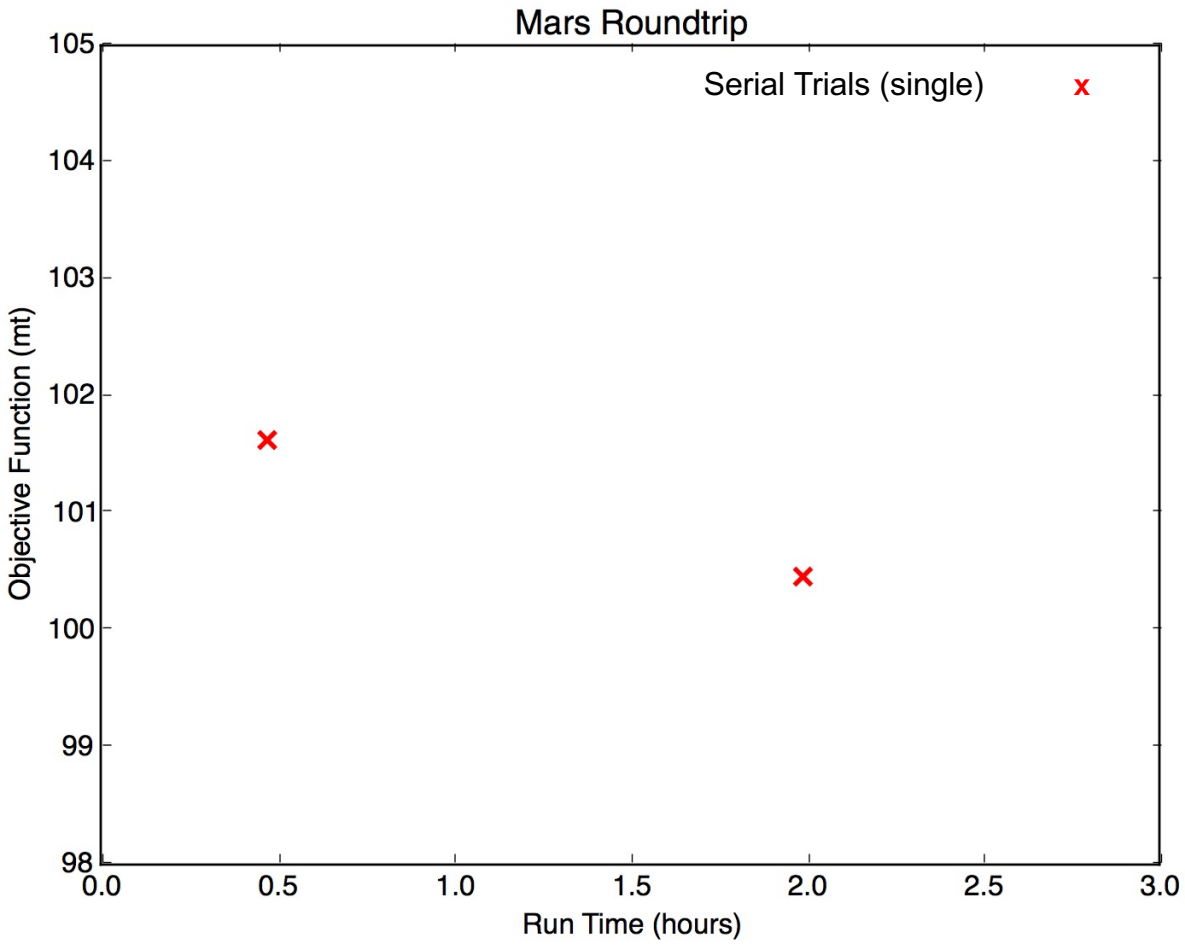


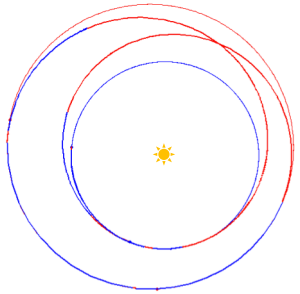
NRHO to LGA Escape

Roundtrip Earth-to-Mars

300-days at Mars

Large Example Results





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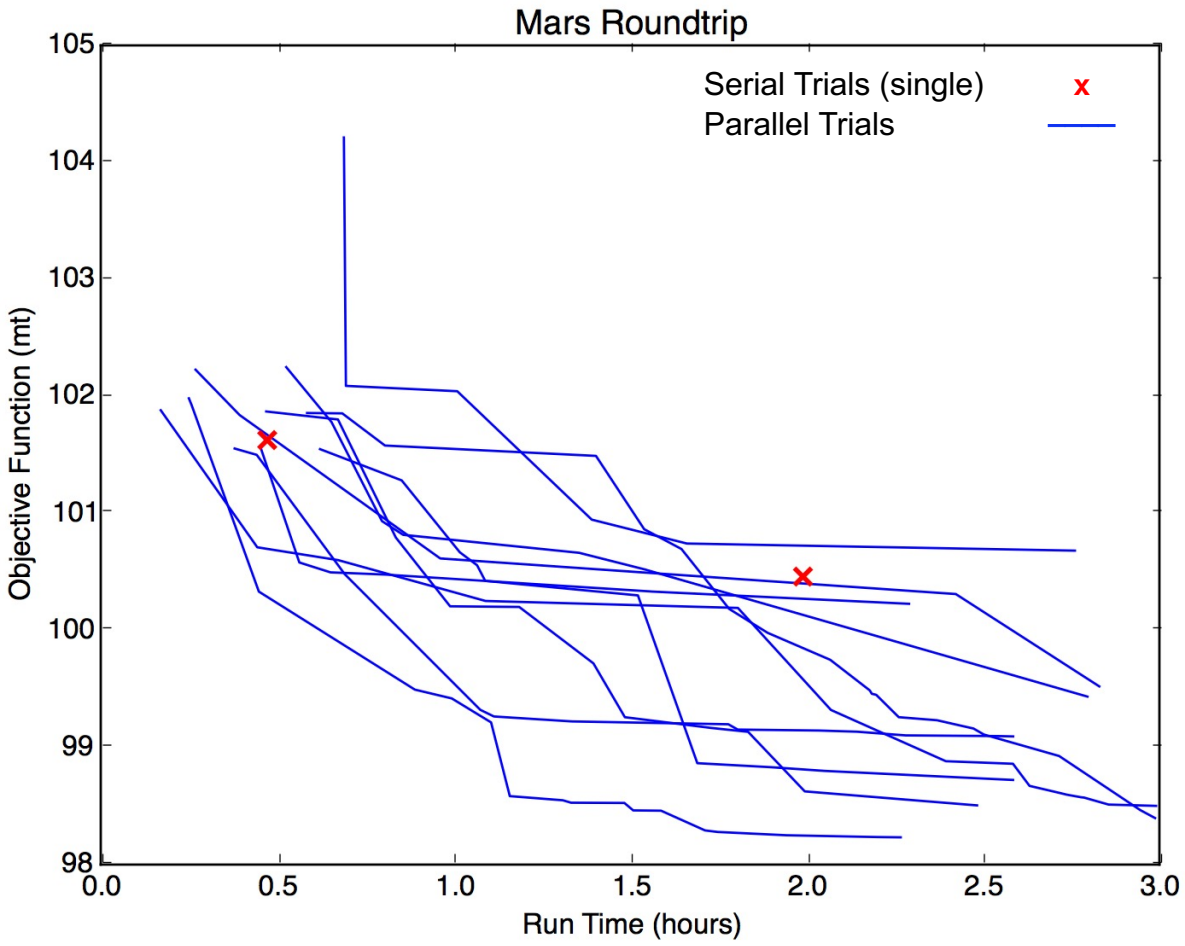

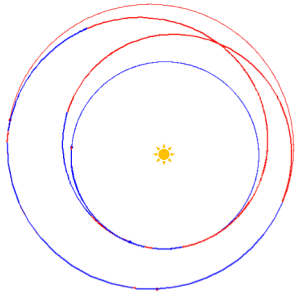

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Conclusions

1. **PMBH can find feasible solutions faster & more reliably**
2. **PMBH can find more optimal solutions faster & more reliably**
3. **PMBH can solve problems that are impractical with serial MBH**
4. **Questions Answered:**
   - Do I really have to locate a feasible solution ”by hand”? **NO.**
   - Is there a more optimal solution nearby? **PROBABLY.**
   - Can this somehow be done while I’m out to lunch or home for the night? **YES.**

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