Arthropod Structure revealed by ultra-fast Tomography and Online Reconstruction
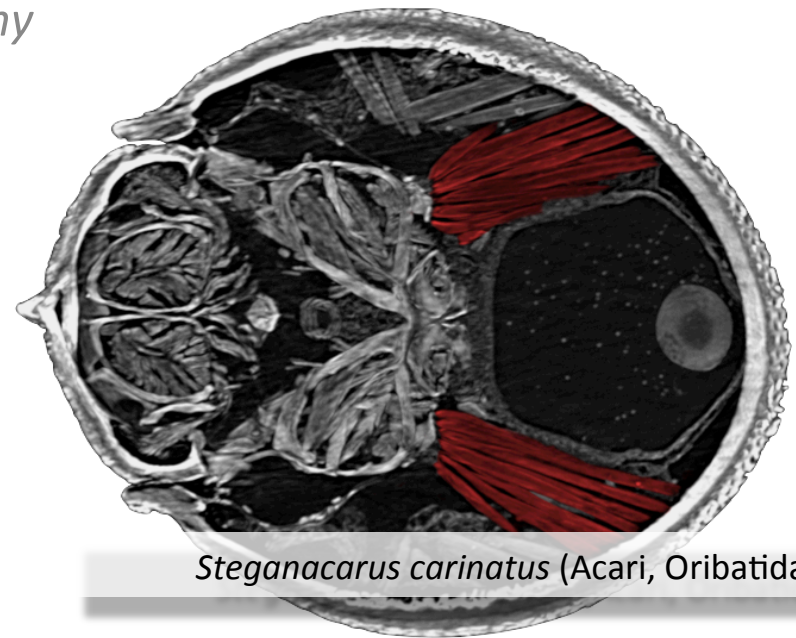
A new method for high-speed X-Ray tomography

astor

Arthropod Structure revealed by ultra-fast Tomography and Online Reconstruction

Science-driven development of

- Management of large datasets
- Cloud-based analysis environment
- Advanced segmentation
  of 4D X-ray images

Steganacarus carinatus (Acari, Oribatida)

Network for functional morphology and systematics:

TECHNISCHE UNIVERSITÄT DARMSTADT
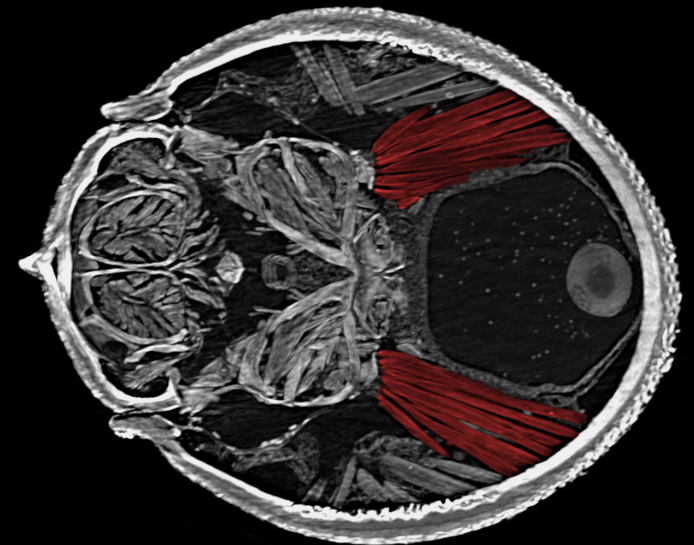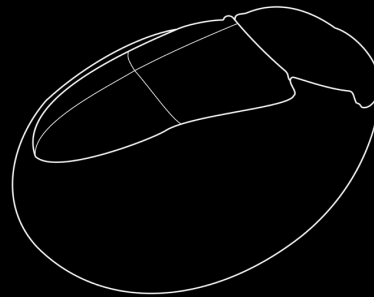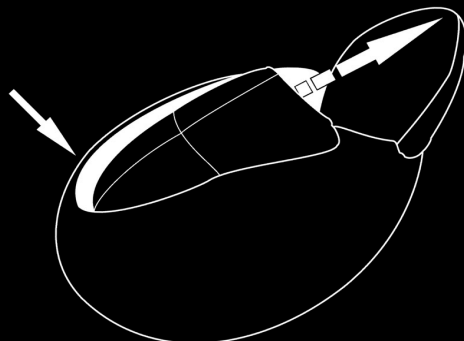
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

KIT Karlsruhe Institute of Technology

ANKA

Use Case: Functional Morphology
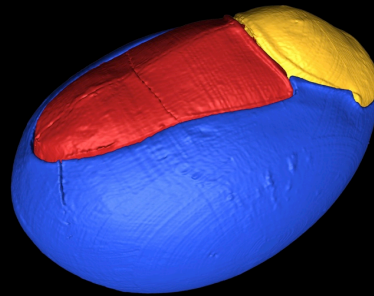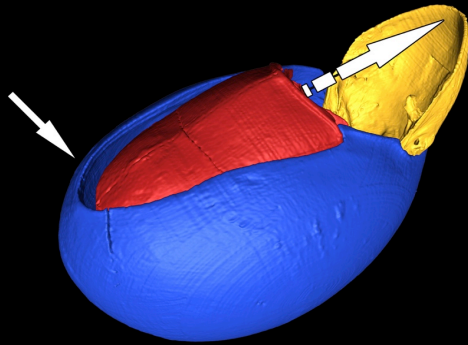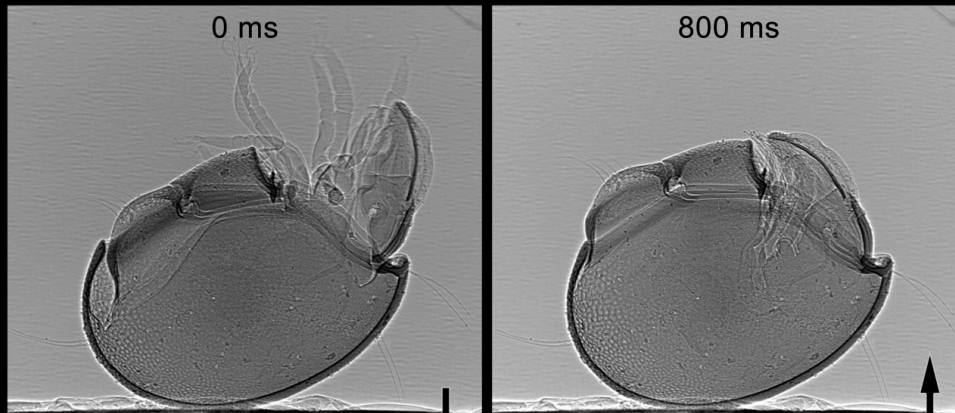
Further Use Cases

Use case 2:

Natural heritage in amber

Staatliches Naturkunde Museum Stuttgart

High-throughput scans
with sample changer

Use case 3:

Bionic of walking

Online measuring forces in ants

University of applied sciences Bocholt

In-vivo

Micro-CT-of a unkown wesp in amber
Hymenoptera: Chalcidoidea: Pteromalidae
Collection SMNS, BB-2621

Ultrafast Synchrotron Tomography

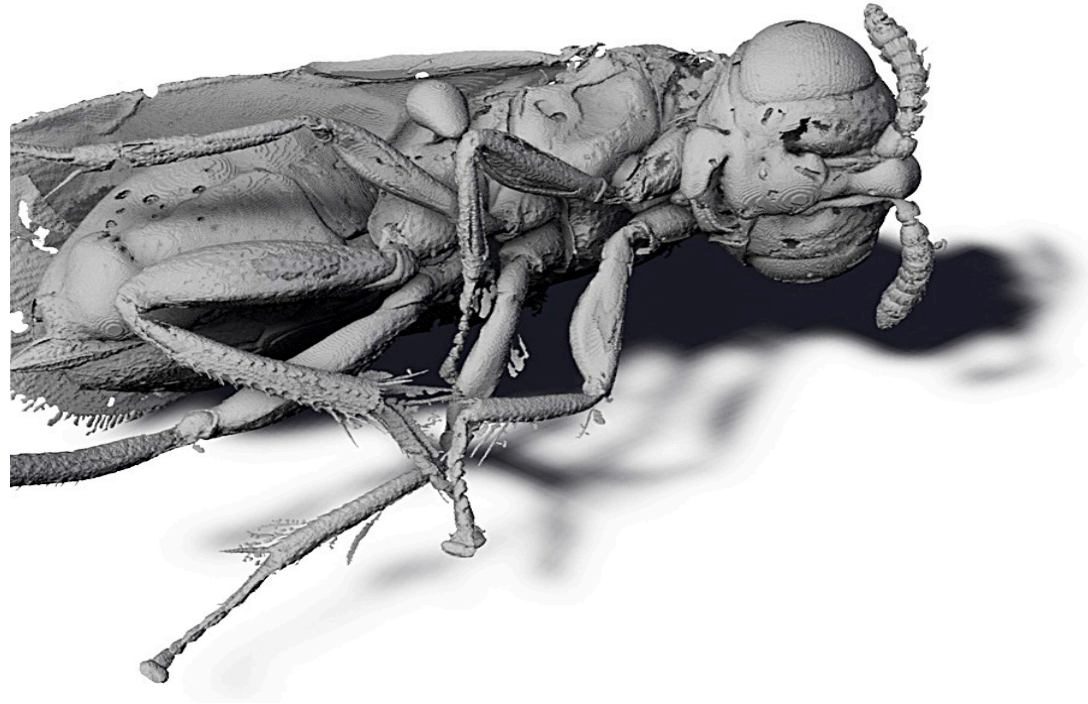**Morphological dynamics can be recorded due to:**

- optimized X-ray setup
- online tomographic reconstruction
- interplay of high time and space resolution

Example: T. dos Santos Rolo et al. PNAS 2014;111:3921-3926

from Helmholtz review:
„[...], studies of biological and other complex systems will be of highest priority in the foreseeable future.“
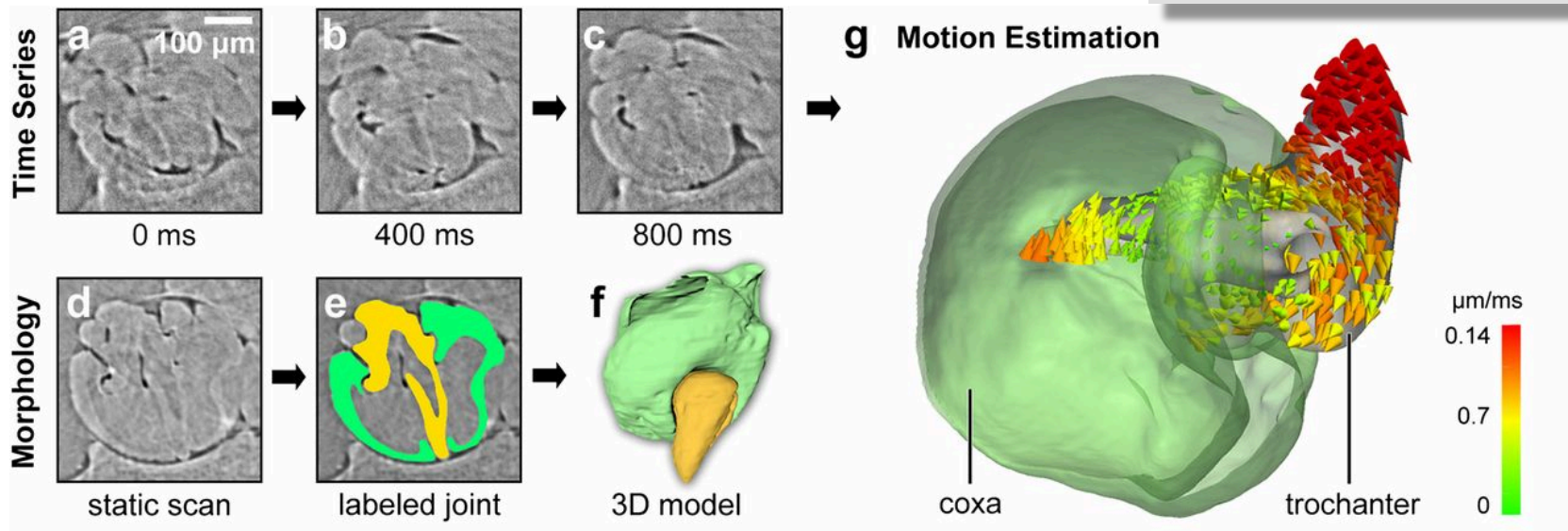
But:

- Analysis is challenging, requires interdisciplinary teams
- Data rates and datasets are huge (> 100 GB)

New Technologies at ANKA

2008
GPU optimization
FBP / PyHST

2010
UFO Project
BMBF German-Russian Funding

DAQ Hardware

Computing & Algorithms

Analysis & Data

2011
UFO Camera

2011
UFO Computing Framework

2012
UFO DAQ Platform

2013
ASTOR
BMBF

Fast control System "Concert"

DMA-IPCore 3GB/sec

Beam monitoring KAPTURE

IR Spectro-meter

Linux drivers libUCA

Tango interfaces

Python 2 GPU Compiler

Multi-core/node Scalability

Infiniband DAQ Network

Workflows

VMs for Analysis
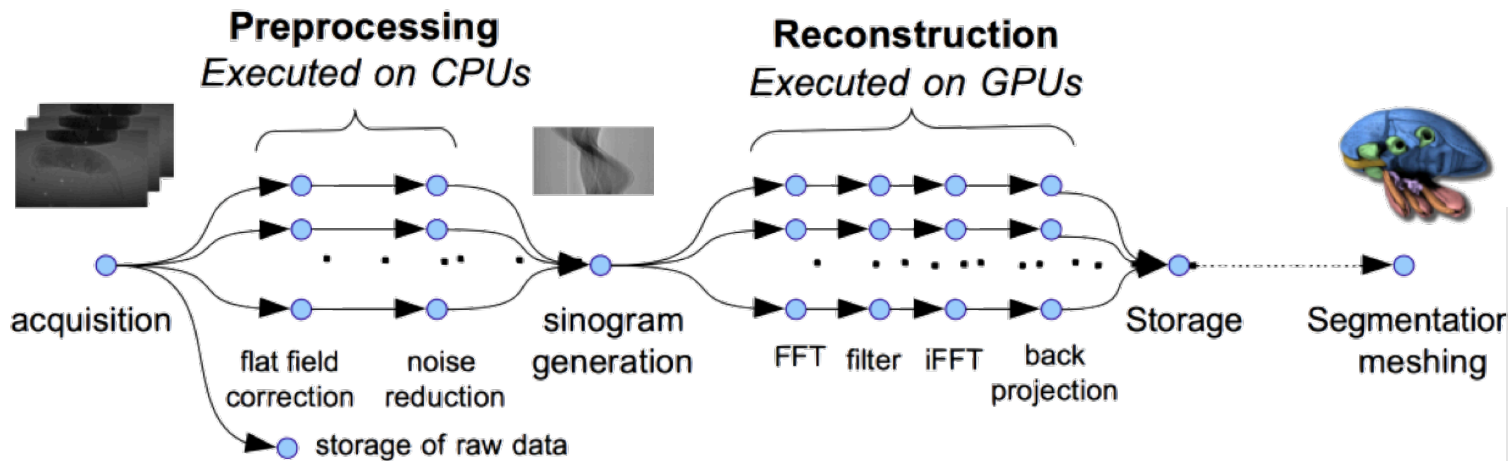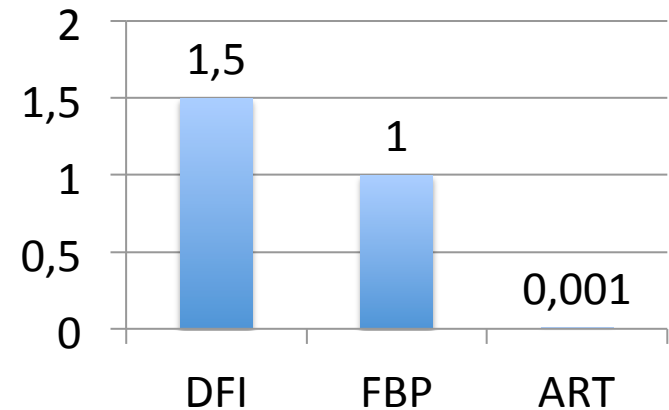
3D Web Visualization

4D Segmentation

In use at: ANKA (IMAGE, CT-LAB, ...), SIBIR-2, ESRF ID19, PETRA-3, HZDR, ...

UFO Parallel Processing Framework

astor

- Free and open-source
- Supports OpenCL parallel hardware
- Hardware-specific optimizations
- Fast pipelined architecture
- Scheduling across multiple devices and nodes
- Introspection interface to Python and other scripting languages
- Integrated with Tango control system

Reconstruction w single GPU (GB/s)

Bar chart values: DFI 1,5; FBP 1; ART 0,001

Preprocessing *Executed on CPUs* — acquisition, flat field correction, noise reduction, storage of raw data, sinogram generation

Reconstruction *Executed on GPUs* — FFT, filter, iFFT, back projection, Storage, Segmentation / meshing

In use at:
- ANKA
- ESRF
- PETRA 3
- HZDR

Next: Real-time Computing with GPU Clusters
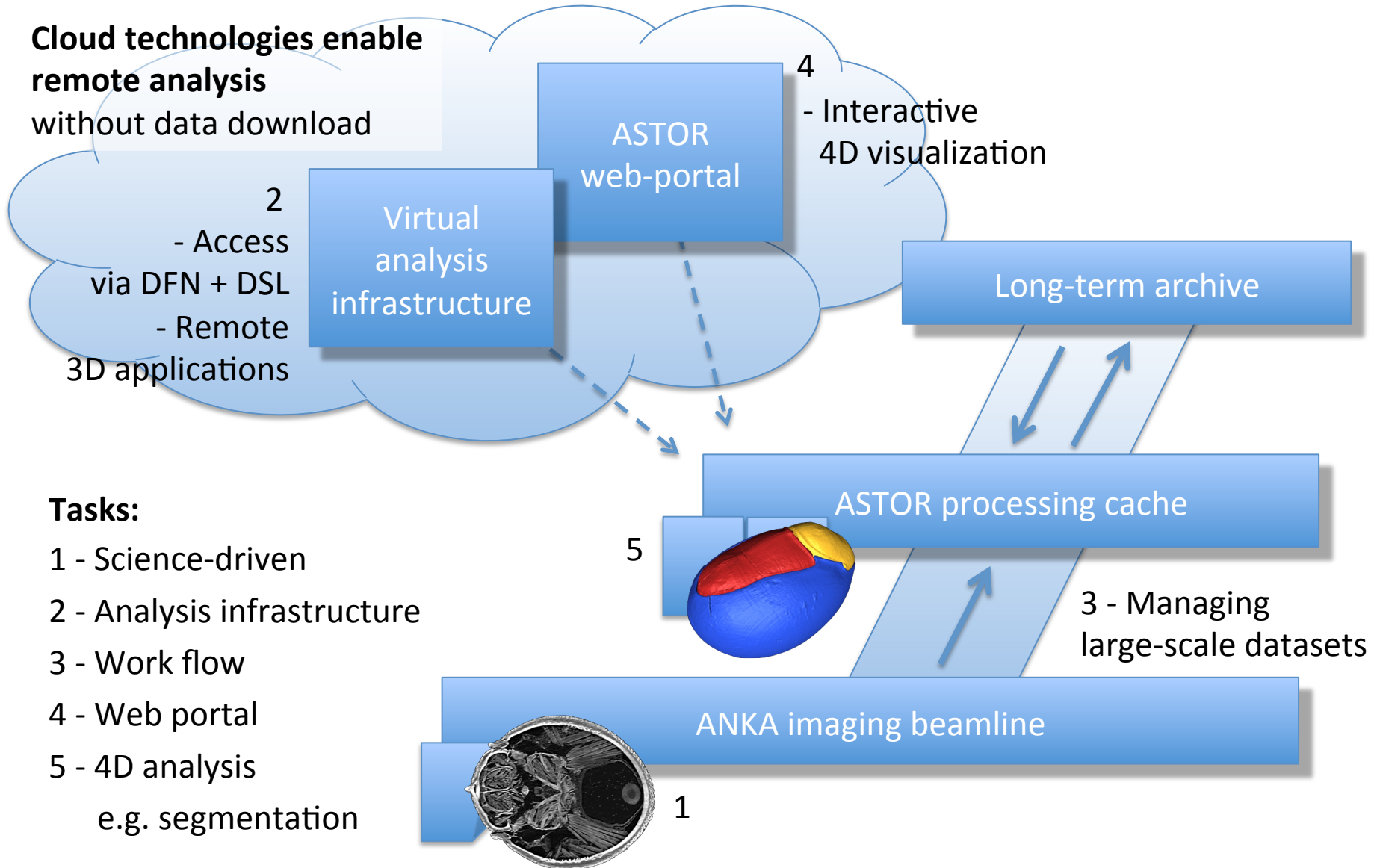
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- GPUs enable
  - Advanced algorithms
  - Higher data rates
- Problem:
  - Data transfer
- Solution:
  - Distributed DAQ Systems
  - DAQ + GPU + fast storage in a cluster

- Status: reconstruction in few seconds
- Goal: Data rates > 5 GB/s

Scalable
FPGA computing

Fast
storage

GPU computing

Data Source → Input stage → FPGA → QSFP+

Memory

DAQ / cameras

Infiniband network

Virtual Analysis Infrastructure

astor
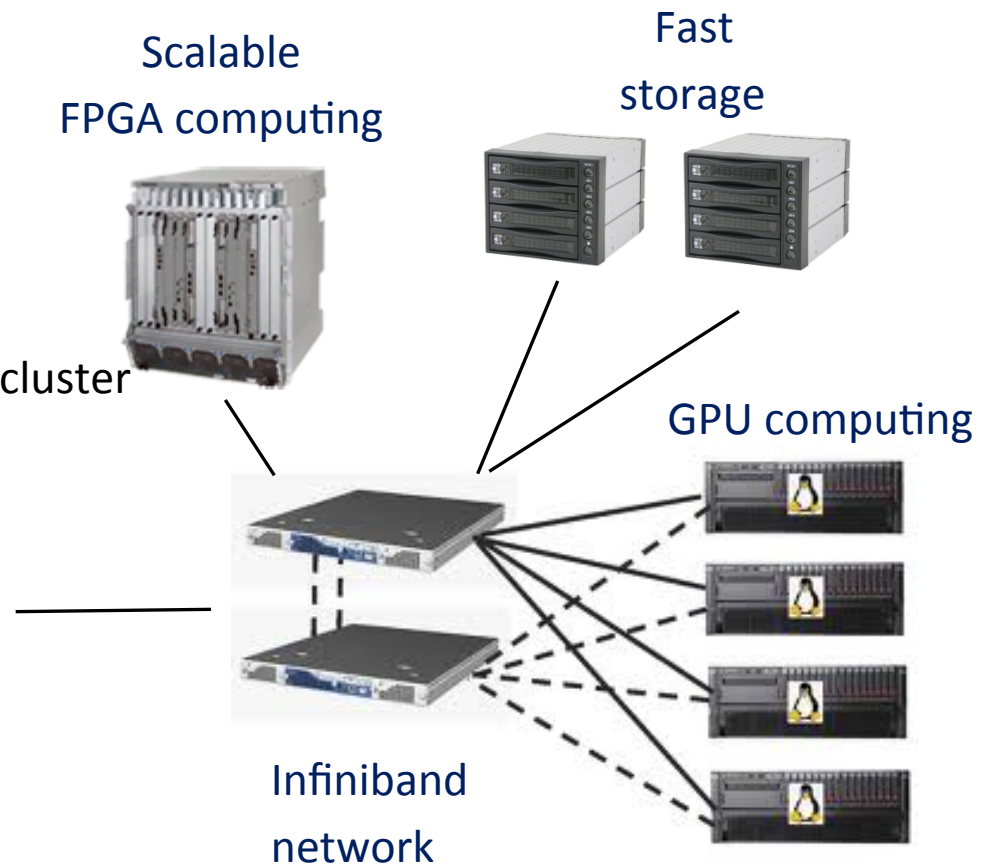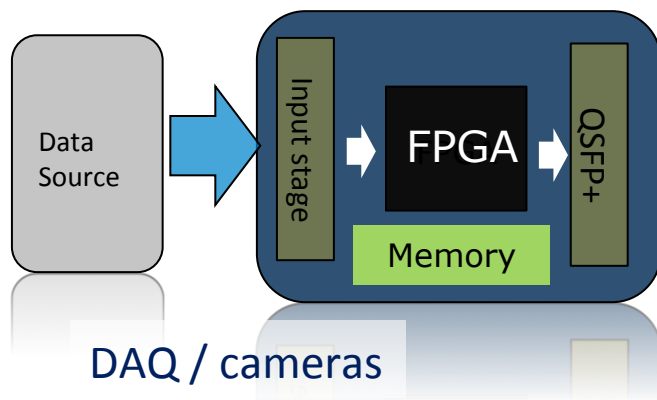
Cloud technologies enable remote analysis without data download

ASTOR web-portal

4
- Interactive 4D visualization

2
- Access via DFN + DSL
- Remote 3D applications

Virtual analysis infrastructure

Long-term archive

ASTOR processing cache

5

3 - Managing large-scale datasets

Tasks:

1 - Science-driven

2 - Analysis infrastructure

3 - Work flow

4 - Web portal

5 - 4D analysis

   e.g. segmentation

ANKA imaging beamline

1

ASTOR architecture

ASTOR Portal

ASTOR Web-catalog

Initiate analysis

ASTOR Analysis Services

ASTOR goals:

web-based data visualization

get data catalog from

request data + store results

remote data analysis services

ANKA Proposal System

ASTOR Data Management

WAVe Visualization Service

referenceable raw data catalog (DOI)

get user information

manage recorded and archived data

UFO Station

Processing Cache

Long-term Archive LSDF

transmit data

archive + restore data

Computer infrastructure

astor

			Investment 2014

VM1   VM2

VM3   VM4

VM1   VM2

VM3   VM4

VM-Storage

10GE

ASTOR Webserver

Virtualization 1

Virtualization 2

VM-Temp Storage

10GE

10GE

Data Management

GPU2   GPU3   GPU1

GPU4   GPU5

Investment 2015

Infiniband FDR

Ethernet

10GE

10GE

UFO GPU Server

Processing Cache

LSDF Front-end
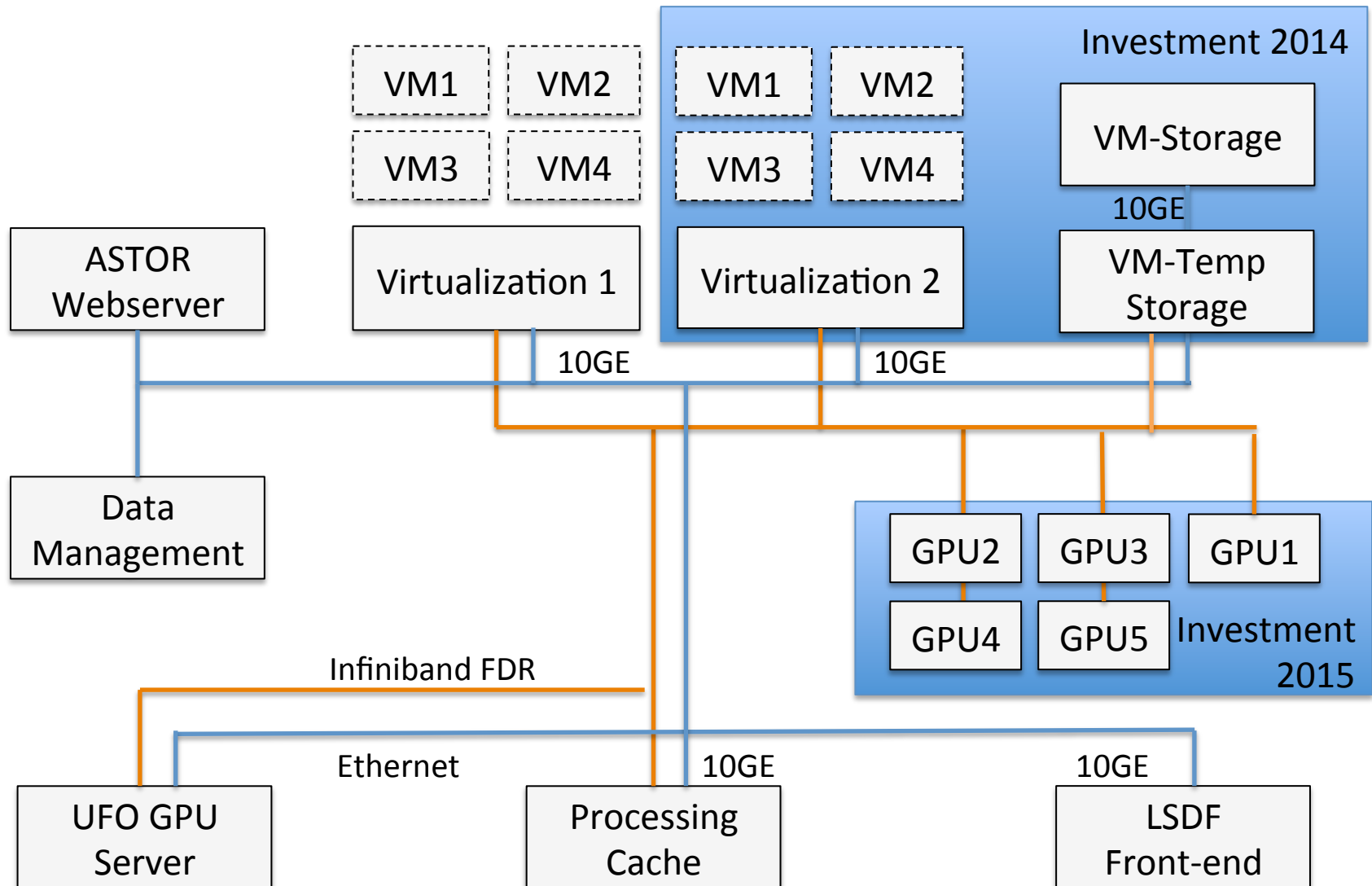
Management Endpoint for VMs

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User Interfaces over **SOAP-API**
- Web Service / .NET Client
- Command Line Interface

Cloud Service Bus

ASTOR WEB-Portal
(based on **YVAINE**)

User Management
- Active Directory Authentication
- Load Statistics / Measurement
- Billing

VMware vSphere Adapter (via VMware SDK)
- **GPU & I/O-Device PCIe Initial Placement Logic**
- Image Management / Provision

HTTPS

Authorization:
Umbrella

VM1   VM2   VM3

PCoIP via
Horizon Client
(maybe Browser-Plugin)

Windows guests:
Amira, VG Studio Max, UFO Framework, …

Web-Portal Requirements

- Manages data sets and analysis
  - Data catalog
  - Ordered by data types (sample, measurment, analysis, publication, …)
  - Invite colleagues (r) and share ownership (r/w)
  - References by publications
- Fast 3D Visualization
  - Basic filters
  - Measurement of dimensions
  - Alignment
- VM management
  - Start/Stop, access path
  - Manage GPUs + Licenses for commercial apps (e.g. Amira, vgStudio)
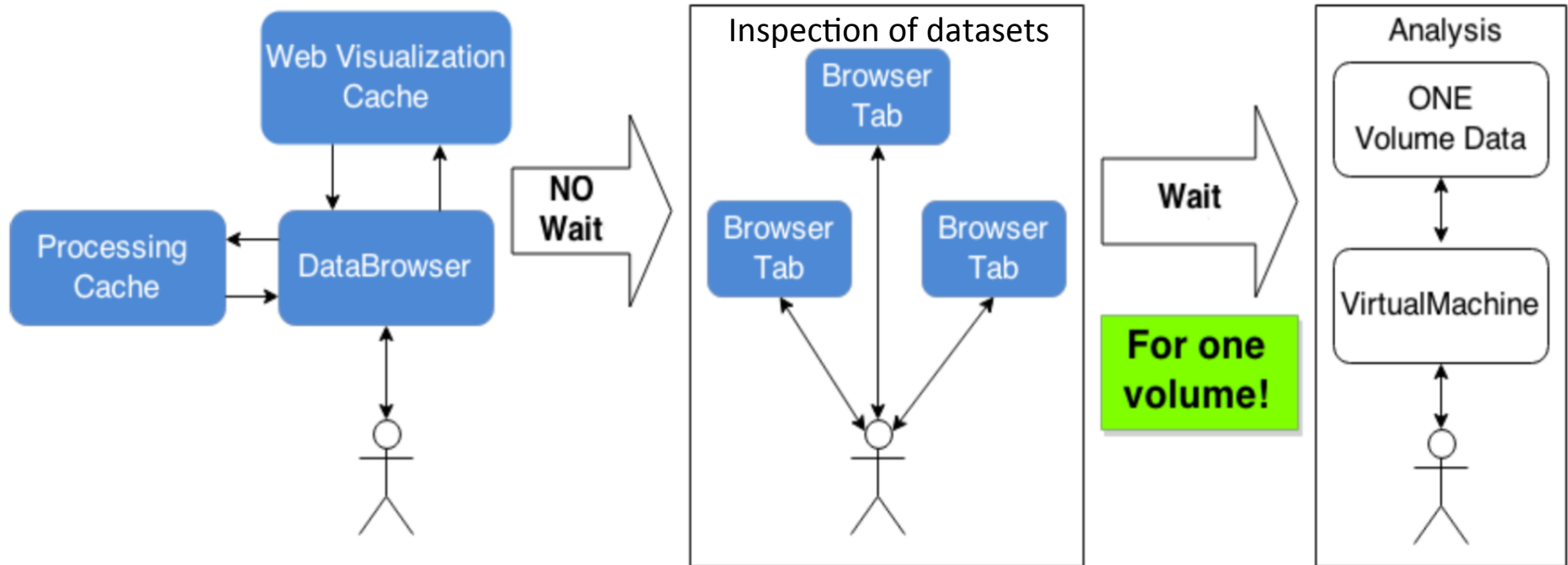- Inline annotations
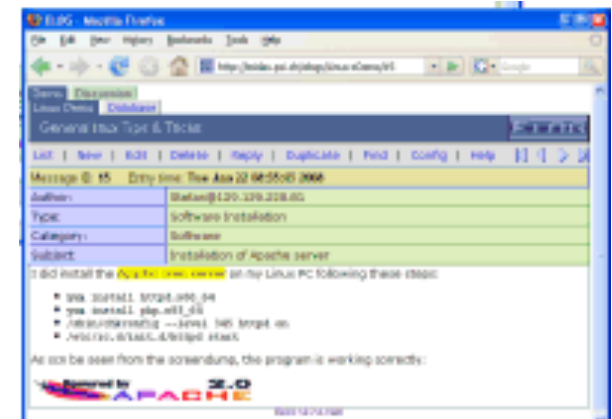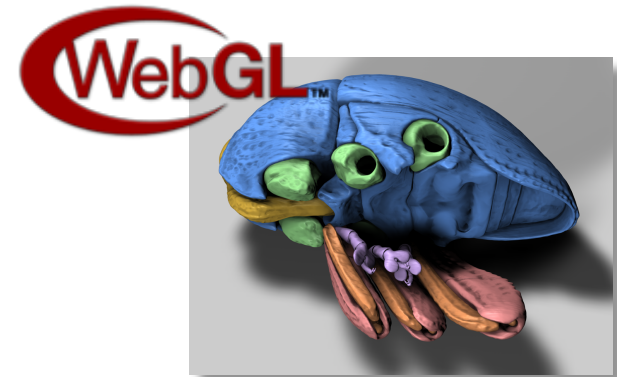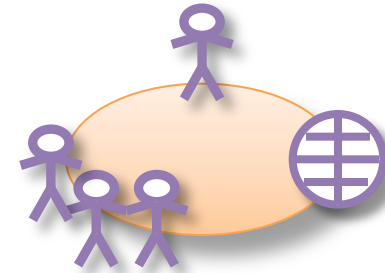
YVAINE - VM Management Web-Portal

WAVe – Web Analysis of Volumes

Goals:

- Fast preview of reconstructed raw data
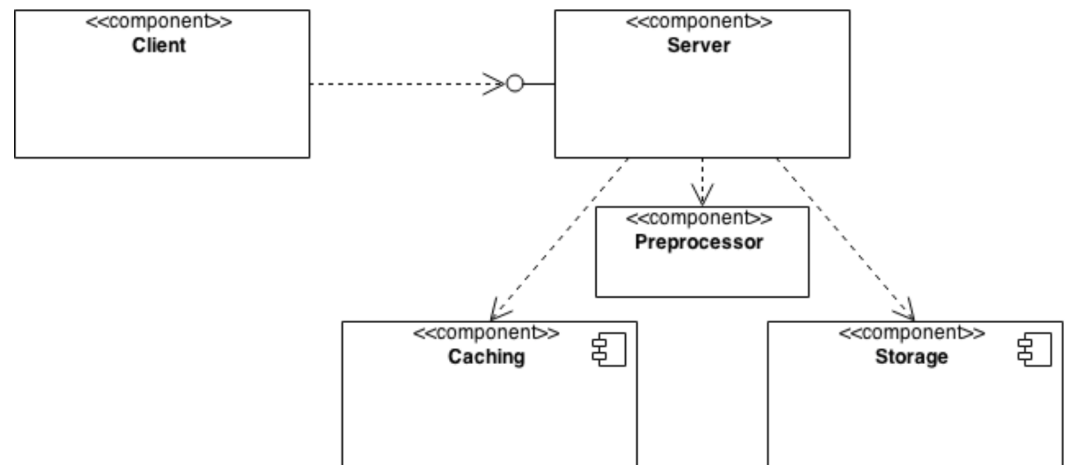- Cache archived data

Workflow:

Requirements

WAVe

- is used for « preview »

- includes pre-processing + caching

- provides basic analysis functions
  (e.g. background reduction, filters, measurements)

- provides zooming

- works with big datasets > 100GB

- works with 3D + time

- has low latency

- scales for many users

- provides intuitive usage

- is easy to maintain

Volume rendering by ray casting

astor

- Splits volume transparent layers
- For each layer texure maps are calculated
- Depending on the orientation
  textures are added

- Algorithm by Congote et al , *VISIGRAPP 2009*

Texture map

3D dataset

Projection
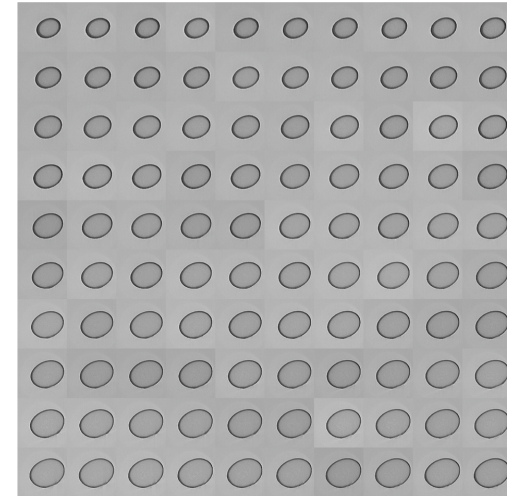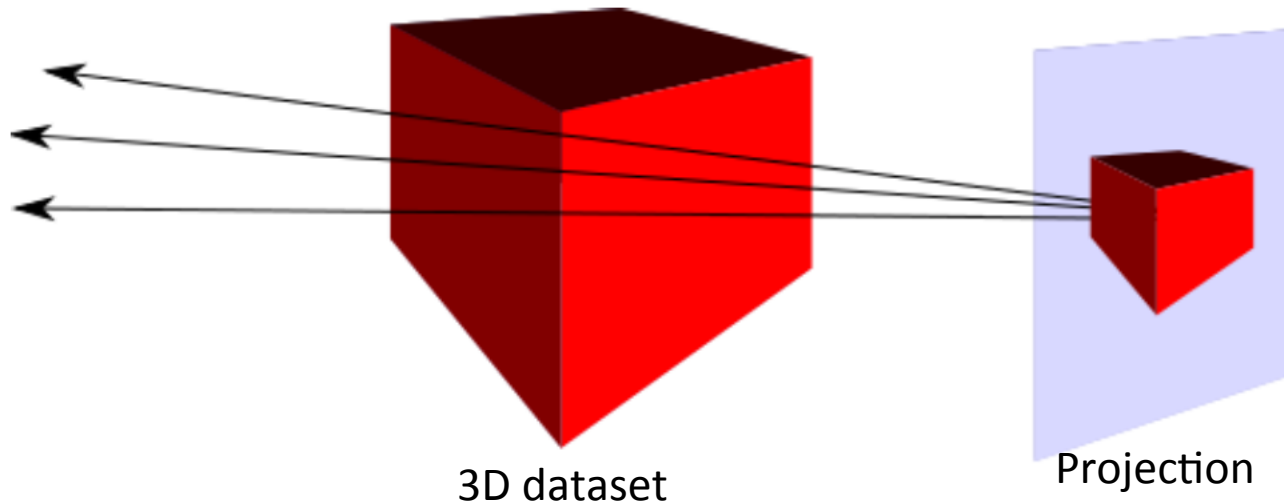
Prototype: 3D Visualization in the Web

Segmentation methods

- Goals
  - **Improve manual segmentation in slices**
  - Transfer to neighboring slices
  - Transfer to sequential time steps
- Under evaluation: Active contour models

Segmentation methods

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Segmentation methods

- Goals
  - Improve manual segmentation in slices
  - Transfer to neighboring slices
  - **Transfer to sequential time steps**
- Under evaluation: Active contour models

$t=t_0$

$t=t_1$
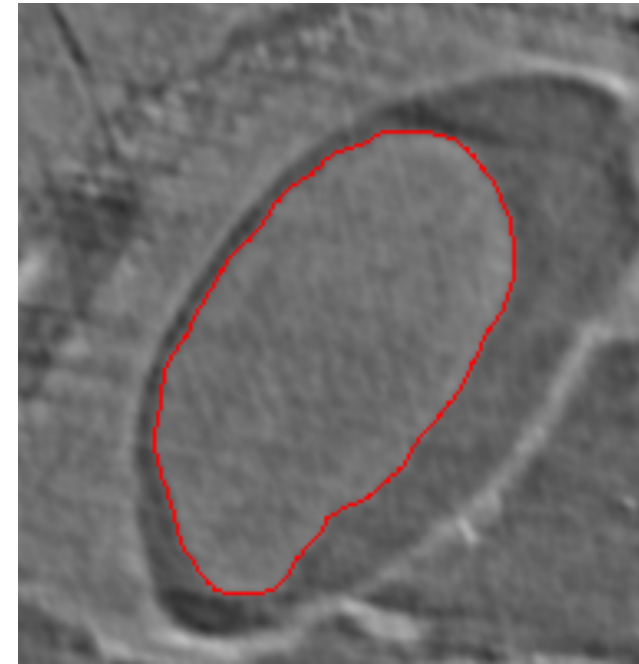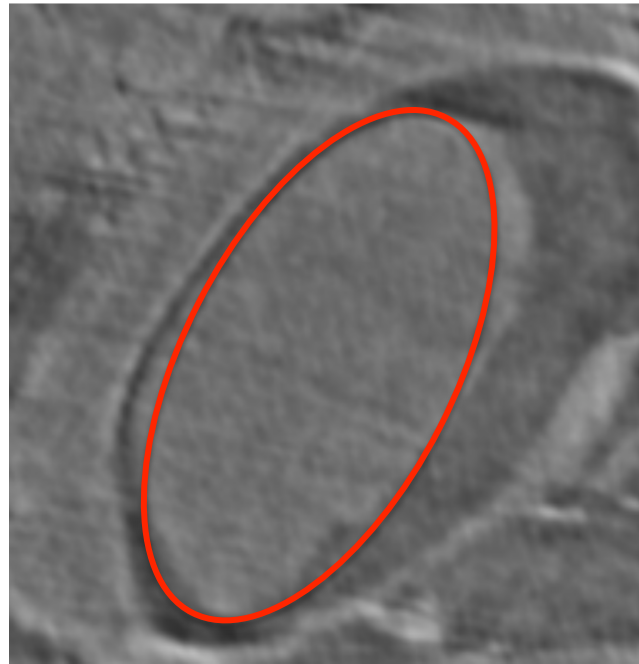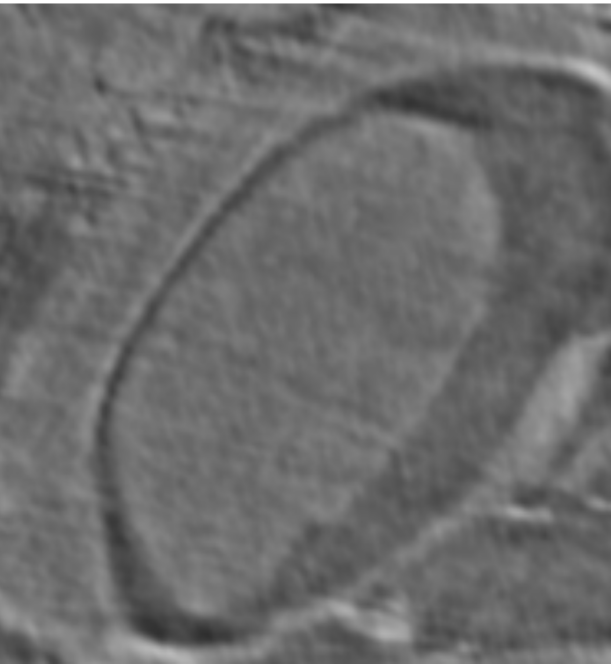
Algorithms

- Idea: Given initialization, gradual (supervised) improvement
- Methods/Algorithms:
  - Gradient vector flow
  - Global vs local criteria

Results:

- Sensitive to initialization
- Sensitive to parameter, selection of free parameters?
- Calculation is slow, but acceleration by GPU possible

Next:

- Stochastic Partial Differential Equations
- Automatic calculation of weighting parameters
- Application to 3D datasets
- Implementation of algorithms in Amira, MITK

Processing

Figure: xaqi.png
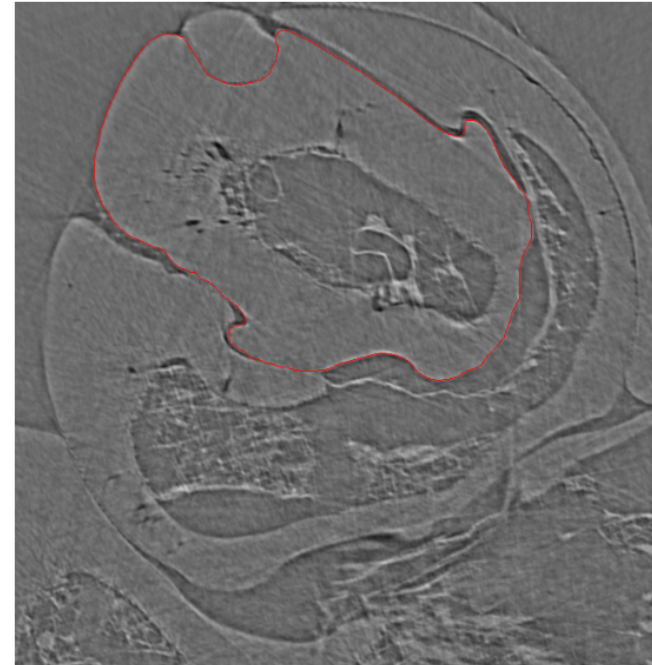
Figure: xavw.png

	xaqi (304 pixels)		xavw (1304 pixels)	
	GVF	ACWE	GVF	ACWE
CPU only	63 sec	39 sec	738 sec	646 sec
GPU	29 sec	16 sec	141 sec	26 sec

i5-4670 CPU 3.40GHz
GeForce GTX770

Image Processing Tools

Software requirements:

- Multi-platform;

- Extensibility:

  – Plugin System;

  – Open Source license.

- Development:

  – Community Size: > 3 person;

  – Last Update: 2014 year;

  – Programming Language: C / C++ / Python;

  – Developer Documentation.

Segmentation toolkits

| Requirements	Software					
	Amira	ilastik	ITK-Snap	MITK	Seg3D	3D Slicer
Simple interface	Yes	Specific	Specific	Yes	Yes	Yes
Work with 4D data	No	Yes [1]	No	No	No	No
Undo and Redo	Undo	No	Yes	Yes	Yes	Yes
Cancellation of the processing	No	No	No	No	Yes	No
Zooming	Fixed	Free	Free	Free	Free	Free
Configurable key bindings	No	Yes	Yes	No	No	No
Labels interpolation	Yes	No	No	No	Yes	No
Labels propagation	No	No	No	No	No	No
Labels management:						
Add and Remove	Yes	Yes	Yes	Yes	Yes	Yes
Reordering	No	Yes	No	Yes	No	No
Multiple selection	No	No	No	Yes	No	No
Grouping	No	No	No	No	No	No
Documentation	Yes	Yes	Yes	Yes	Yes	Yes
Session saving and loading	Yes	Yes	Yes	Yes	Yes	Yes

[1] ilastik: Each 3D volume in a 4D data set is processed independently.
4D Volume is represented by several 3D TIFFs.

Large datasets

astor

Full Volume: 1968 x 1968 x 1496

Software	1100 slices (4.2 Gb)	1200 slices (4.5 Gb)	Full (5.5 Gb)
Seg3D	OK	Can't open	Can't open
ilastik	Can't open	Can't open	Can't open
ITK-Snap	Crash	Crash	Crash
MITK	OK	OK	OK
3D Slicer	OK	Crash	Crash
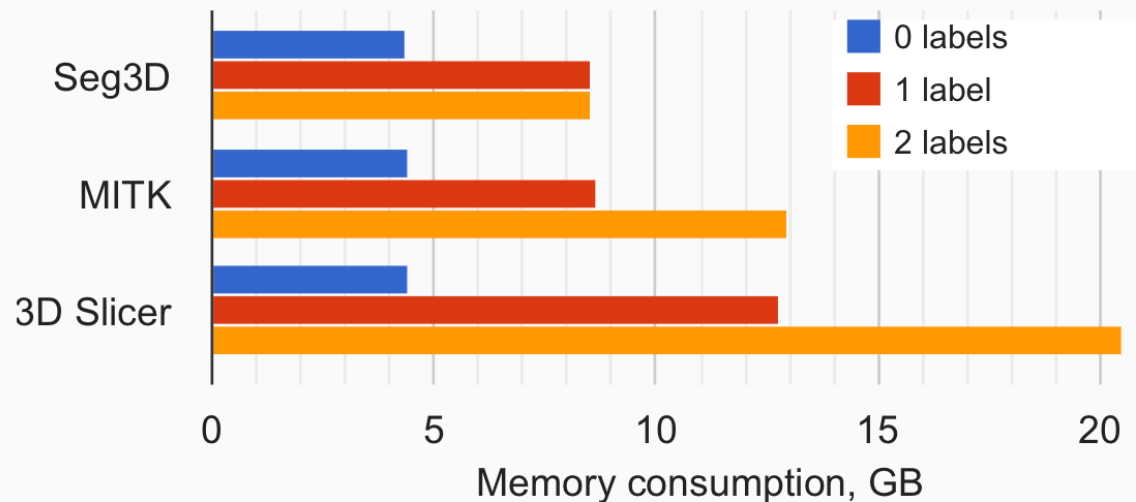
Segmentation platform?

Open source tools

- All free tools base on VTK/ITK
- Candidates:
  - MITK (German Cancer Research Center, Heidelberg) and 3D Slicer (Harvard University) due to their architecture, documentation and nice plugin system.
  - Seg3D (University of Utah Scientific Computing and Imaging (SCI) Institute) due to simple architecture and Photoshop-like interface.

Commercial tools

- Negotiations with FEI/Amira on extended programming interfaces
  - Development option available
  - FEI seems to be interested in user feedback

Summary

Data management

- Remote access to imaging application is possible
  - Selected: Vmware Horizon
- Virtualization of GPUs and Infiniband adapters
  - VMs are used for segmentation + development

Visualization

- Fast browsing of volumetric data is crucial
  - Multi-level caching
  - 3D data in the web is possible

Analysis

- 3D + time datasets requires dedicated analysis methods
  - Tools can't handle time sequences (Open source + Amira)
  - Problems with large TIFF files and memory management