Integrating Local Feature Detectors in the Interactive Visual Analysis of Flow Simulation Data

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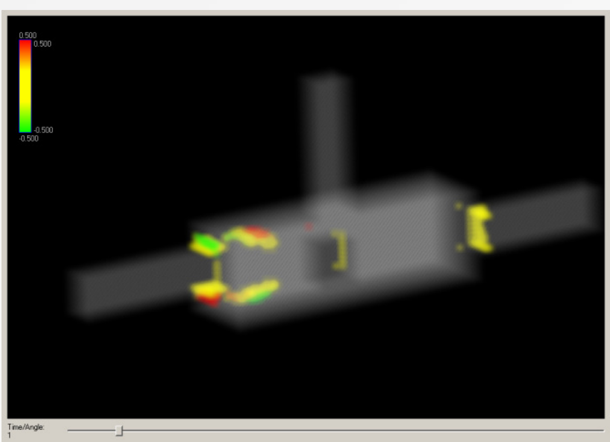
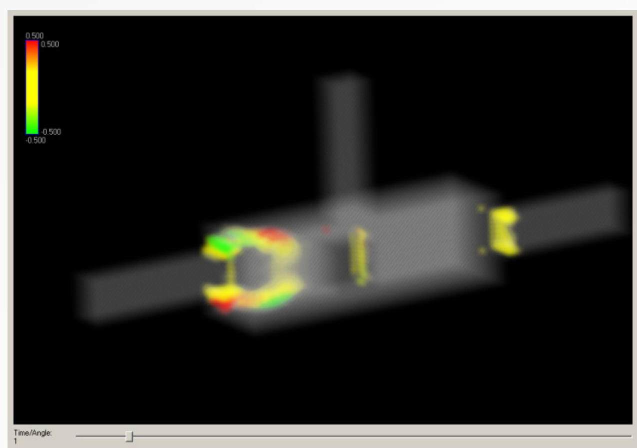
Agenda

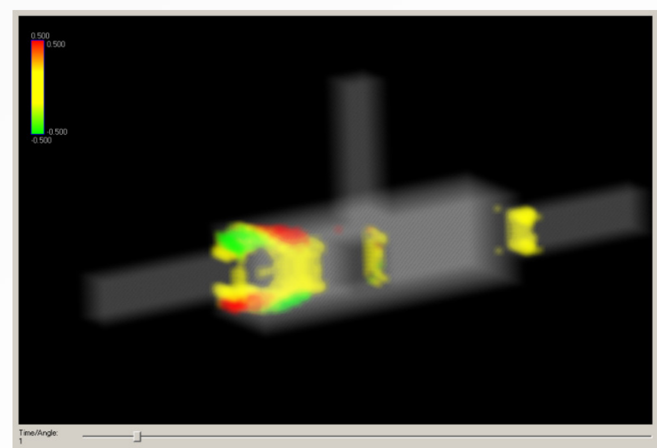
- Introduction
- Smooth vortex region detectors
- Case study: cooling jacket

Introduction

- Vortices difficult → many definitions → many detectors
- Common criteria give binary (yes/no) results for each cell
- Standard approach: compute iso surfaces of detector response
- Engineers interactively search for good iso-values → interaction using the value of the detector response

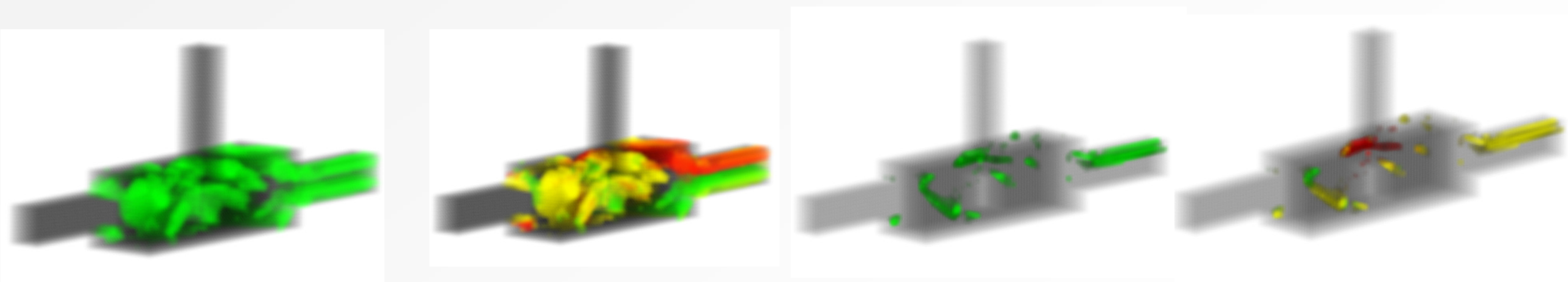






Idea

- Get access to the benefits of multiple detectors at the same time
- Allow additional attributes to be included in the vortex flow feature analysis
- Make strength of detector response available for analysis
- **Solution**: integration of smooth reformulation of the detectors into an interactive framework



$\lambda_2 < -100$ + Helicity mapped to color + Positive helicity and low pressure + Temperature mapped to color

Smooth Detectors - Swirling Strength

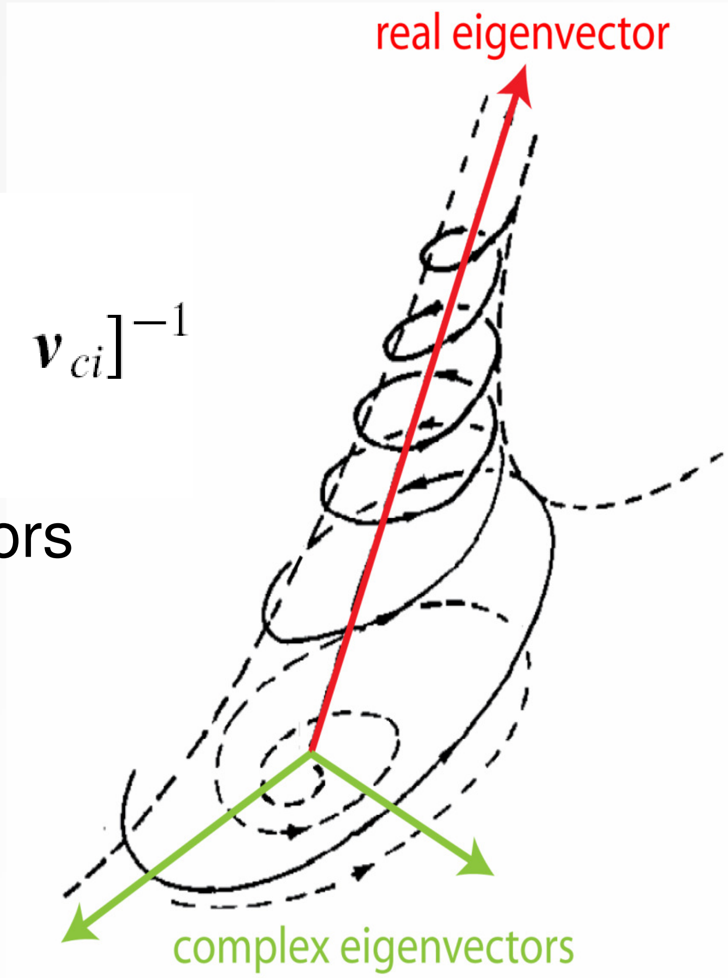
- Jacobian **J** can be decomposed as

real eigenvalue complex eigenvalues

$$[\boldsymbol{v}_r \;\; \boldsymbol{v}_{cr} \;\; \boldsymbol{v}_{ci}] \begin{bmatrix} \lambda_r & & \\ & \lambda_{cr} & \lambda_{ci} \\ & -\lambda_{ci} & \lambda_{cr} \end{bmatrix} [\boldsymbol{v}_r \;\; \boldsymbol{v}_{cr} \;\; \boldsymbol{v}_{ci}]^{-1}$$

eigenvectors

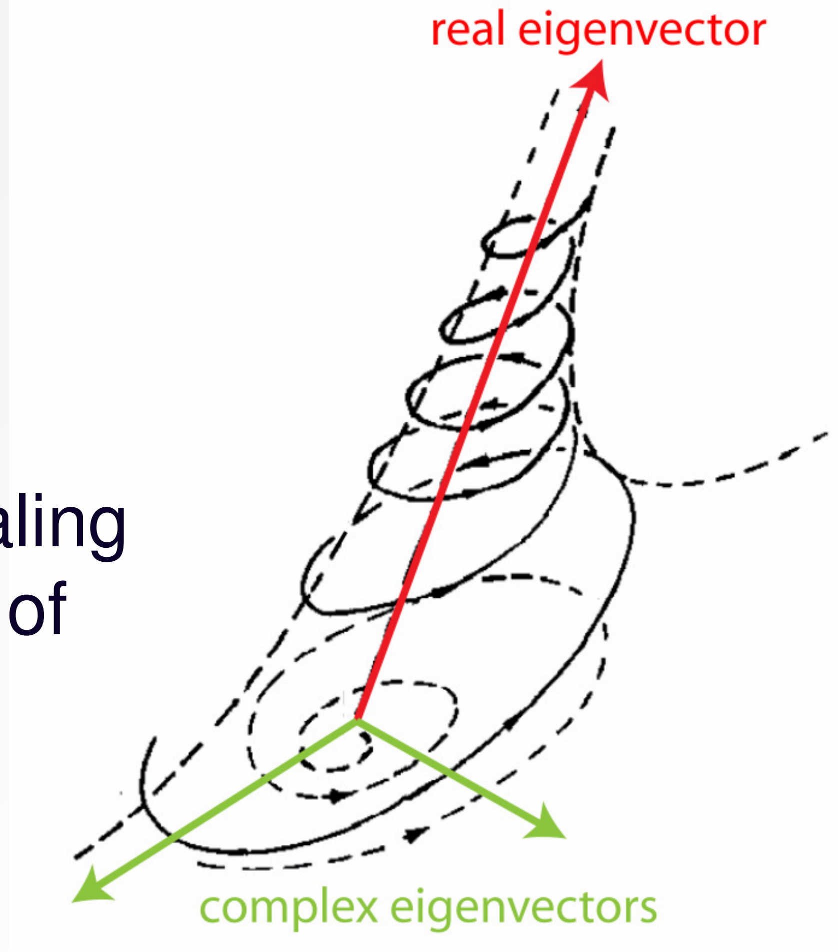
- If $\lambda_{ci} > 0$ in a local curvilinear coordinate system the streamlines are determined by the eigenvalues



Swirling Strength

- Binary formulation: Vortex if we have a complex eigenvalue pair
- λ_{ci} determines speed of rotation
- Smooth formulation by linear scaling speed of rotation using min/max of λ_{ci}:

  Fuzzy- $\lambda_{ci} = (\lambda_{ci}\text{-min})/(\text{max-min})$



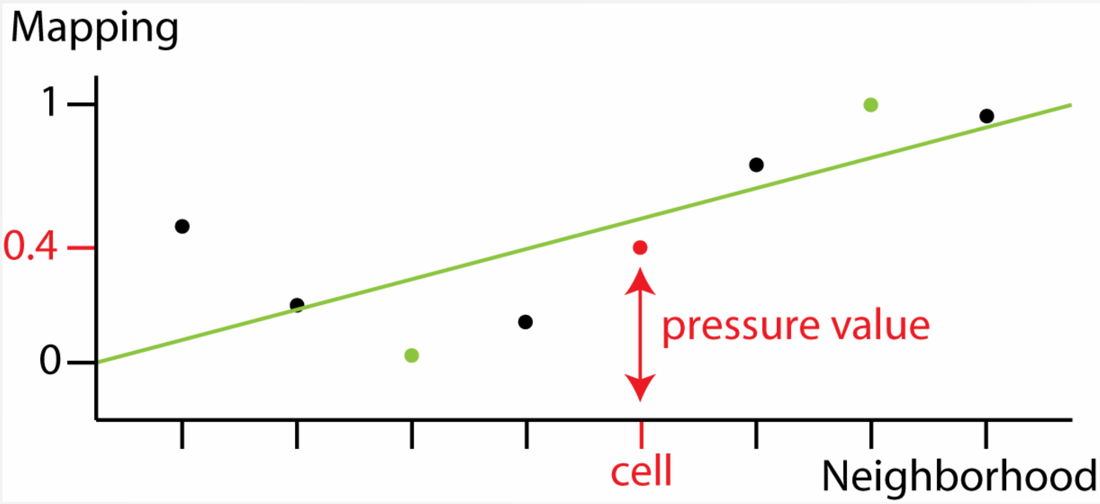
Smooth Detectors - Lambda 2

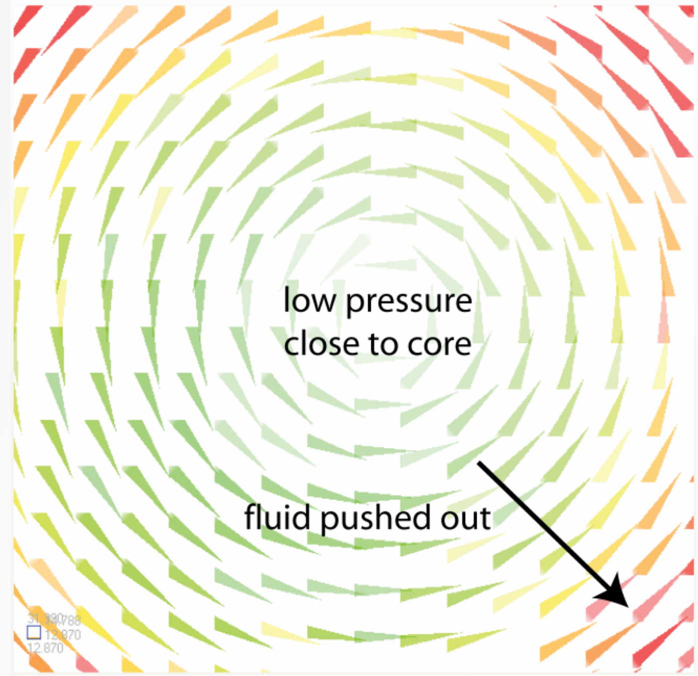
- Rate-of-strain tensor $S=0.5(\mathbf{J}+\mathbf{J}^T)$ and rate-of-rotation tensor $\Omega=0.5(\mathbf{J}-\mathbf{J}^T)$
- First Idea: Vortex where $||S||<||\Omega||$ (Hunt1988)
- Improvement: require „$||S||<||\Omega||$“ only in one eigenplane:
  - Compute eigenvalues of $S^2 + \Omega^2$
  - $S^2 + \Omega^2$ has three real eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3$
  - If $\lambda_1<0$ then „$||S||<||\Omega||$“ in all directions
  - If $\lambda_1>0$ and $\lambda_2<0$ then „$||S||<||\Omega||$“ in one eigenplane
  - Binary: $\lambda_2<0$
- Smooth criterion:

$$\lambda_{2Fuzzy}(x) = \begin{cases} 0 & : \quad \lambda_2(x) \geq 0 \\ 1 & : \quad \lambda_1(x) \leq 0 \\ scale_D(-\lambda_2(x)) & : \quad otherwise \end{cases}$$

simply linear scaling

Smooth Detectors - Local pressure extrema

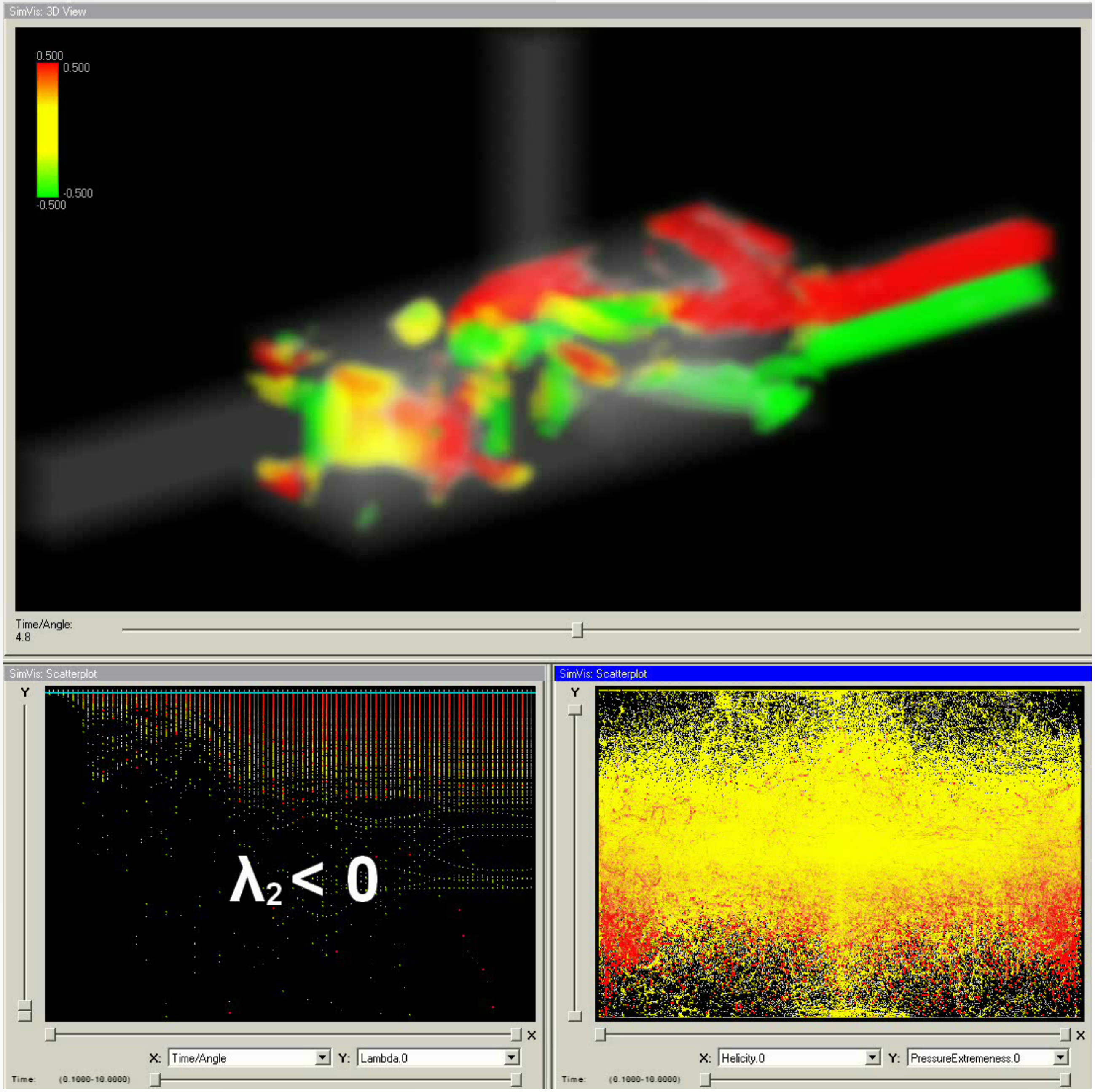




- Neighborhood around cell N
- Scale values locally to get fuzzy-extremumness attribute

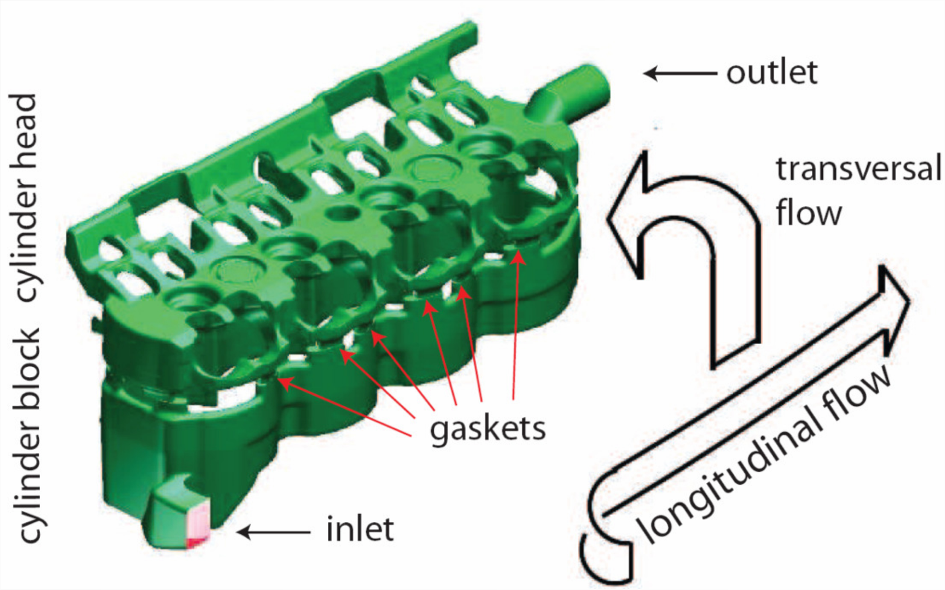
$$extremum_{Fuzzy}(a(\mathrm{x})) = \begin{cases} 0.5 & : \quad max = min \\ scale_{\mathrm{N}}(a(\mathrm{x})) & : \quad otherwise \end{cases}$$

Video


SimVis: 3D View
0.500
-0.500
Time/Angle:
4.8
SimVis: Scatterplot
$\lambda_2 < 0$
X: Time/Angle
Y: Lambda.0
SimVis: Scatterplot
X: Helicity.0
Y: PressureExtremeness.0

Case Study: Cooling Jacket

- Cooling four cylinder engine
- Need temperature close to optimum (~ 363° K)
  - Good overall heat transport
  - Even distribution of flow to each cylinder
  - Avoid regions of stagnant flow



Hauser et al. 2006

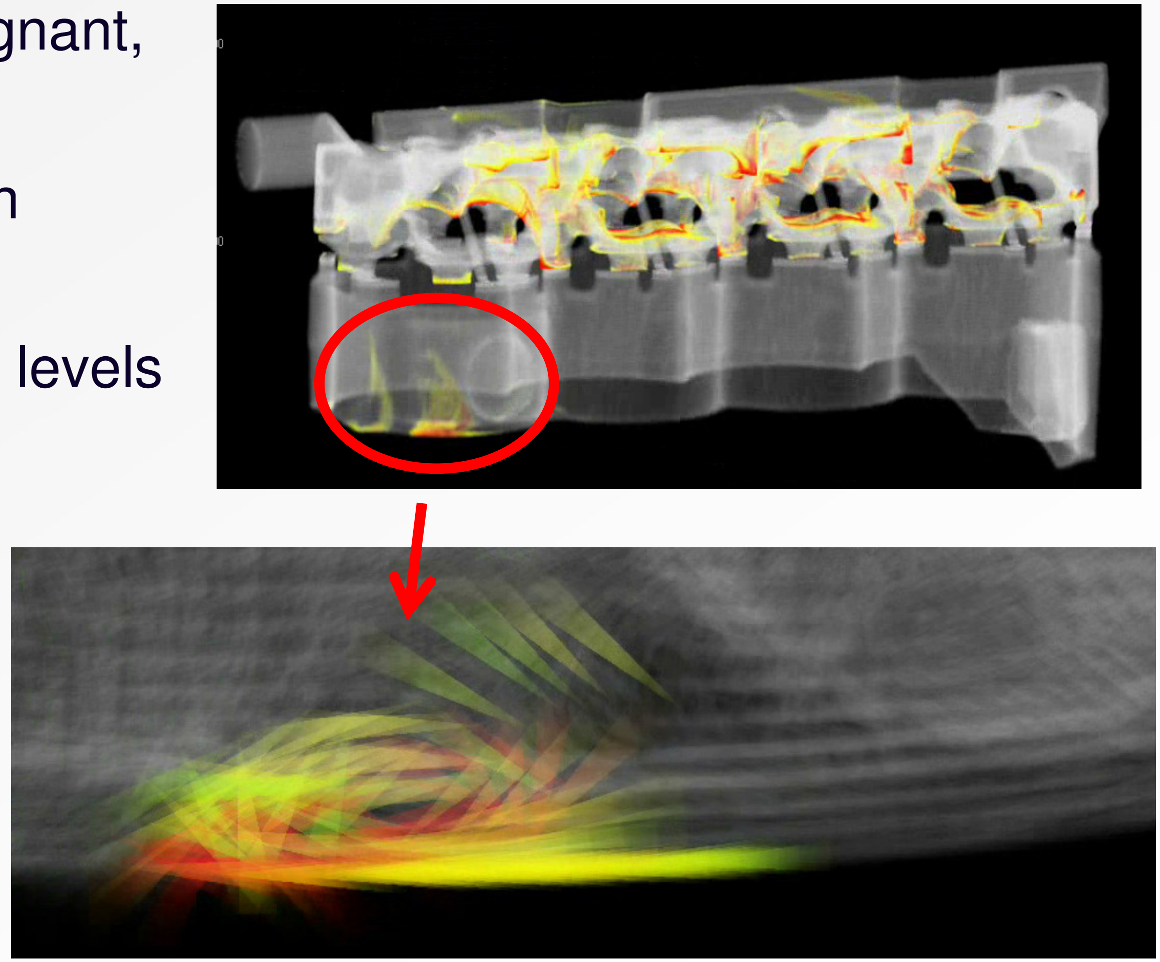
- Finding: vortical motion can both improve and hinder heat transport

[Dataset: ~1,5 mio cells (tetrahedra, prisms & hexahedra)]

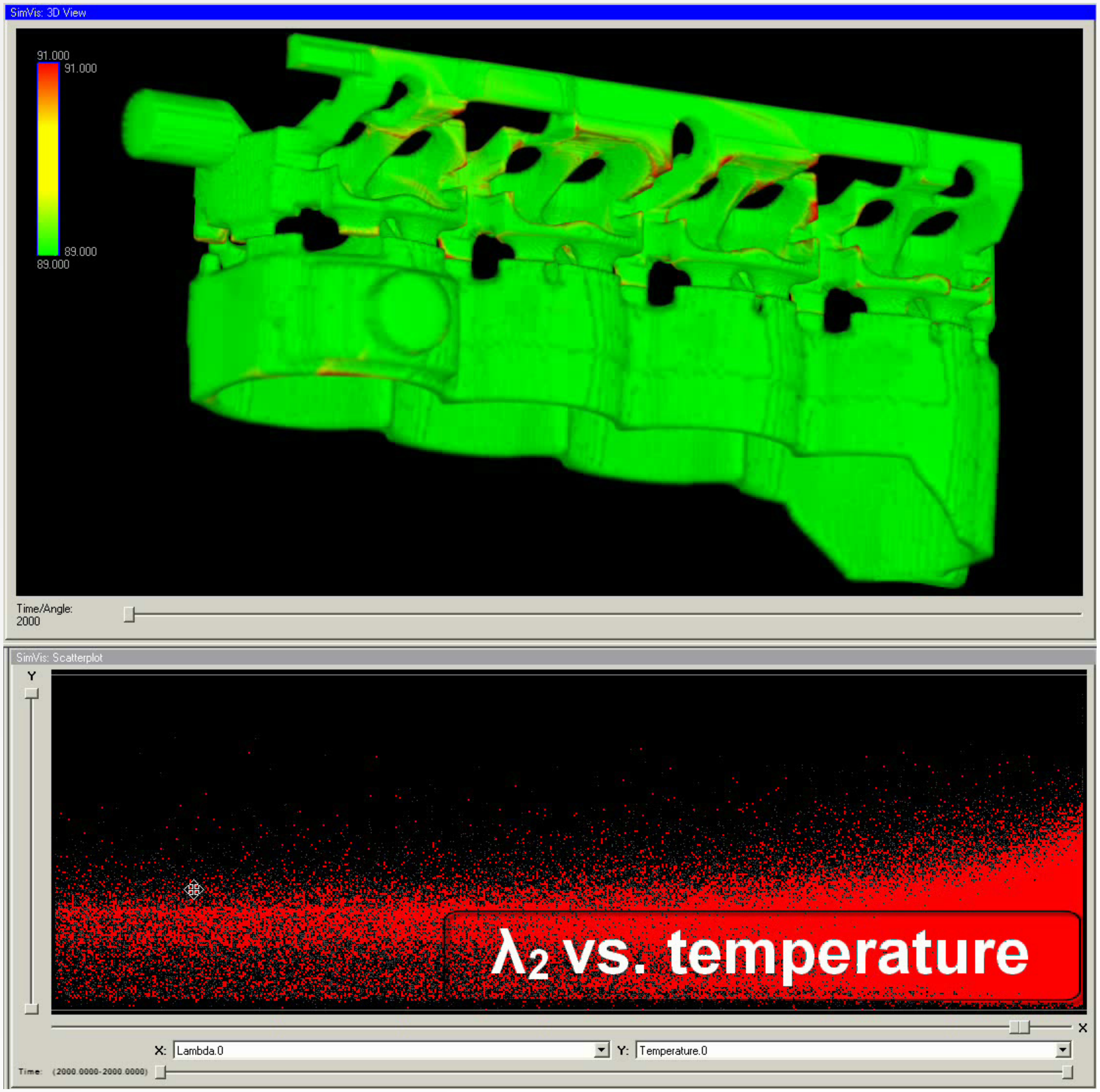
Reduced Transport Due To Vortical Motion

- Select regions of near stagnant, hot flow for overview
- Unexpected large region in cylinder block!
- Restrict to medium to high levels of the λ_2 vortex detector
- Zoom shows vortex to cause heat build-up

→ Vortex reduces heat-transport



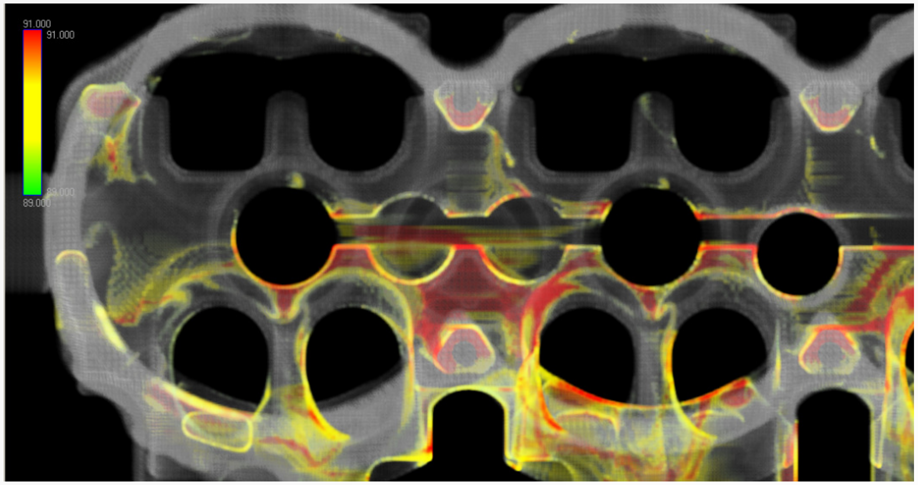
Video

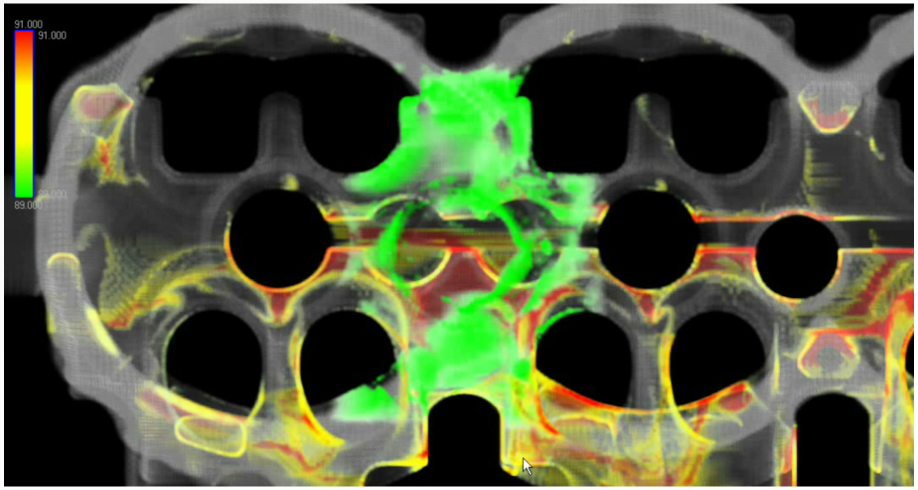

SimVis: 3D View
91.000
91.000
89.000
89.000
Time/Angle:
2000
SimVis: Scatterplot
Y
λ2 vs. temperature
X
X: Lambda.0
Y: Temperature.0
Time: (2000.0000-2000.0000)

Gasket Vortices Improve Heat Transport

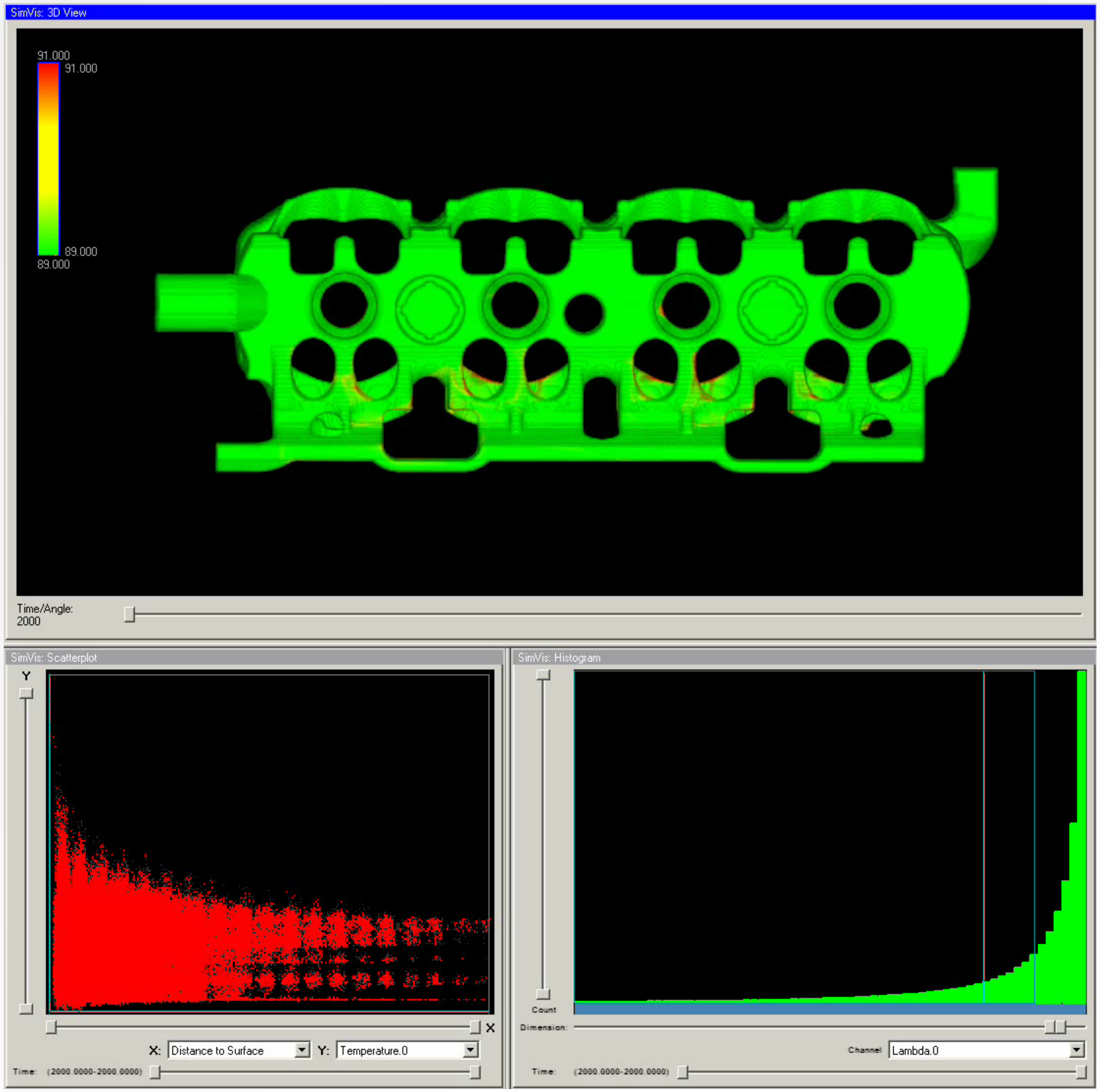
- Combustion heats top of cylinder most
- Inspection of surface reveals critical areas
- Intensive fluid transport away from surface necessary
- Gaskets cause vortical motion
- Combined visualization reveals: turbulence behind gasket is key

→ Vortex neccessary for heat-transport





Video



SimVis: 3D View
91.000
91.000
89.000
89.000
Time/Angle:
2000
SimVis: Scatterplot
Y
X
X: Distance to Surface
Y: Temperature.0
Time: (2000.0000-2000.0000)
SimVis: Histogram
Count
Dimension:
Channel Lambda.0
Time: (2000.0000-2000.0000)

Conclusions

- We have presented smooth formulations of vortex detectors that give insight into strength of the vortex
- Using multiple views the user can analyse the relation between vortex regions and other attributes
- User study on real-world data showed approach to be useful
- Engineers gave positive response to the ability to combine attributes and vortex detector response!

Thank you! Questions?

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