

Improvements to the Pegasus5 Overset CFD Software

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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

Introduction

Motivation for Improvements to Pegasus5

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

Background: Pegasus 5.0 and 5.1 Development

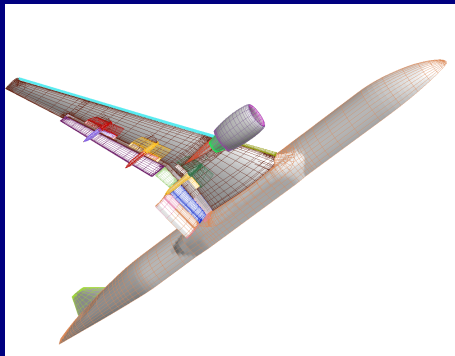
Version 5 History

- 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

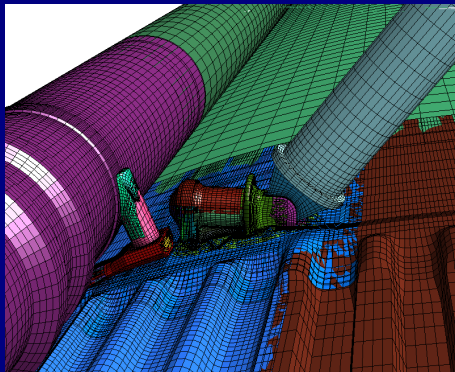
- Enabled AST Program level-1 milestone: High-Lift Aircraft CFD in 50 days (2000)



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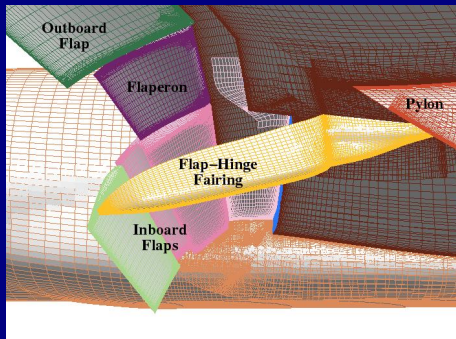
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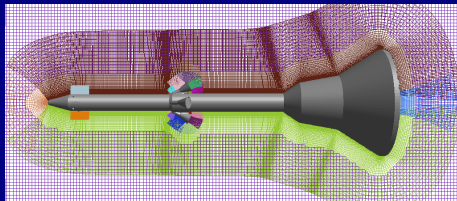
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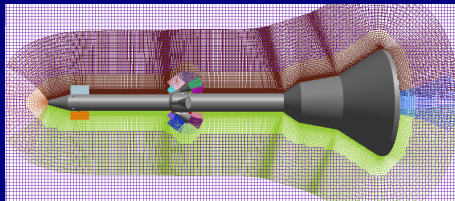
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- Space Shuttle Program Return-To-Flight (2003-2006)
- Boeing high-lift and cruise CFD analysis
- Orion Launch Abort Vehicle (2010-2013)
- Distributed to over 400 outside organizations and users



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 Pegasus4

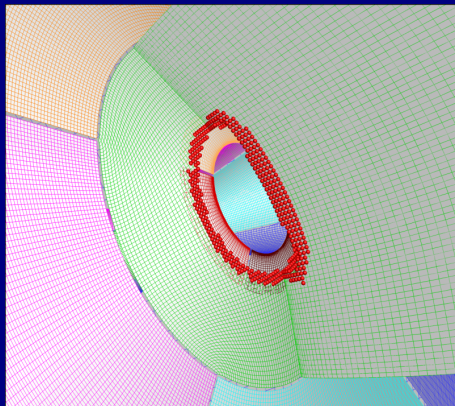
New Features in Pegasus 5.2

- Released April 2014, NASA 1750.2A compliant



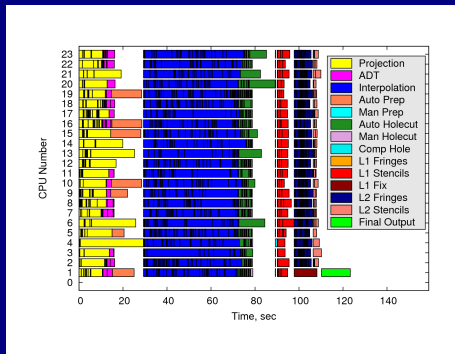
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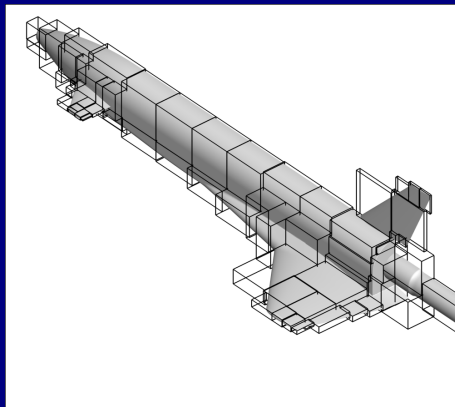
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- Improved parallel performance



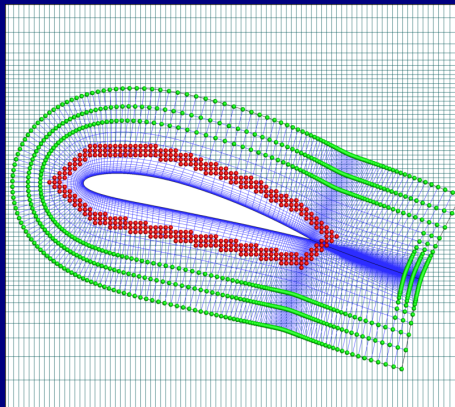
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- New domain decomposition option for hole cutting



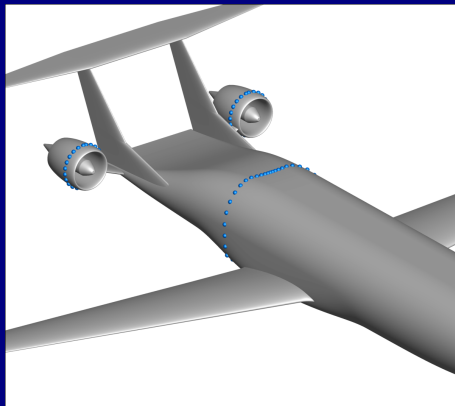
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- Triple-fringe layer option



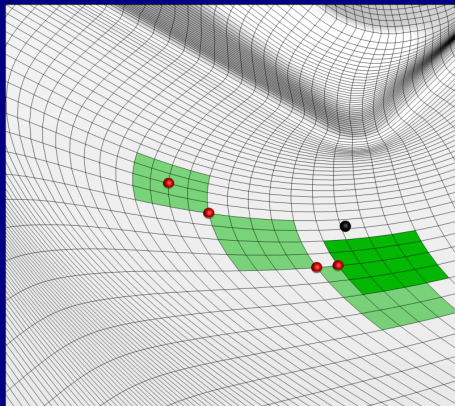
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- Support for Overflow data-surface zones



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- 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

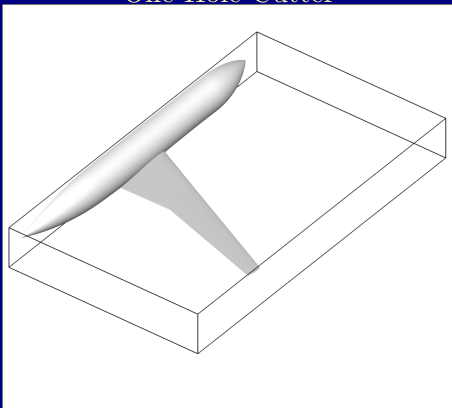


New Feature: Automatic HCUT Creation

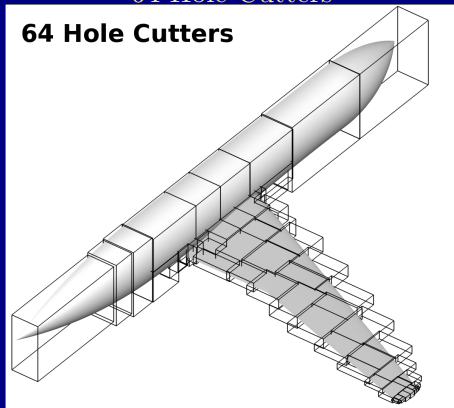
Automatic Decomposition To Fit The Geometry

- Enhance auto hole cutting using domain decomposition

One Hole-Cutter

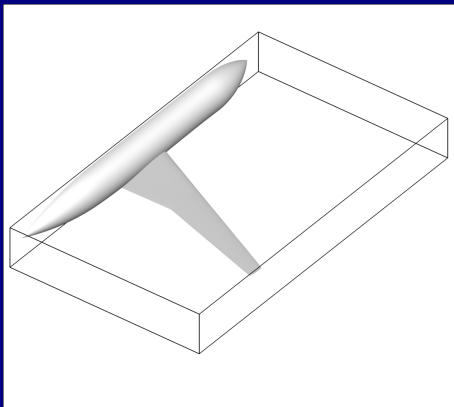


64 Hole-Cutters



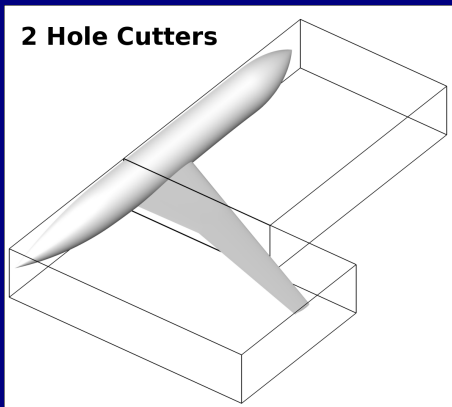
Auto HCUT Creation: Approach

- Recursively split the domain



Auto HCUT Creation: Approach

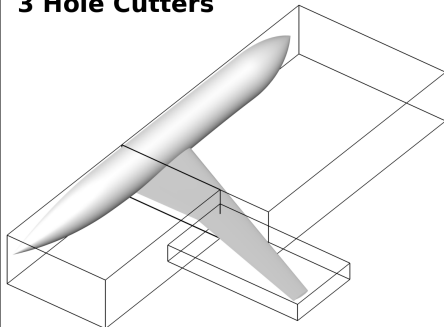
- Recursively split the domain
 - Split the box in the longest dimension



Auto HCUT Creation: Approach

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

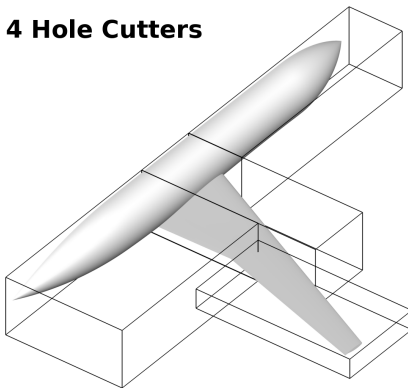
3 Hole Cutters



Auto HCUT Creation: Approach

- Recursively split the domain
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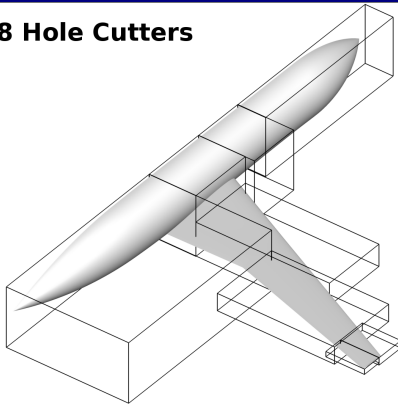
4 Hole Cutters



Auto HCUT Creation: Approach

- Recursively split the domain
 - Split the box in the longest dimension
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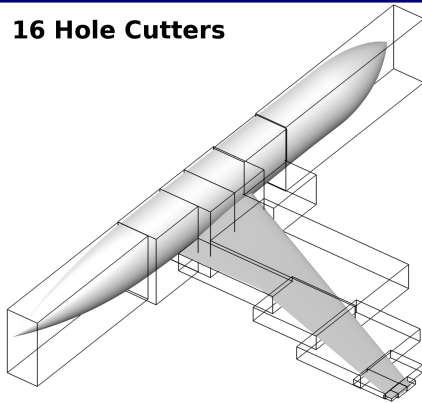
8 Hole Cutters



Auto HCUT Creation: Approach

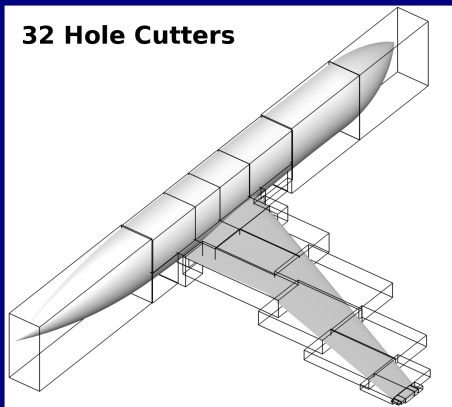
- Recursively split the domain
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16 Hole Cutters



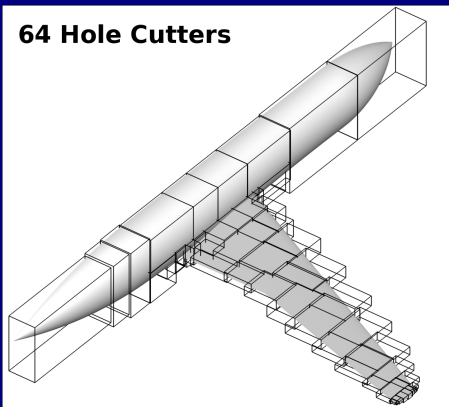
Auto HCUT Creation: Approach

- 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

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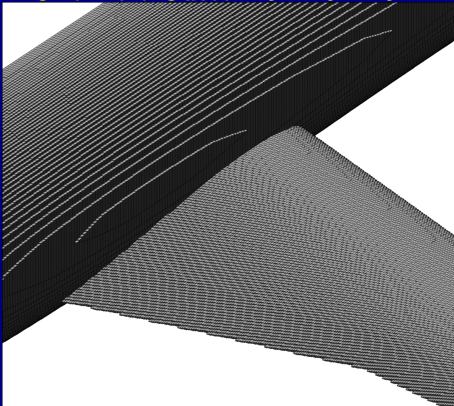
Automatic Decomposition Features

- 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

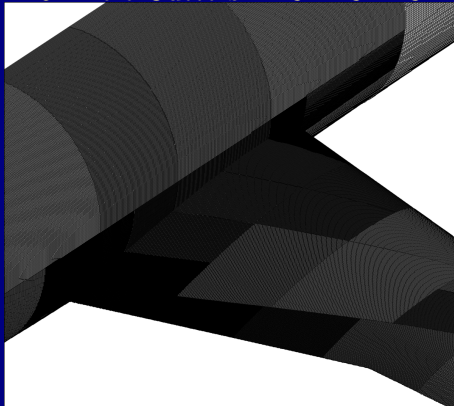
Wing-Body Test Case: Cartesian Fringe Elements

Ratio of Total Cartesian Volume = 10.1

One Hole-Cutter: 512x512x512



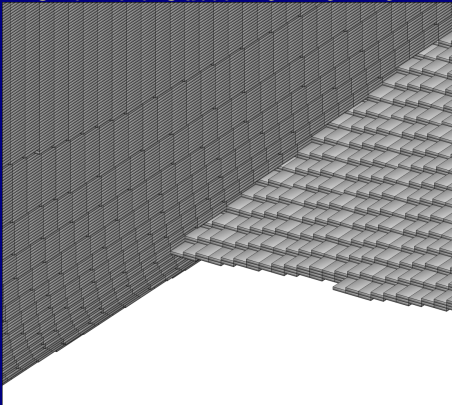
64 Hole-Cutters: 128x128x128



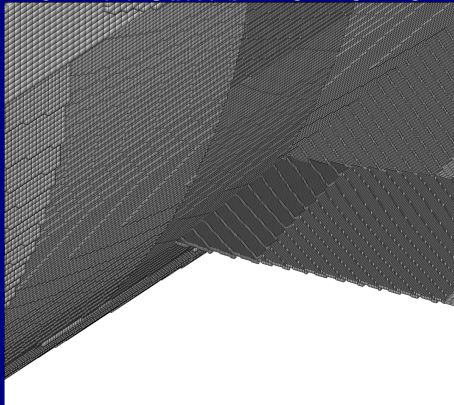
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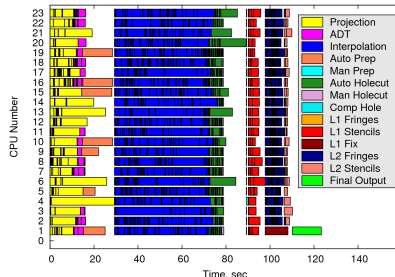
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Improved Parallel Performance

Example: 55 zones, 79 million points

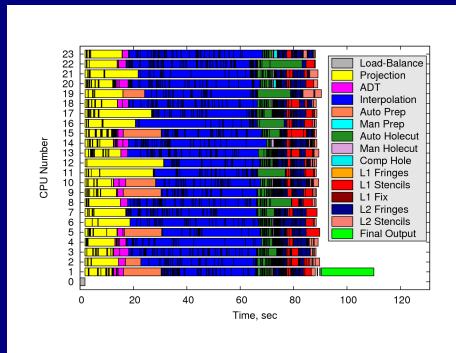
- Original approach:
coarse-grained parallelization
 - Force synchronization
between major process
groups
 - Complete all projection
processes before starting
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 - Cannot scale to large
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Improved Parallel 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

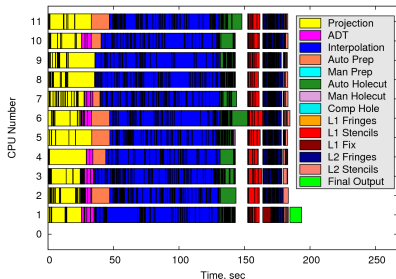


Scaling of New Parallel Approach

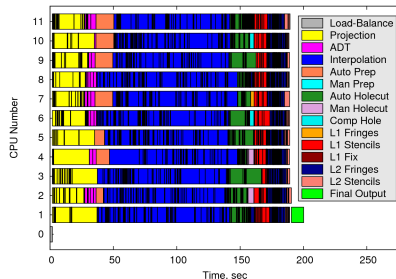
MPCV Launch Abort Vehicle: 55 zones, 79 million points

12 MPI Processes

Old Algorithm



New Algorithm

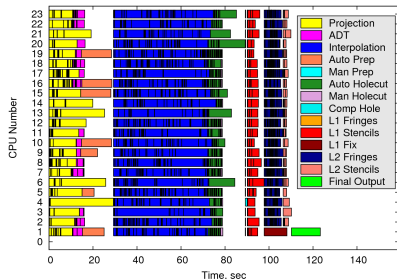


Scaling of New Parallel Approach

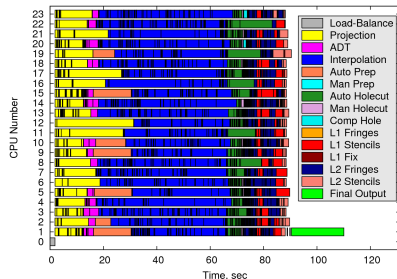
MPCV Launch Abort Vehicle: 55 zones, 79 million points

24 MPI Processes

Old Algorithm



New Algorithm

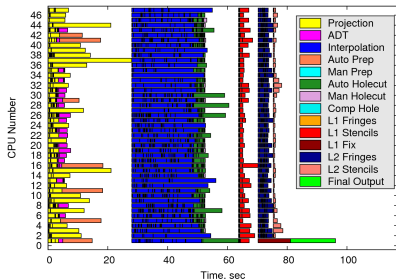


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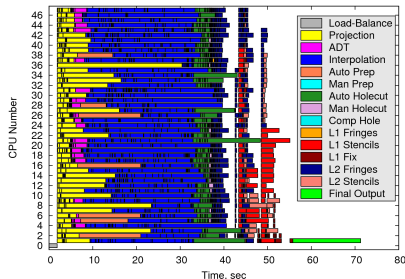
MPCV Launch Abort Vehicle: 55 zones, 79 million points

48 MPI Processes

Old Algorithm



New Algorithm

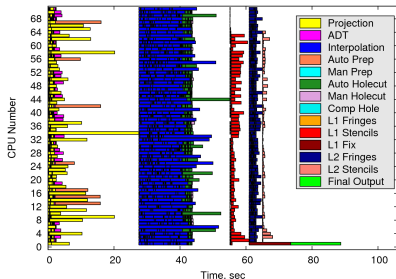


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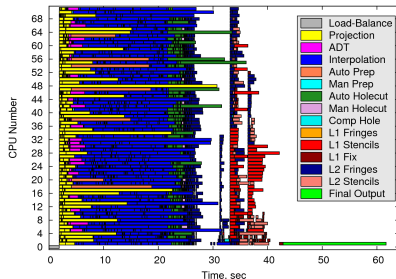
MPCV Launch Abort Vehicle: 55 zones, 79 million points

72 MPI Processes

Old Algorithm



New Algorithm

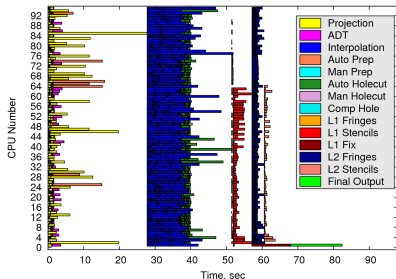


Scaling of New Parallel Approach

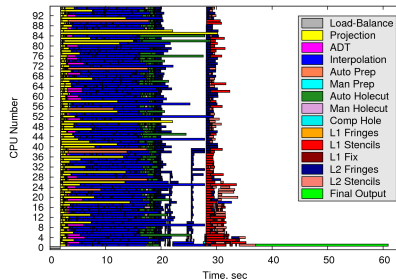
MPCV Launch Abort Vehicle: 55 zones, 79 million points

96 MPI Processes

Old Algorithm



New Algorithm

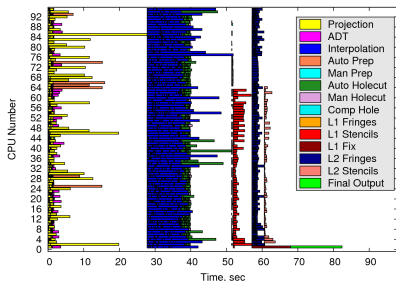


Scaling of New Parallel Approach

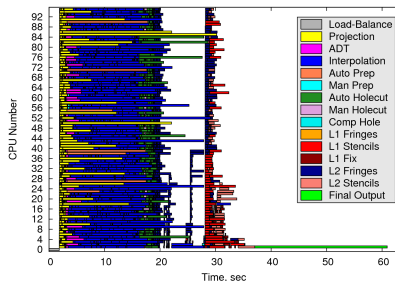
MPCV Launch Abort Vehicle: 55 zones, 79 million points

Asymptotic performance: $0.5 \mu\text{sec}$ per grid-pt

Old Algorithm



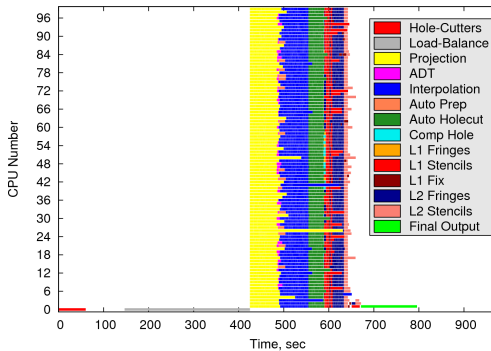
New Algorithm



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

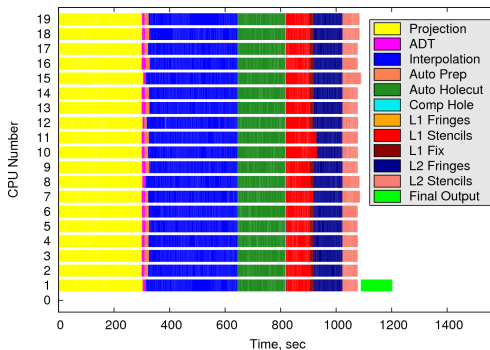
- 100 CPUs
- Significant start-up time:
building process
dependency
link-lists
- Significant final
output time: serial
output



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

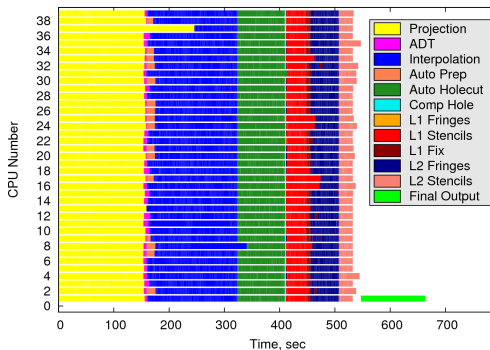
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100



Performance of New Parallel Approach

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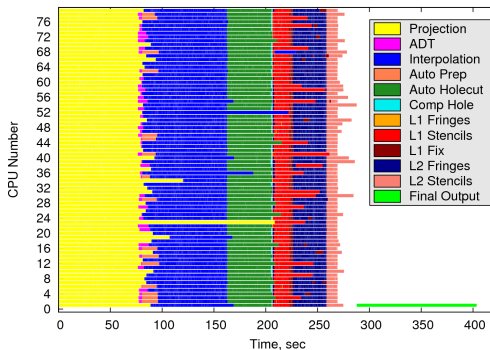
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550



Performance of New Parallel Approach

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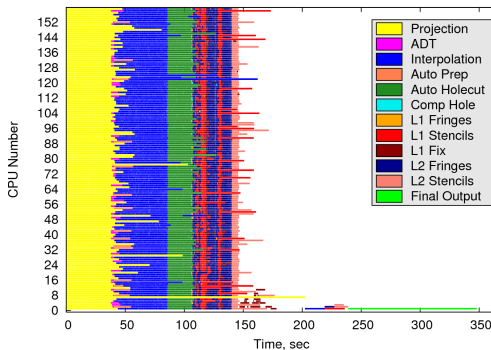
- Wallclock-time to create overset, sec:
- 20 CPUs: 1100
- 40 CPUs: 550
- 80 CPUs: 280



Performance of New Parallel Approach

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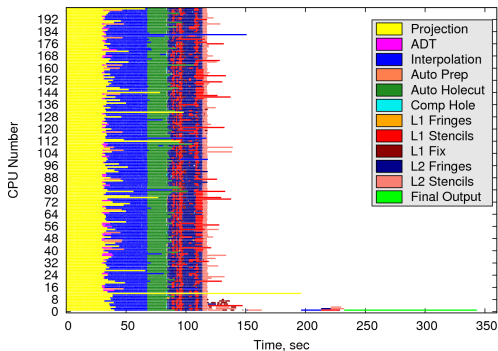
- Wallclock-time to create overset, sec:
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- 80 CPUs: 280
- 160 CPUs: 240



Performance of New Parallel Approach

Space Launch System: 892 zones, 375 million points

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



Asymptotic performance: $0.6 \mu\text{sec}$ 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: ≈ 5 micro-seconds per sub-iter per grid pt

	NITNWT	Points (millions)	100 CPU _s	200 CPU _s	400 CPU _s	800 CPU _s
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

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
 - $\approx 0.6 \mu\text{seconds}$ per grid point
 - Further process optimization required for additional scaling improvements
- Potential applications to time-dependent moving body problems
 - Pegasus 5.2 can re-process the entire grid in 0.1 to 2.0 times one time-step in Overflow