Improvements to the Pegasus5 Overset CFD Software

Stuart E. Rogers

Applied Modeling and Simulation Branch/Code TNA
NASA Advanced Supercomputing Division
NASA Ames Research Center, Moffett Field, CA

12th Symposium on Overset Composite Grids
and Solution Technology
October 8th, 2014

Outline

- Introduction: motivation and background
- New Features in Pegasus version 5.2
- Automatic decomposition into multiple hole-cutters
- Improved parallel performance
- Assessment of computational cost
- Conclusion

- Complex geometries and larger grids drive need for improved automation and efficiency
    - Reduce user input
    - Reduce orphans
    - Improve hole-cutting
    - Improve parallel execution
- Requests from users for additional features
- Assess potential for use in unsteady moving-body problems

Background: Pegasus 5.0 and 5.1 Development

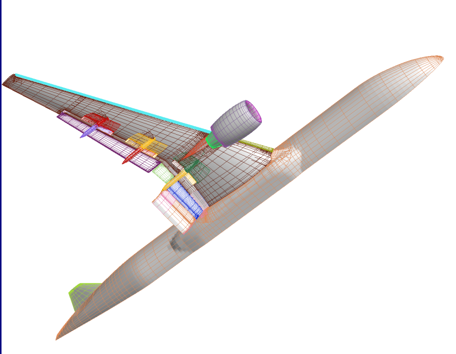
Version 5 History

- Version 5.0: 5th-generation overset software
  - Developed 1998 - 2000
  - Initially funded by NASA Advanced Subsonics Technology (AST) Program
  - Primary Authors: Norman Suhs and William Deitz, Microcraft
  - Completely new version of the software written in Fortran90
  - Significant improvements in oversetting process
  - Massive reduction in required user input
  - Working version delivered to NASA Ames
- Version 5.1 developed and supported by NASA:
  - NASA Space Shuttle Program
  - Constellation/MPCV Programs

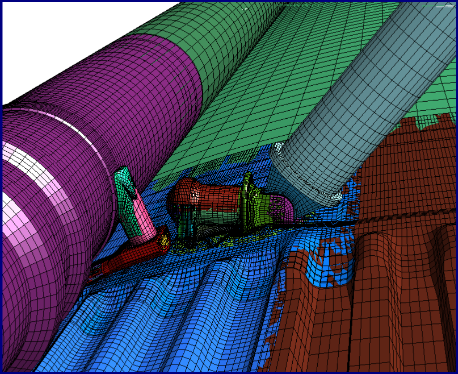
Background: Pegasus5 Usage

Version 5 History: 1998 to present

- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)



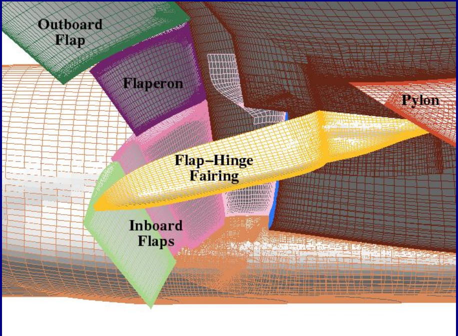
- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)
- Space Shuttle Program Return-To-Flight (2003-2006)



Background: Pegasus5 Usage

Version 5 History: 1998 to present

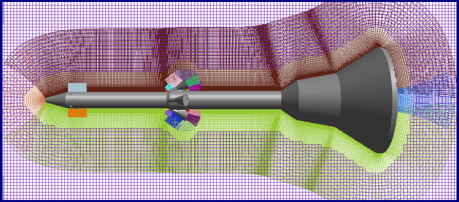
- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)
- Space Shuttle Program Return-To-Flight (2003-2006)
- Boeing high-lift and cruise CFD analysis



Background: Pegasus5 Usage

Version 5 History: 1998 to present

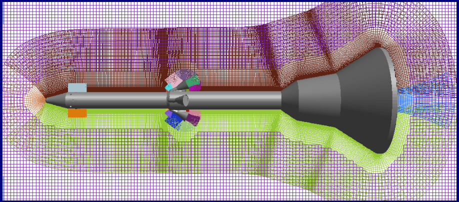
- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)
- Space Shuttle Program Return-To-Flight (2003-2006)
- Boeing high-lift and cruise CFD analysis
- Orion Launch Abort Vehicle (2010-2013)



Background: Pegasus5 Usage

Version 5 History: 1998 to present

- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)
- Space Shuttle Program Return-To-Flight (2003-2006)
- Boeing high-lift and cruise CFD analysis
- Orion Launch Abort Vehicle (2010-2013)
- Distributed to over 400 outside organizations and users

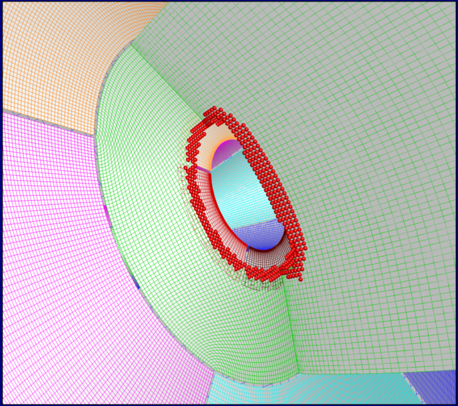


Background: Pegasus5 Features and Capabilities

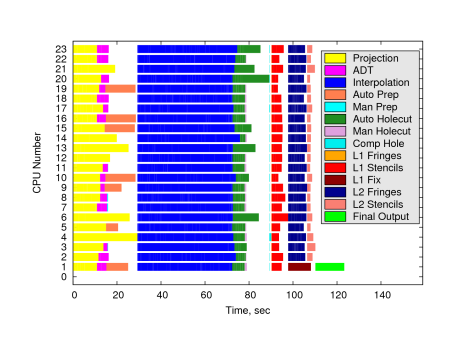
- Automatic hole-cutting
  - Multi-step hybrid method using indirect and direct hole cutting
  - Cartesian hole maps provide indirect representation of hole shape
  - Line-of-sight test using surface-grid elements: direct refined hole cutting
- Hole optimization through use of “level 2” interpolation
- Internal projections between overlapping surface grids
- Finds best interpolation stencil through exhaustive search
- Parallel execution using MPI
- Automatic restart capability
- Maintains manual hole-cutting capability from Pegsus4

- Released April 2014, NASA 1750.2A compliant

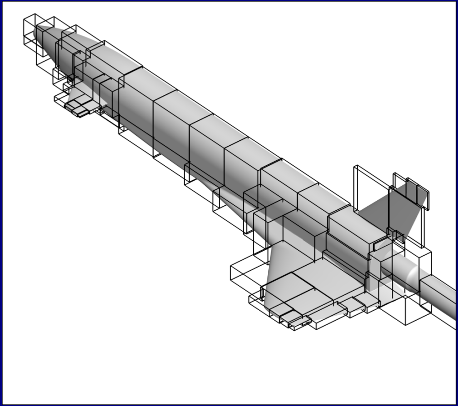
- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability



- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability
- Improved parallel performance

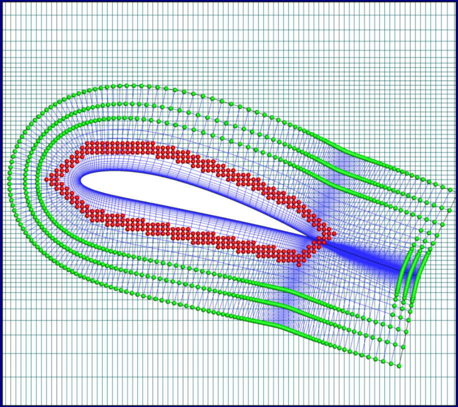


- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability
- Improved parallel performance
- New domain decomposition option for hole cutting



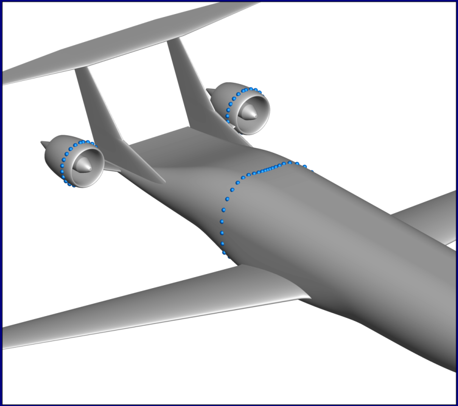
New Features in Pegasus 5.2

- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability
- Improved parallel performance
- New domain decomposition option for hole cutting
- Triple-fringe layer option



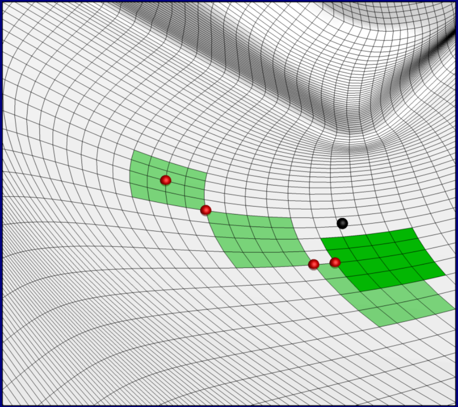
New Features in Pegasus 5.2

- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability
- Improved parallel performance
- New domain decomposition option for hole cutting
- Triple-fringe layer option
- Support for Overflow data-surface zones



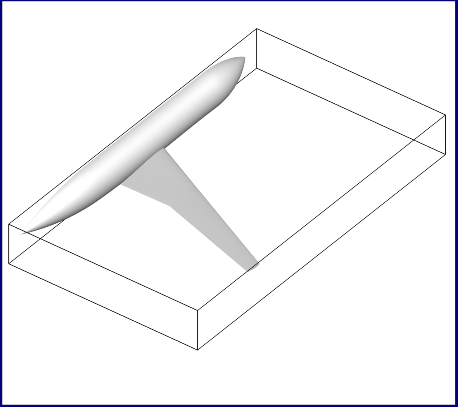
New Features in Pegasus 5.2

- Released April 2014, NASA 1750.2A compliant
- Cell-centered grid capability
- Improved parallel performance
- New domain decomposition option for hole cutting
- Triple-fringe layer option
- Support for Overflow data-surface zones
- Manual hole-cut efficiency improvements

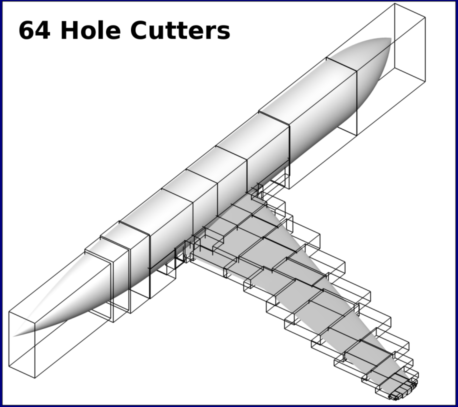


- Enhance auto hole cutting using domain decomposition

One Hole-Cutter

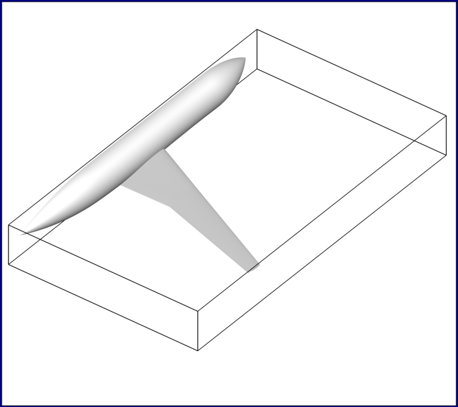


64 Hole-Cutters



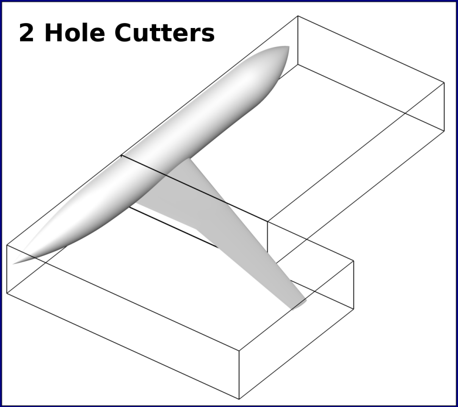
Auto HCUT Creation: Approach

- Recursively split the domain



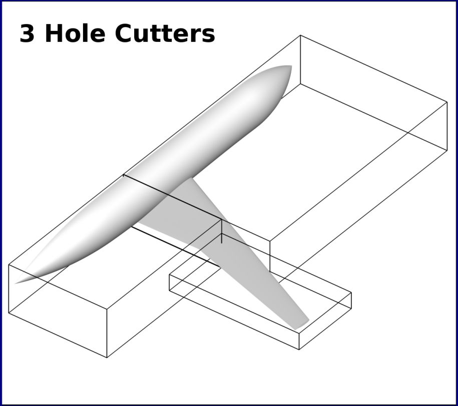
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension



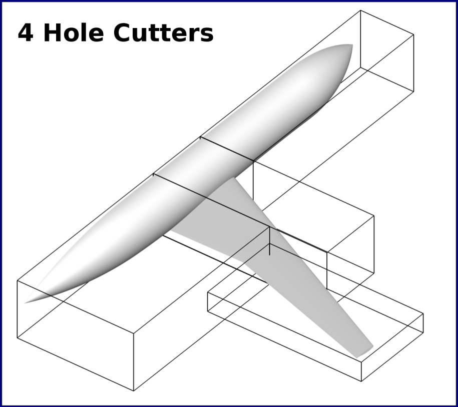
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points



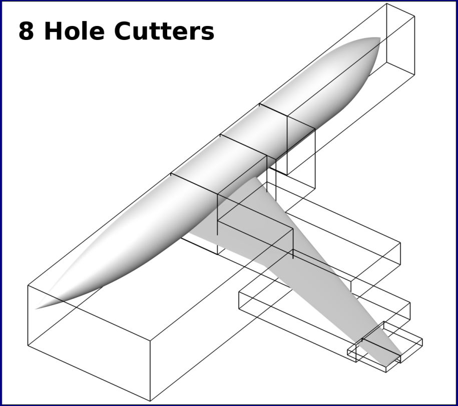
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points



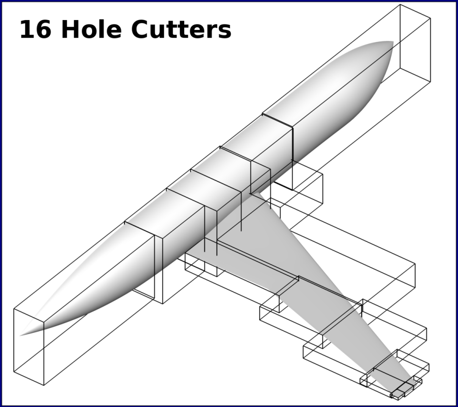
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points



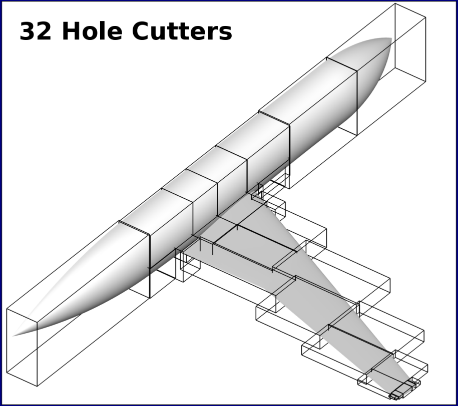
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points



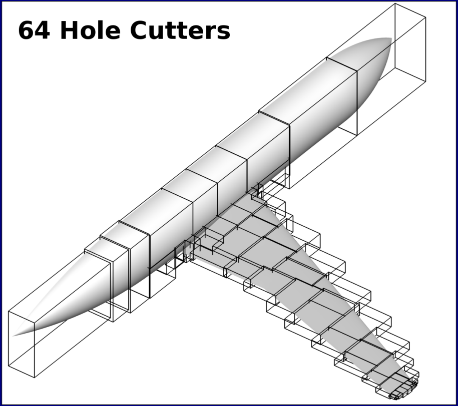
Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points
  - Never create a box completely inside



Auto HCUT Creation: Approach

- Recursively split the domain
  - Split the box in the longest dimension
  - Split the box with the most surface-grid points
  - Never create a box completely inside



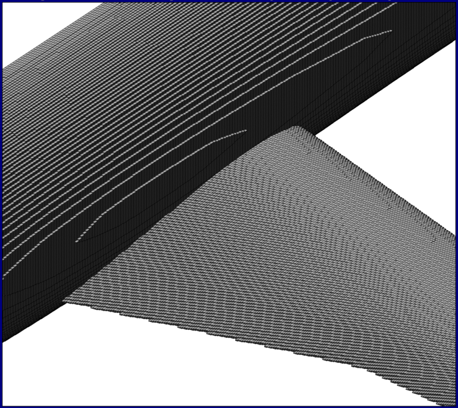
Automatic Decomposition Features

- Auto detection of which solid walls are contained in each hole-cutter
- Auto detection of which meshes can be cut by each hole-cutter
- Improved parallel efficiency
- Improved hole-cutting resolution
- Each hole-cutter can use fewer Cartesian elements

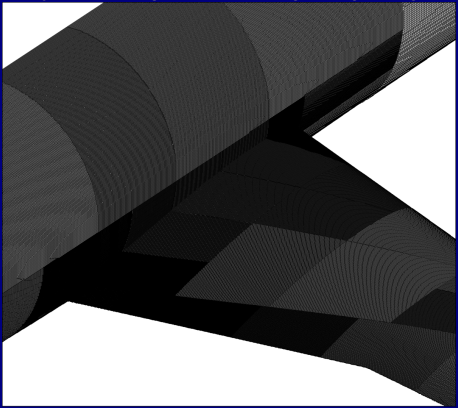
Wing-Body Test Case: Cartesian Fringe Elements

Ratio of Total Cartesian Volume = 10.1

One Hole-Cutter: 512x512x512



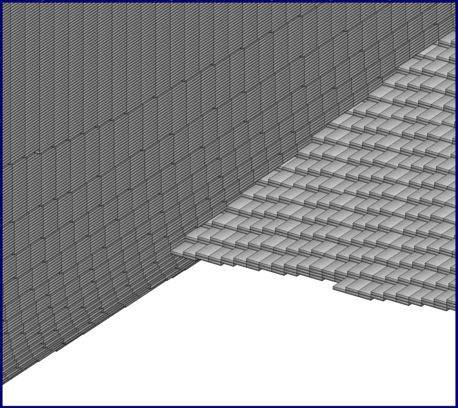
64 Hole-Cutters: 128x128x128



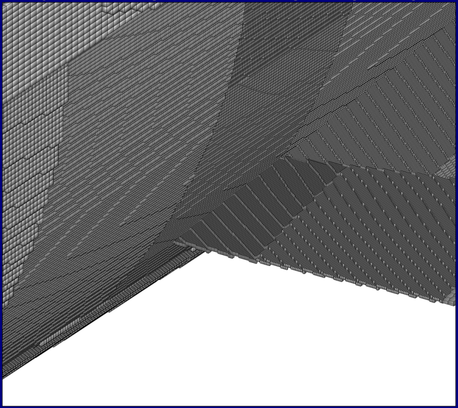
Wing-Body Test Case: Cartesian Fringe Elements

Ratio of Total Cartesian Volume = 10.1

One Hole-Cutter: 512x512x512



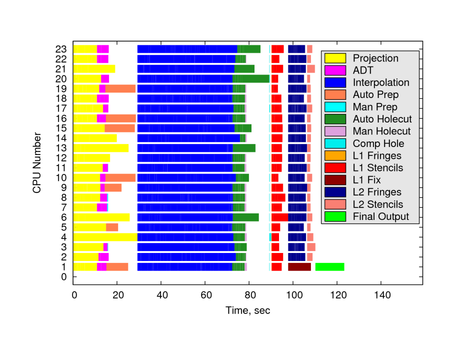
64 Hole-Cutters: 128x128x128



Improved Parallel Performance

Example: 55 zones, 79 million points

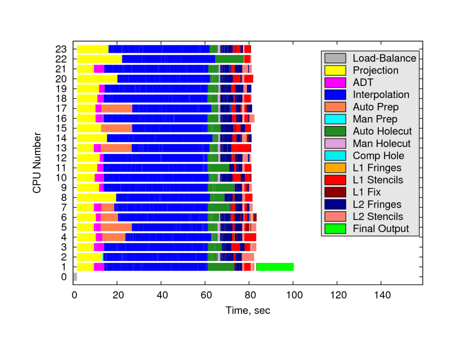
- Original approach: coarse-grained parallelization
  - Force synchronization between major process groups
  - Complete all projection processes before starting interpolation
  - Cannot scale to large numbers of CPUs



Improved Parallel Performance

Example: 55 zones, 79 million points

- Original approach: coarse-grained parallelization
  - Force synchronization between major process groups
  - Complete all projection processes before starting interpolation
  - Cannot scale to large numbers of CPUs
- New approach: finer-grained parallelization
  - Build process dependency map for each individual process
  - Improves ability to scale to more processors

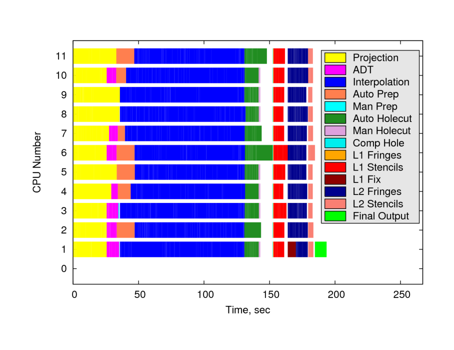


Scaling of New Parallel Approach

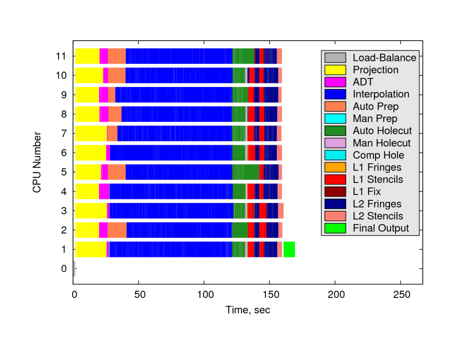
MPCV Launch Abort Vehicle: 55 zones, 79 million points

12 MPI Processes

Old Algorithm: 194 sec



New Algorithm: 168 sec

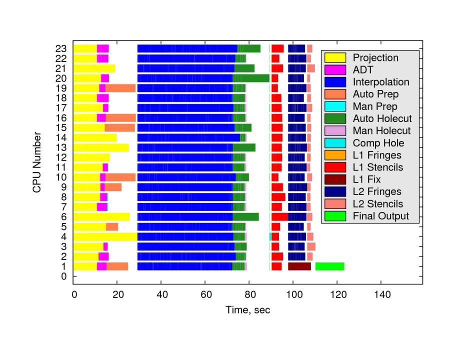


Scaling of New Parallel Approach

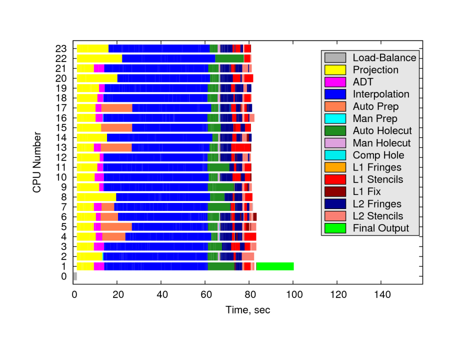
MPCV Launch Abort Vehicle: 55 zones, 79 million points

24 MPI Processes

Old Algorithm: 124 sec



New Algorithm: 99 sec

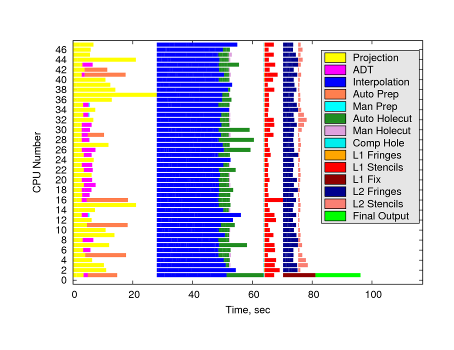


Scaling of New Parallel Approach

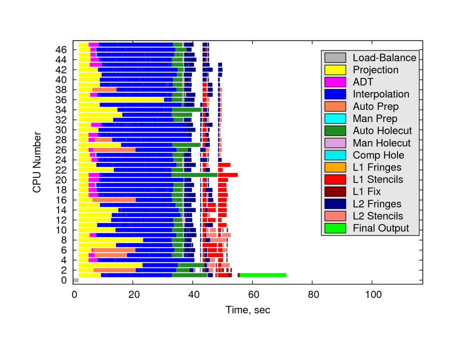
MPCV Launch Abort Vehicle: 55 zones, 79 million points

48 MPI Processes

Old Algorithm: 96 sec



New Algorithm: 70 sec

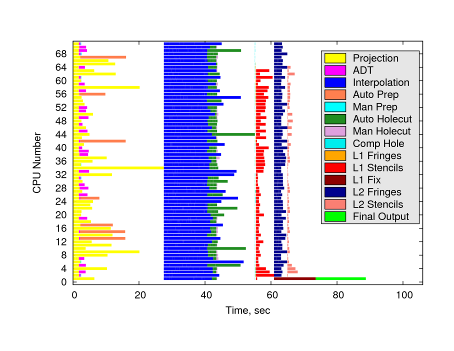


Scaling of New Parallel Approach

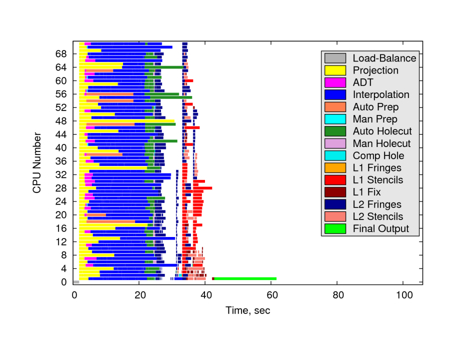
MPCV Launch Abort Vehicle: 55 zones, 79 million points

72 MPI Processes

Old Algorithm: 89 sec



New Algorithm: 61 sec

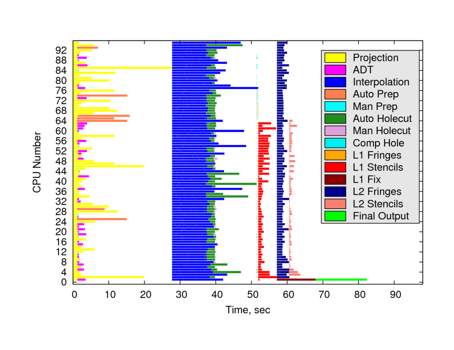


Scaling of New Parallel Approach

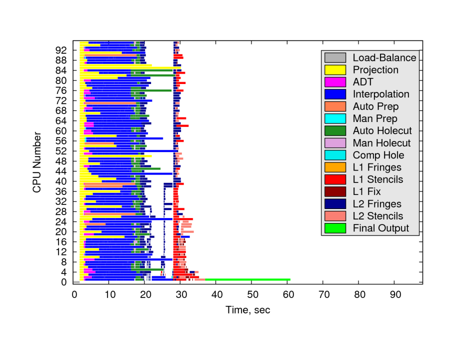
MPCV Launch Abort Vehicle: 55 zones, 79 million points

96 MPI Processes

Old Algorithm: 84 sec



New Algorithm: 60 sec

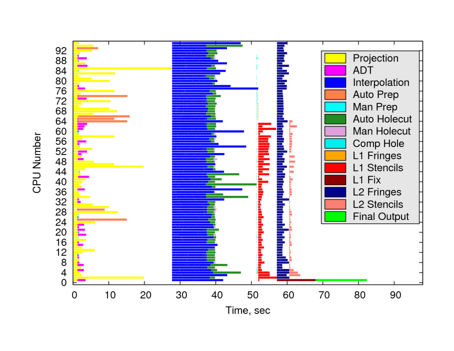


Scaling of New Parallel Approach

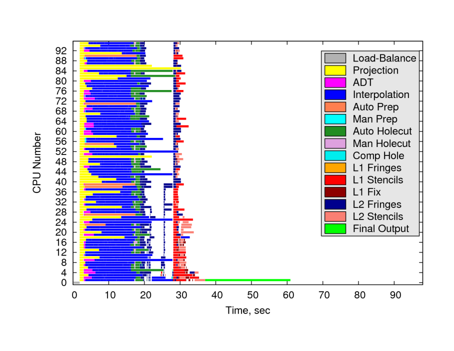
MPCV Launch Abort Vehicle: 55 zones, 79 million points

Asymptotic performance: 0.5 μsec per grid-pt

Old Algorithm: 84 sec



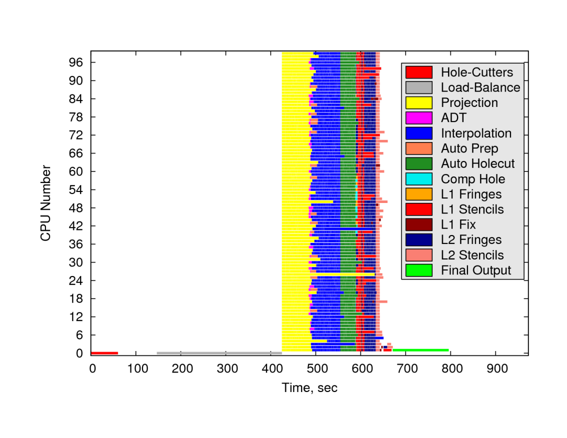
New Algorithm: 60 sec



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

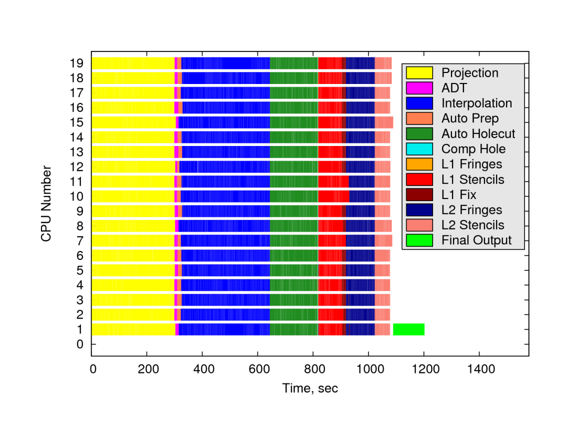
- 100 CPUs
- Significant start-up time: building process dependency link-lists
- Significant final output time: serial output



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

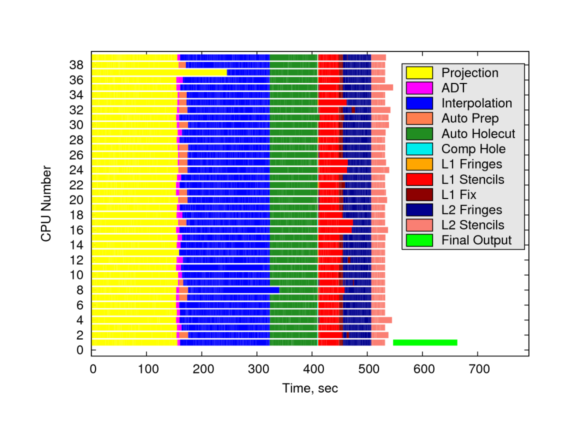
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

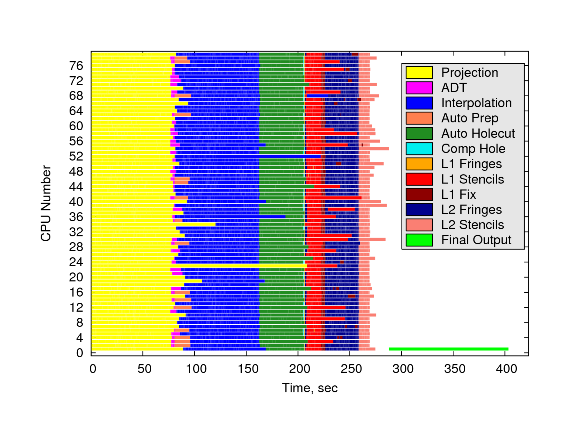
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

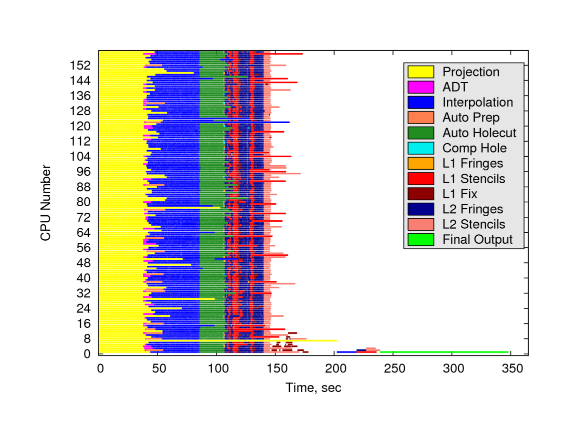
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550
- 80 CPUs: 280



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

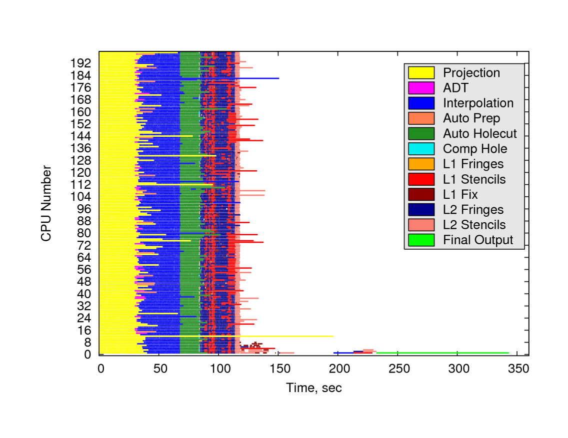
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550
- 80 CPUs: 280
- 160 CPUs: 240



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550
- 80 CPUs: 280
- 160 CPUs: 240
- 200 CPUs: 240



Asymptotic performance: 0.6 μsec per grid-pt

Relative cost of Overflow and Pegasus 5.2

Intel Ivy-Bridge Nodes

- Approximate wall-clock time per time step, in seconds
  - Dual time-stepping time-advance algorithm
  - Overflow: $\approx$ 5 micro-seconds per sub-iter per grid pt

	NITNWT	Points (millions)	100 CPUs	200 CPUs	400 CPUs	800 CPUs
Overflow	10	100	50	25	–	–
Overflow	50	100	250	125	–	–
Pegasus5		100	60	60	–	–
Overflow	10	200	100	50	25	–
Overflow	50	200	500	250	125	–
Pegasus5		200	120	120	120	–
Overflow	10	400	–	100	50	25
Overflow	50	400	–	500	250	125
Pegasus5		400	–	240	240	240
X-ray/DCF		400	–	150	67	52

Conclusion

- Released version 5.2 of Pegasus
- Many improvements and some new features
- Automatic domain decomposition into automatic hole cutters
- Improved parallel efficiency through fine-grained parallelization
  - ≈ 0.6 μseconds per grid point
  - Further process optimization required for additional scaling improvements
- Potential applications to time-dependent moving body problems