Video and **I**mage **A**nalytics for the **M**arine **E**nvironment (VIAME): An Open Source Framework for Underwater **I**mage Processing

Dr. Anthony Hoogs
Senior Director of Computer Vision
anthony.hoogs@kitware.com
518-881-4910

Keith Fieldhouse
Assistant Director of Computer Vision
Keith.fieldhouse@kitware.com
518-836-2190

Topics

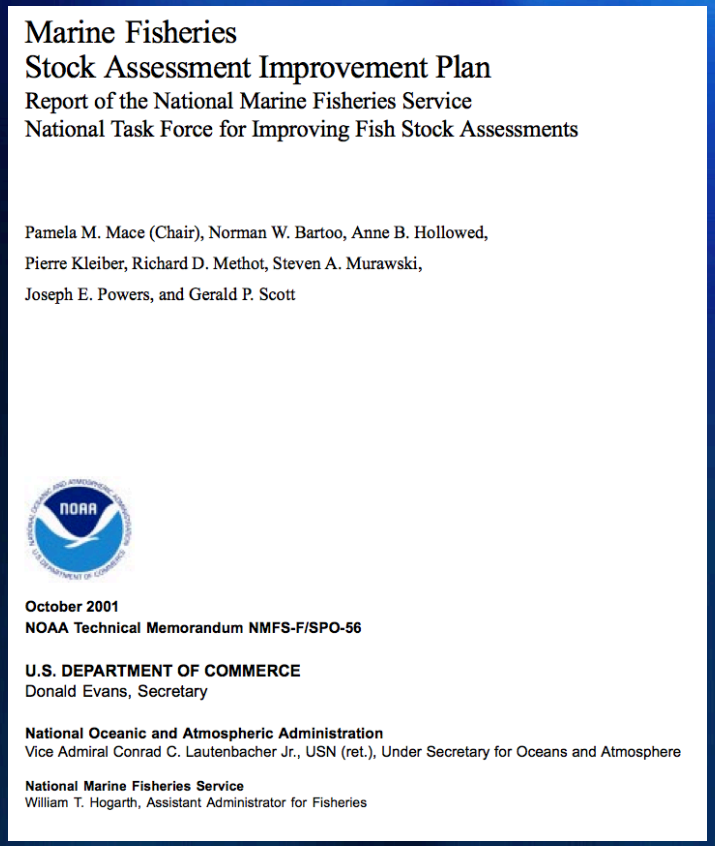
- AIASI Background
- Open-source software at Kitware
- KWIVER
- VIAME Common Processing Environment
- Additional KWIVER Capabilities

Pacific Islands Fisheries Science Center
NOAA National Marine Fisheries Service

NOAA Fisheries Strategic Initiative on Automated Image Analysis

Benjamin L. Richards
NOAA Fisheries, Pacific Islands Fisheries Science Center
Fisheries Research and Monitoring Division, Stock Assessment Program

Stock Assessment Data Needs



Marine Fisheries
Stock Assessment Improvement Plan
Report of the National Marine Fisheries Service
National Task Force for Improving Fish Stock Assessments

Pamela M. Mace (Chair), Norman W. Bartoo, Anne B. Hollowed,
Pierre Kleiber, Richard D. Methot, Steven A. Murawski,
Joseph E. Powers, and Gerald P. Scott

October 2001
NOAA Technical Memorandum NMFS-F/SPO-56

U.S. DEPARTMENT OF COMMERCE
Donald Evans, Secretary

National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher Jr., USN (ret.), Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries

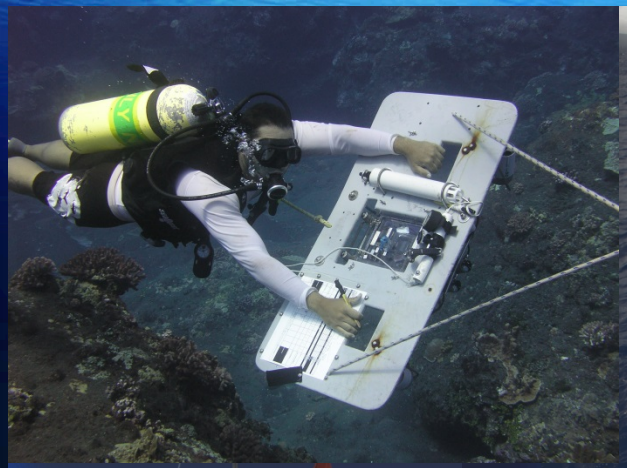
Mace et al. 2001

- Accurate and precise estimates of species-specific size-structured abundance

  Numbers – species – length

- "Greatest impediment to producing accurate, precise, and credible stock assessments is the lack of adequate input data"
- No index of abundance for 40% of stocks in 1999 Status of Fisheries Report
- Improved technologies to:
  - sample, survey, or experiment with species of interest in situ,
  - decrease sampling error,
  - increase sampling intensity,
  - increase the area or number of species covered.

Optical Technologies



- Fishery-Independent
- Non-extractive
- Increase efficiency
- More accurate, precise, and synoptic
- Reduced measurement/calibration errors
- Increase temporal and spatial survey coverage
- Deployable from vessels of opportunity

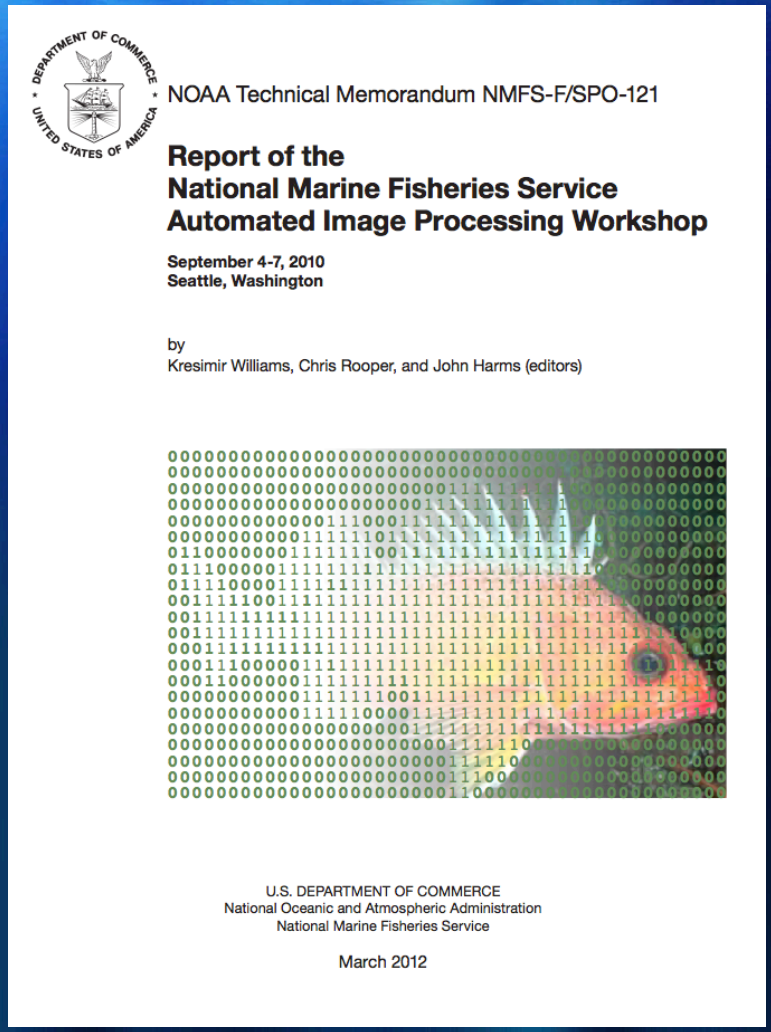
Really Large Data Sets

Challenges

- Data streams exceed capabilities of human analysts
  - 100,000 - millions of images in a matter of days
- Data products not available quickly enough for use in stock assessments
- Automated tools must be developed to increase speed of analysis, reduce costs, improve assessments

NMFS Workshop on Automated Image Processing

- Recommendations
  - Inter-disciplinary collaboration
  - Create international forum or working group for automated analysis of images from marine image-based sampling systems
  - Development of a database to facilitate in feature recognition for marine organisms
    - Shared image bank
  - Optimal allocation of automation in analysis
    - Easy vs Hard problems
    - Partial automation
  - Modular approach with medium for exchange



NOAA Technical Memorandum NMFS-F/SPO-121

Report of the National Marine Fisheries Service Automated Image Processing Workshop

September 4-7, 2010
Seattle, Washington

by
Kresimir Williams, Chris Rooper, and John Harms (editors)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

March 2012

Williams et al (2012)

NMFS Strategic Initiative on Automated Image Analysis

- Mission
  - Develop guidelines, set priorities, and fund projects to develop broad-scale, standardized, and efficient automated analysis of still and video imagery for use in stock assessment

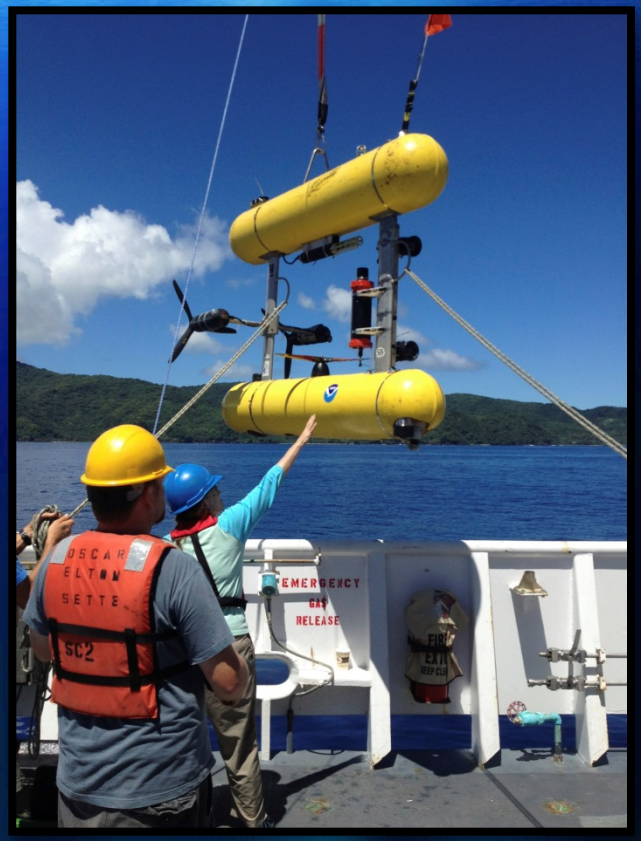
- Benjamin Richards *(chair)*
  NOAA Pacific Islands Fisheries Science Center
- Alexandra Branzan Albu
  University of Victoria
- *Elizabeth Clarke*
  NOAA Northwest Fisheries Science Center
- George "Randy" Cutter
  NOAA Southwest Fisheries Science Center
- Duane Edgington
  Monterey Bay Aquarium Research Institute
- Dvora Hart
  NOAA Northeast Fisheries Science Center
- David Kriegman
  University of California, San Diego
- *Clay Kunz*
  Google
- Michael Piacentino
  SRI International
- Lakshman Prasad
  Los Alamos National Laboratory
- Charles Thompson
  NOAA Southeast Fisheries Science Center
- Kresimir Williams
  NOAA Alaska Fisheries Science Center

Image Classes

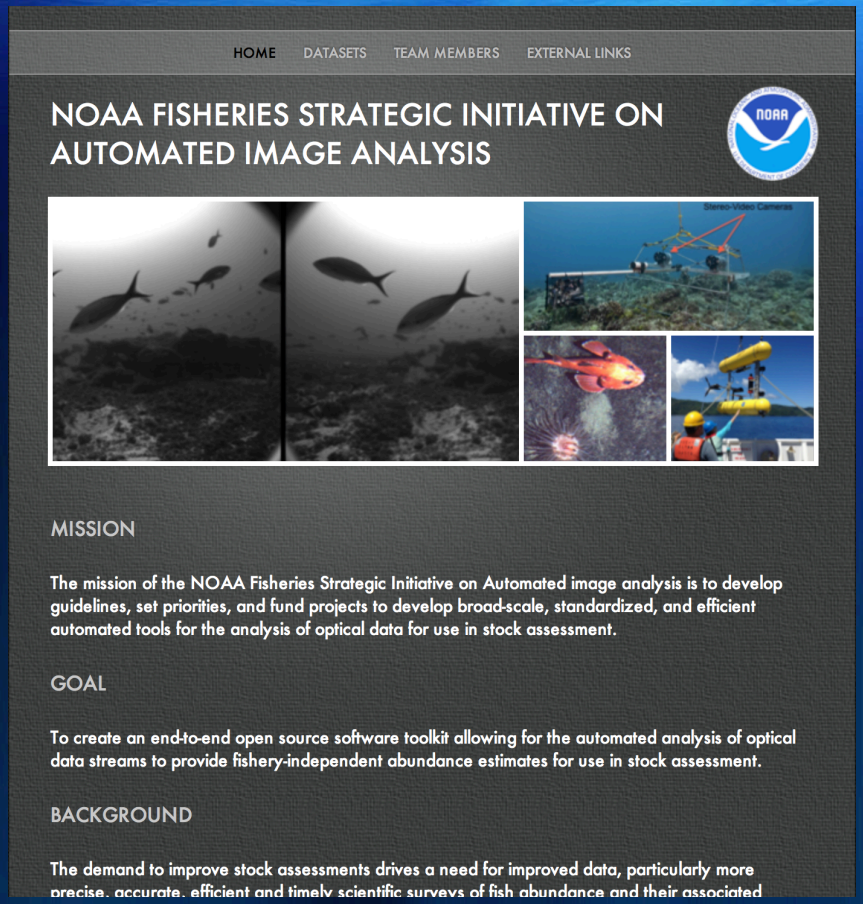
- Still vs Video Imagery
  - Mono vs Stereo
    - Static vs Dynamic Backgrounds
      - Natural vs artificial lighting
- Targets
  - Benthic Habitat
  - Benthic Fish or Invertebrates
  - Fish in trawls
  - Fish in situ
  - Fish on deck
  - Marine mammals

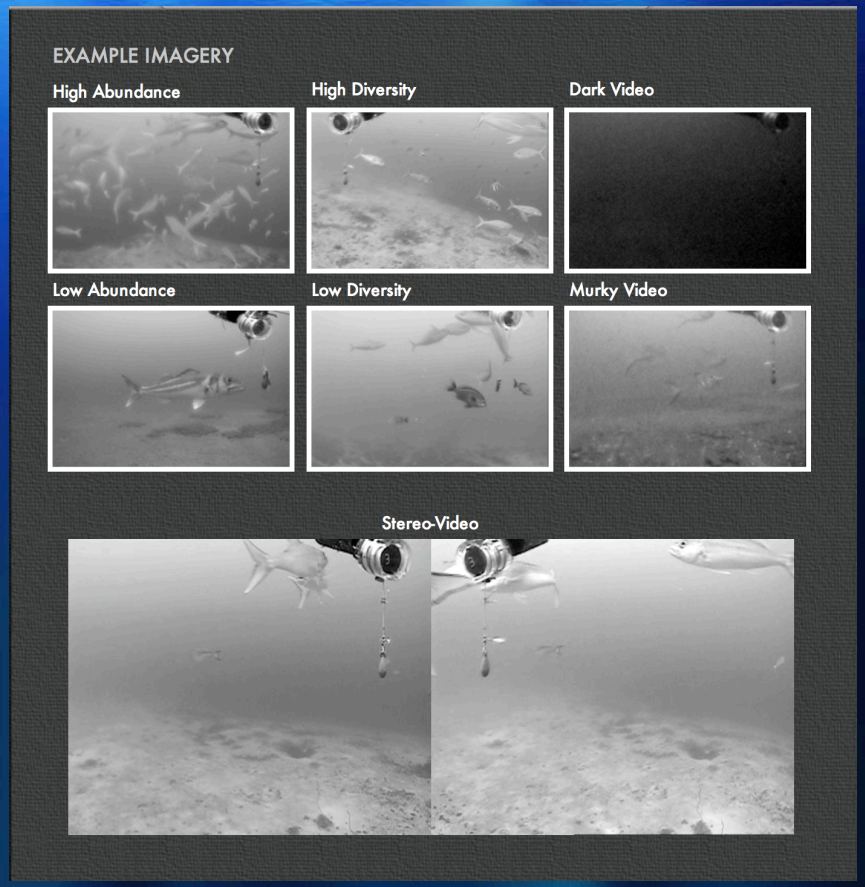
Example Data Streams

- Single Camera Still Imagery
  - Aerial Photography – Seals
- Stereo Still Imagery
  - AUVs - Groundfish
- Single Camera Video
  - Towed Camera Systems – Scallops
  - ROVs – West Coast Groundfish
- Stereo-Video
  - Fixed Camera Systems – Reef and Hawaii Bottomfish
  - Trawl nets – Alaska Pollock
  - AUVs – Hawaii Bottomfish
  - Submersibles – West Coast Groundfish



Links to Image Resources





http://marineresearchpartners.com/nmfs_aiasi/Home.html

Image Analysis Toolbox

- Collection of tools (software) to automate image/video analysis
- Must be readily available & usable by survey & stock assessment scientists
- Stand-alone applications that combine GIU & calculation engine

http://nft.nefsc.noaa.gov

NOAA's National Marine Fisheries Service

NOAA Fisheries Toolbox

General
- Welcome
- About NFT
- Toolbox Design
- Comparing NFT Models
- Download Models
- Frequently Asked Questions
- User Support
- NFT History and Milestones
- Referencing NFT Software

Model List
- A Stock Production Model Incorporating Covariates
- Age Structured Assessment Program
- Age Structured Projection Model
- An Index Method
- Collie-Sissenwine Analysis
- Depletion Corrected Average Catch Model
- Dual Zone VPA
- Instanteous Rates
- Kalman Filter
- Length Based Yield Per Recruit
- Management Strategy Evaluation
- Model Compare
- Population Simulator - Age Based
- Population Simulator - Length Based
- Productivity and Susceptibility Analysis
- Rivard Weights
- Statistical Catch at Age Model
- Statistical Catch at Length Model
- Stock Recruitment Fitting Model
- Stock Synthesis Version 3
- Survival Estimation in Non-Equilibrium situations
- Virtual Population Analysis
- Visual Report Designer
- Yield Per Recruit

Welcome to the
NOAA Fisheries Toolbox
Version 3.1

The NOAA Fisheries Toolbox (NFT) is a suite of biological modeling software programs that can be used in fisheries stock assessments.

Currently Available Models

		Version		Date Updated
Estimation of Stock Size and Mortality				
A Stock Production Model Incorporating Covariates	(ASPIC)	5.34.9		2/08/2011
Age Structured Assessment Program Model	(ASAP)	3.0.17	UPDATED	04/14/2014
Collie-Sissenwine Analysis	(CSA)	4.3		01/13/2014
Dual Zone Virtual Population Analysis	(VPA-2BOX)	3.05		8/4/2004
Statistical Catch at Age Model	(STATCAM)	1.4.1		5/2/2008
Statistical Catch at Length Model	(SCALE)	1.0.11		9/13/2013
Stock Synthesis Version 3	(SS3)	3.45f		10/18/2012
Virtual Population Analysis	(VPA)	3.4.5	UPDATED	4/18/2014
Management Scenario Projections				
Age Structured Projection Model	(AGEPRO)	4.2.2		9/17/2013
Biological Reference Points				
Age Based Yield Per Recruit	(YPR)	3.3		9/17/2013
An Index Method	(AIM)	2.5.0		1/31/2014
Length Based Yield Per Recruit	(YPRLEN)	2.1		4/20/2012
Stock Recruitment Fitting Model	(SRFIT)	7.0.1		3/18/2010
Model Performance Evaluation				
Population Simulator - Age Based	(POPSIM-A)	8.2		12/12/2013
Population Simulator - Length Based	(POPSIM-L)	8.0		12/12/2013
Management Strategy Evaluation	(MSE)	4.0		12/23/2013
Visual Report Designer	(VisRpt)	1.6.1		4/2/2008
Models for Data Limited Situations				
Depletion Corrected Average Catch Model	(DCAC)	2.1.1		10/4/2012
Survival Estimation in Non-Equilibrium situations	(SEINE)	1.3		9/15/2008
Model for Analyzing Tagging Data				
Instantaneous Rates	(IRATE)	2.0		4/19/2013
Additional Tools				
Kalman Filter	(KALMAN)	2.3		7/24/2009
Model Compare	(MCOMP)	4.3		2/10/2014
Productivity and Susceptibility Analysis	(PSA)	1.4		3/4/2010
Rivard Weights Calculator	(RIVARD)	2.0		10/24/2008

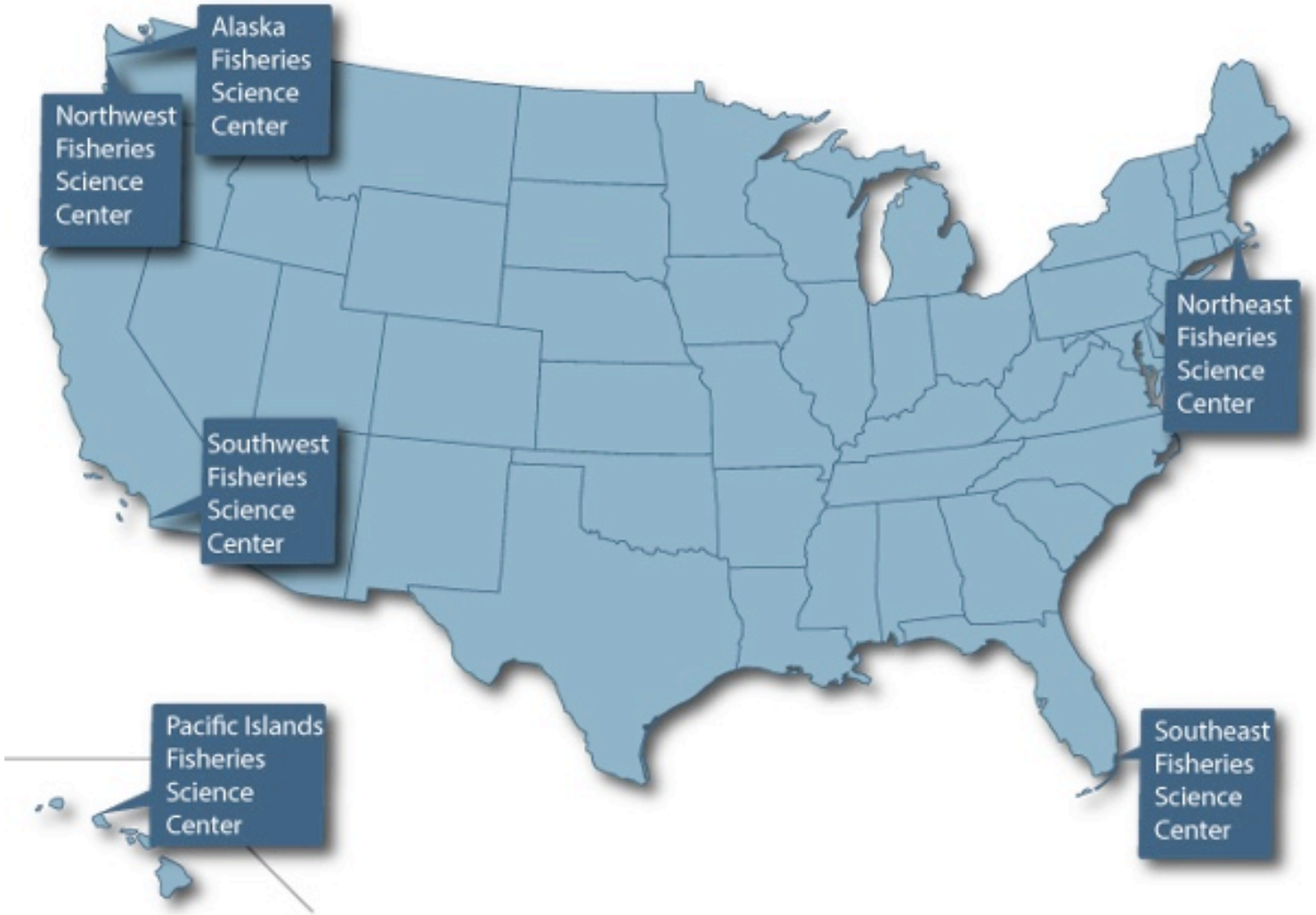
Notes

This suite of programs supersedes the former toolboxes FACT (Fisheries Assessment and Computation Toolbox) and WHAT (Woods Hole Assessment Toolbox).

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by NMFS. It does not represent and should not be construed to represent any agency determination or policy.

NOAA Fisheries Toolbox Version 3.1
website last modified March 6, 2014

NOAA FSC's Involved in AIASI



Current Image/Video Analytics

Capability	Primary data source	POC	Stereo calibration	Stereo processing	Video	Color, contrast correction	scallop detection	fish detection	fish length, sizing	fish tracking	fish classification	anomaly det.	habitat classification	image segmentation
NW SC CamTrawl	Cam Trawl	Williams	yes	yes	4 Hz	no, grayscale		yes	automatic	yes	yes			
ROV video fish detection and tracking	SWFSC ROV video	Cutter	no	no	30 Hz	yes		yes, DPM (UW)	no	yes (UW student)	desired	desired		
ROV stereo fish measurement	SWFSC ROV GigE stereo	Cutter	yes	yes	2-4 Hz	yes		no	manual	no				
WHOI/NEFSC scallop detector	HABCAM towed rig	Dvora	yes	yes	no	yes	yes							
RPI/Kitware scallop detector	HABCAM towed rig	Hoogs	no	no	no	yes	yes							
SRI fish detection, classification, size	PI FSC MOUSS/BotCam	Ben/Mike	yes, accept cal files	yes	30 Hz	no, grayscale		yes		yes	yes			
SEFSC stereo proc	Drop cams from SEFSC	Thompson	yes	yes	yes			yes, basic background	manual	no	no			
Toyon SBIR I	Drop cams from SEFSC	Thompson	yes	yes	yes			yes, basic HOG	manual	yes	yes			
LANL segmentation and shape analysis	HABCAM towed rig	Lakshman	no	yes	no	no	yes	yes	no	no	yes	yes (image)	Yes	yes (polygonal)
Toyon SBIR II	Still Images AUV, drop, towed	Clarke	yes	yes	no	yes (Hanu)		yes	yes	no	yes			
WHOI/NEFSC habitat classifier	HABCAM towed rig	Dvora	yes	yes	no	yes							yes	
NWFSC clustering	AUV and MOUSS	Clarke	no		no	no						yes	partially	

Green	well-implemented; quantified, comparative performance assessment; ready for integration	Yellow	Existing implementation as mature research code; some performance quantification	Red	preliminary research code with ongoing work against major problems
Gray	idea or concept; no implementation				

VIAME Goals

- **V**ideo and **I**mage **A**nalytics for the **M**arine **E**nvironment
- Develop a common software platform for NMFS image and video analysis
  - In close coordination with NOAA community
- Incorporate interactive query refinement for online algorithm improvement for fish detection
  - Can be applied to algorithms from anyone
- Test and enhance parameter auto-tuning capability for underwater video analytics
  - Efficiently find near-optimal performance for any algorithm

Funded by NOAA to integrate R&D in underwater image and video analytics being performed at various NOAA and NOAA-funded institutions

VIAME Project History

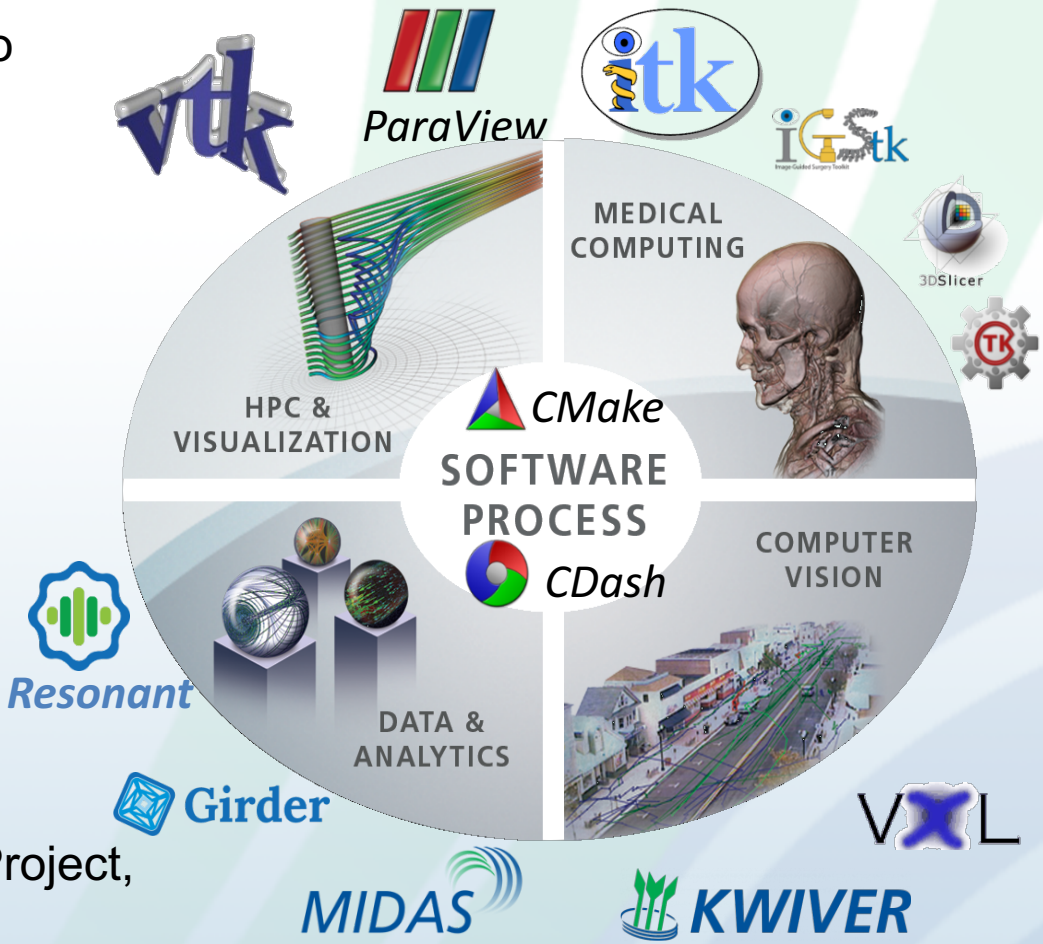
- Dr. Hoogs was invited to join a panel of experts on image and video analytics to develop a National Academies workshop on behalf of NOAA in May 2014
- Invited to join AIASI Committee after the workshop
- In fall 2015, NOAA awarded Kitware a subcontract to develop VIAME (**V**ideo and **I**mage **A**nalytics in a **M**arine **E**nvironment)
  - Based on Kitware's Open Source Heritage
  - Open Source common framework for analytics
  - Approximately 1 FTE in 2016
  - Similar expected in 2017

Topics

- AIASI Background
- Open-source software at Kitware
- KWIVER
- VIAME Common Processing Environment
- Additional KWIVER Capabilities

Kitware Open Source Platforms

- **KWIVER** Kitware Imagery and Video Exploitation and Retrieval
- **VTK** the visualization toolkit
- **ParaView** large data analysis & visualization application
- **ITK** insight image analysis toolkit
- **CMake** cross-platform build system
  - CDash, CTest, CPack, software process tools
- **Resonant/Girder** informatics and information visualization
- **Kiwi & VES** mobile visualization
- IGSTK, CTK, vxl, Open Chemistry Project, VolView, tubeTk, and more…
- **MIDAS** for computational scientific research, testing, and visualization



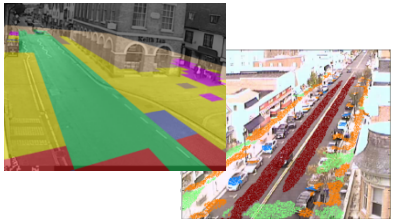
Kitware

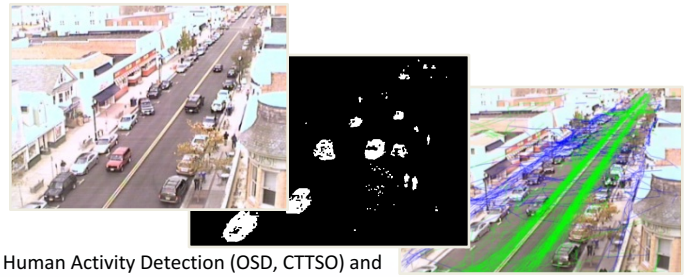
Computer Vision at Kitware

- 25+ team members
- 12 PhDs
- Founded in 2007
- 35+ contracts

Dr. Anthony Hoogs
anthony.hoogs@kitware.com
518-881-4910

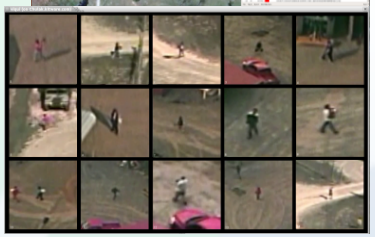
Object and Building Recognition by Function (DARPA)



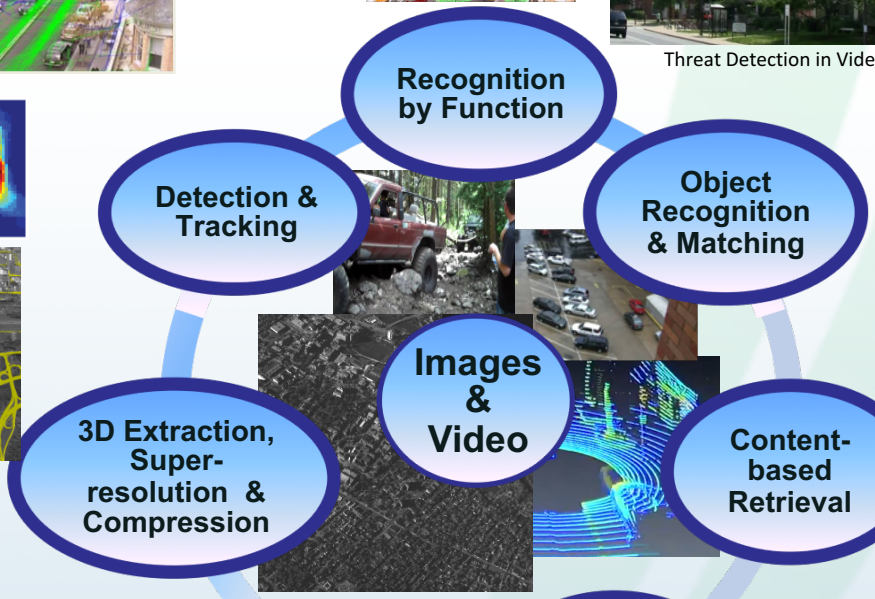


Human Activity Detection (OSD, CTTSO) and Tracking in Wide-Area Video (AFRL)

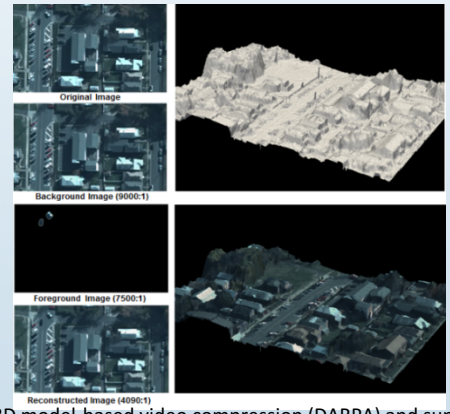
Threat Detection in Video (DARPA)



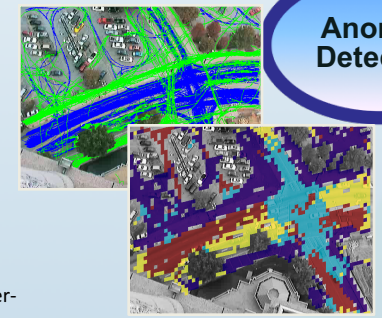
Content-based Video Retrieval by Actions (DARPA VIRAT)



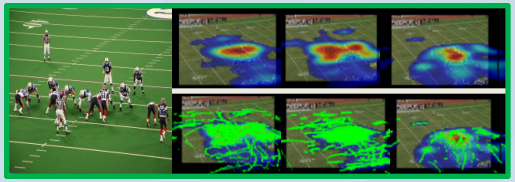
Complex Event Recognition in Internet Videos (GENIE)



3D model-based video compression (DARPA) and super-resolved 3D reconstruction (DARPA)

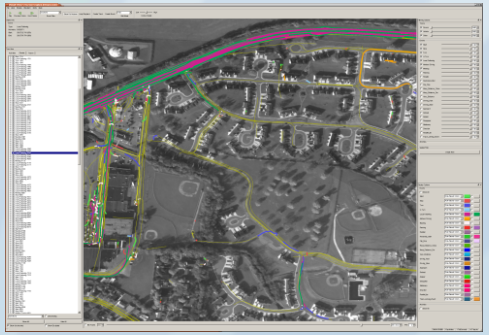


Normalcy Modeling and Anomaly Detection (DARPA PANDA and PerSEAS)



Football Play Recognition (DARPA CARVE)

Wide-Area Motion Imagery Event, Anomaly and Activity Detection (OSD Data to Decisions, DARPA PerSEAS)

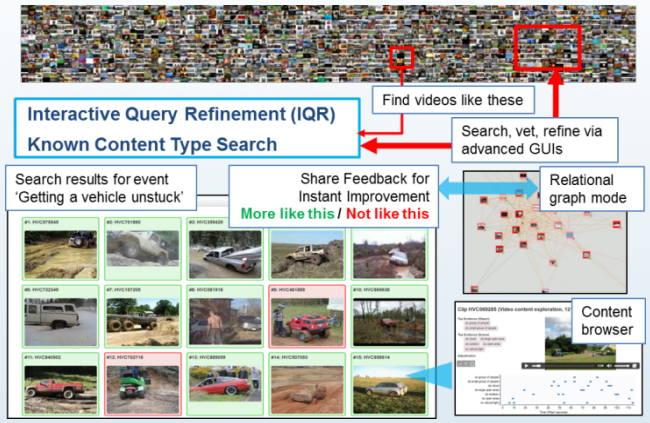


KWIVER.org

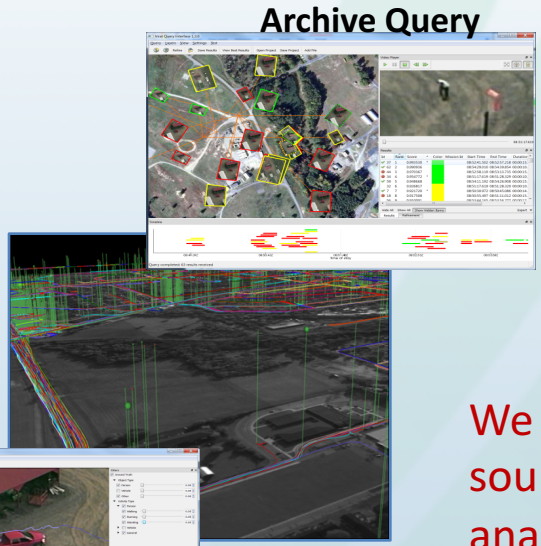
Kitware Image and Video Exploitation and Retrieval Toolkit

An Open Source, production-quality video analytics toolkit

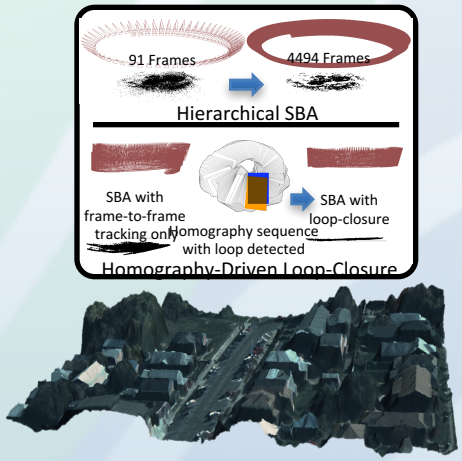
Social Multimedia Query ToolKit



VIBRANT:
Video and Image-Based Retrieval and Analysis Toolkit



Motion-imagery Aerial Photogrammetry Toolkit

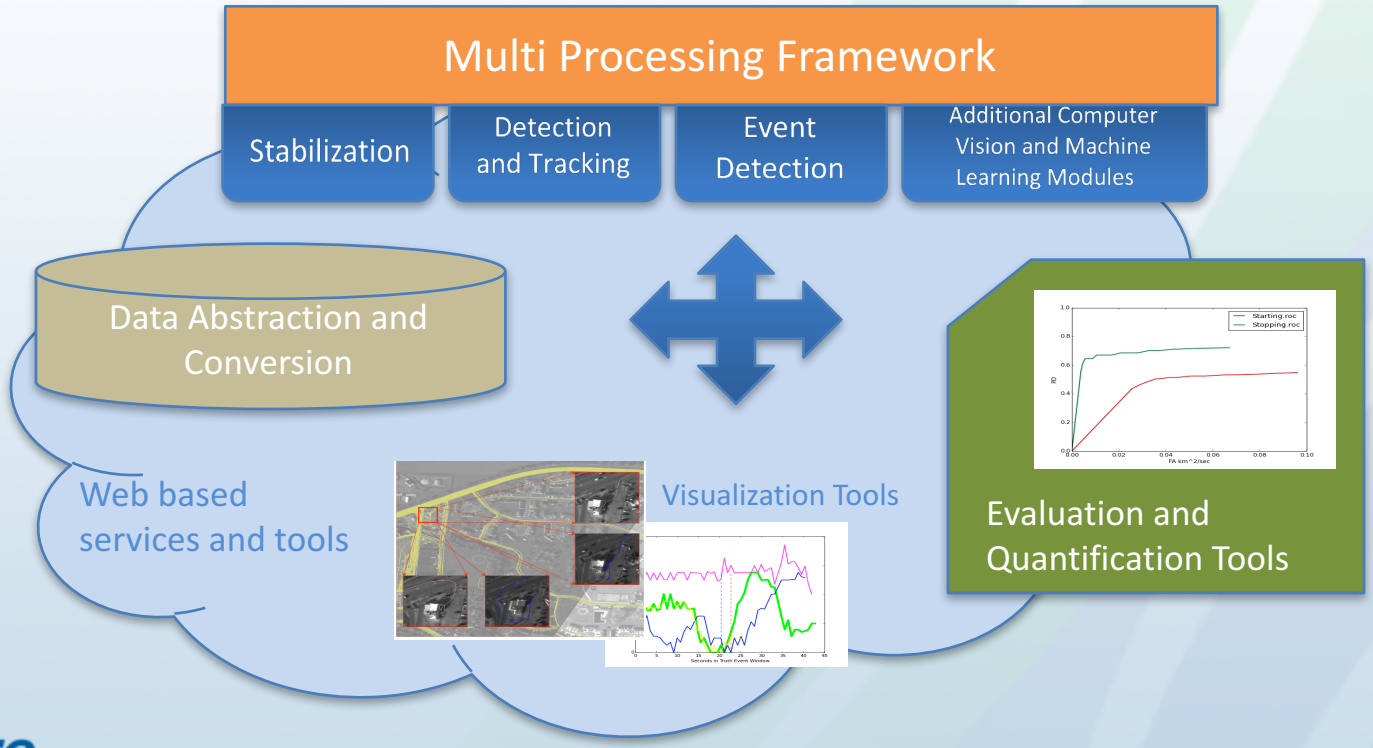


We hope to establish an open-source community for video analytics research and development

Kitware

Enables Video and Image Exploitation Systems

- Provides high quality implementations of key computer vision and machine learning techniques targeted at real-world problems (MAP-Tk, SMQTK, VIAME)
- Provides software engineering libraries for multi-processing, pipeline based computation, dependency management and more (SproKit, Fletch, WorkQL)

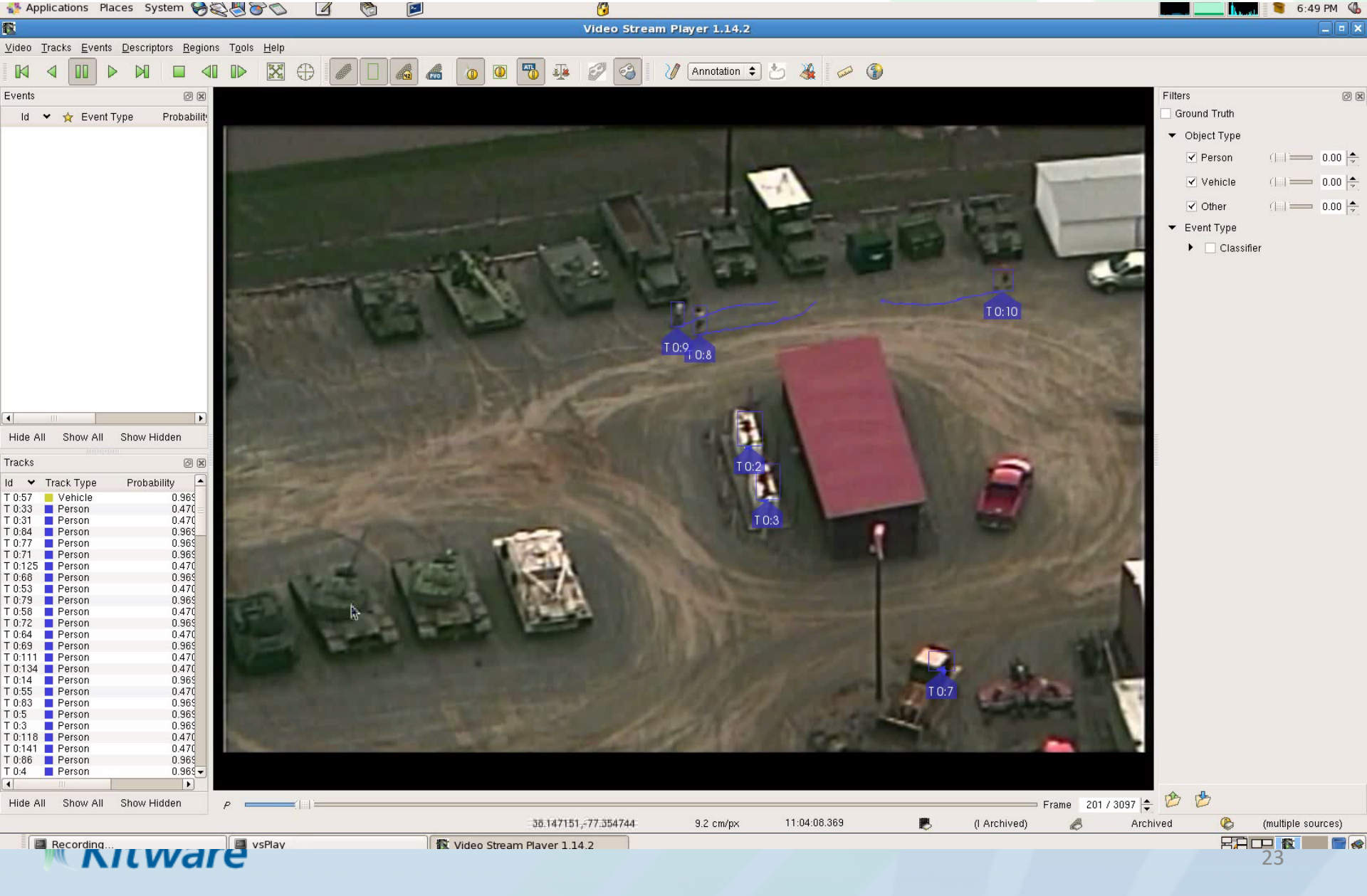


Kitware

KWIVER.org

- Source code repositories maintained at GitHub
- Current toolkits available:
  - Motion-imagery Aerial Photogrammetry Toolkit for video stabilization and online bundle adjustment **MAP-TK**
  - Social Multimedia Query Toolkit for visual context extraction and querying for social multimedia **SMQTK**
  - Stream Processing Toolkit to facilitate multi-state, pipelined processing of data streams **Sprokit**
  - Common data structures and abstractions for computer vision and machine learning systems **VITAL**
  - GPU acceleration of core vision algorithms using OpenCL **VisCL**
  - GUIs and sophisticated visualization tools for content automatically extracted from video, based on VTK **ViVIA**
  - Detection and tracking of movers in video **VIBRANT**
  - CMake tools to set up complex build environments and dependencies **Fletch**

VIBRANT Tracking



VIBRANT Querying

Operational Impact:

- ✓ Rapid search/retrieval from archives ***during real-time video exploitation***
- ✓ Operator interaction and on-the-fly learning to achieve best results

- Exemplar-based query
- Two rounds of feedback on top 10
- 2 hours of Predator surrogate video
- 1675 tracks
- 1095/166 people/vehicle

Returned Clips

Correct False Alarm Uncertain

Kitware

Video Analytics Architecture

Stabilized video to account for platform motion

Refined geo-registration of pixels based on metadata and stabilization

Geo-registered object tracks

Tracks soft-assigned to known object classes

Stabilization

Geo-registration

Tracking

Track classification

Event classifiers

Raw Event Descriptors

Appearance Descriptors

Recognition of specific, pre-specified events

Generic descriptors able to capture event characteristics

Generic descriptors able to capture object appearance

Export to other systems

Interface with other systems using standardized formats

Output to PowerPoint, etc.

Reporting tools

Matching and alerting

Streaming UI

Search models

Iterative Refinement

Forensic UI

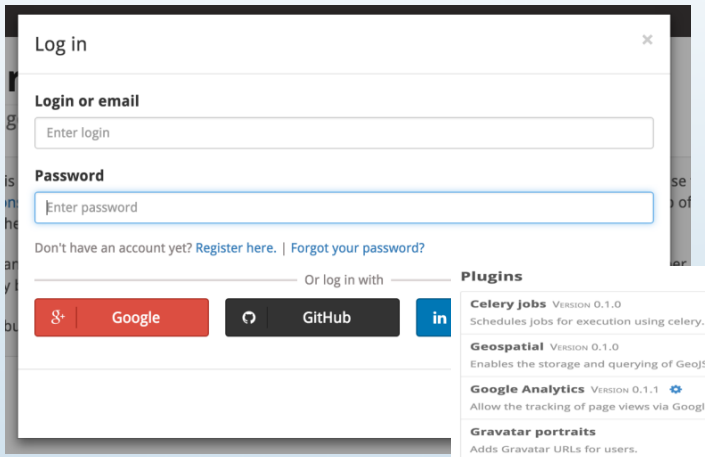
Descriptor Archive

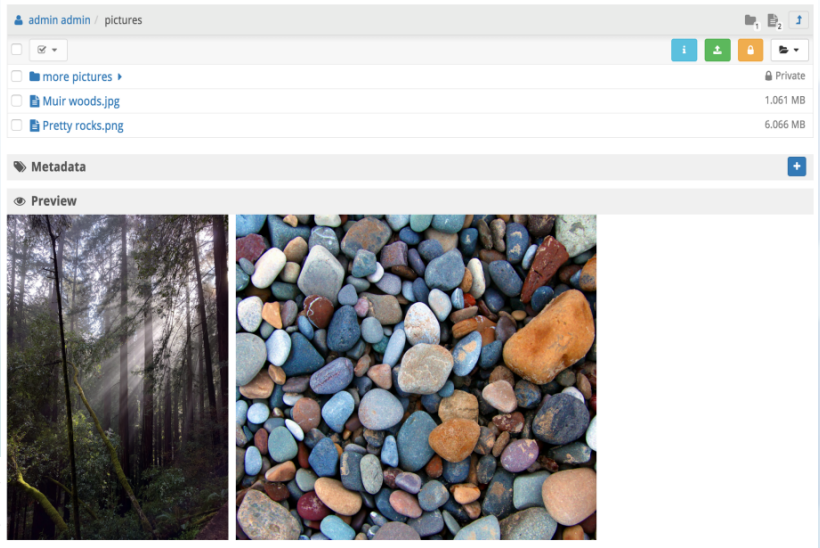
Search

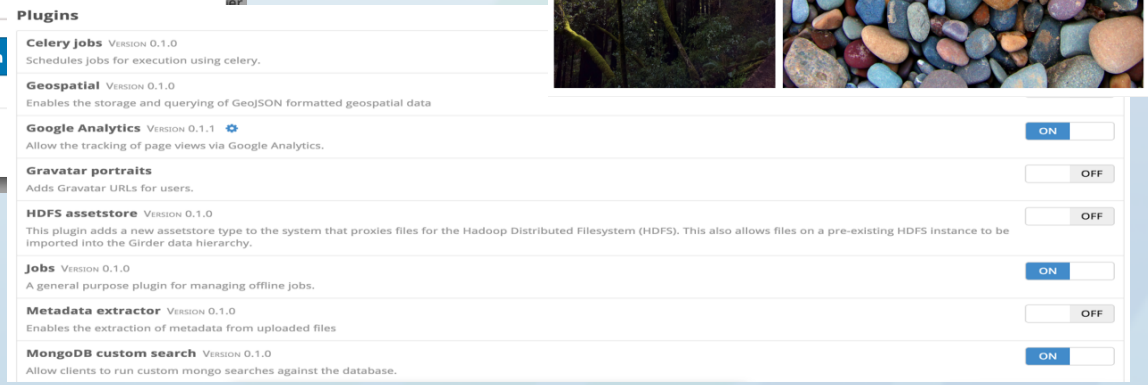
Kitware

Girder

- Data organization and dissemination
- User management & authentication
- Authorization control
- Extensibility

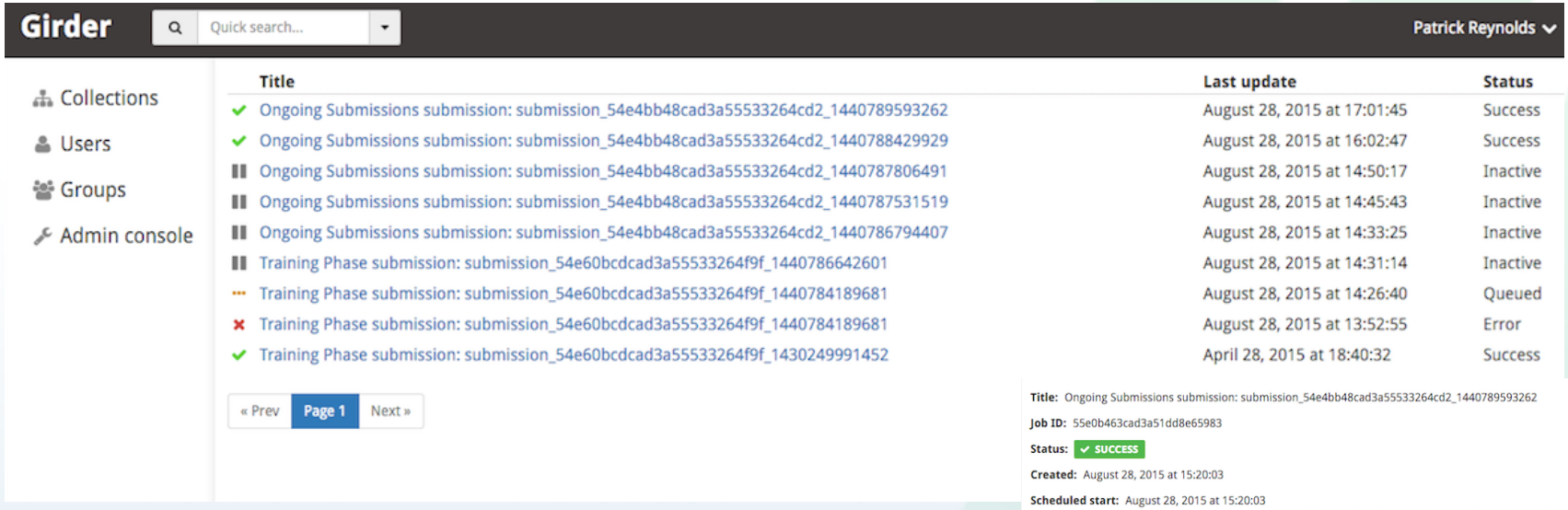


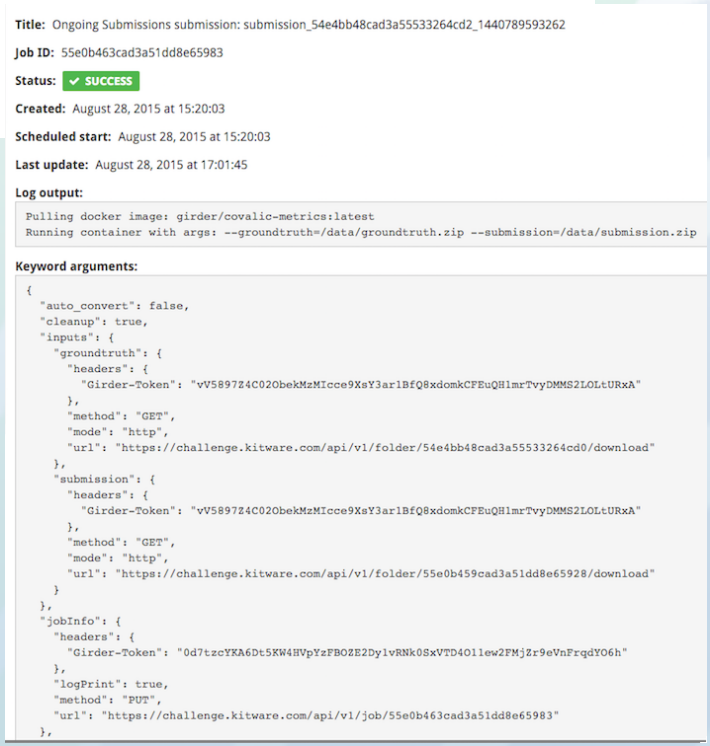


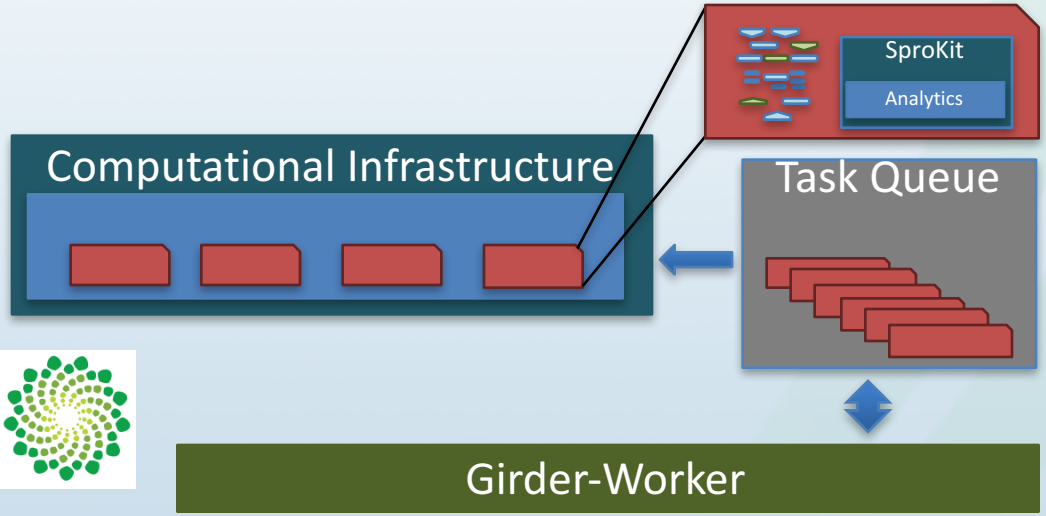


Kitware

Girder-worker: Job Tasking and Management

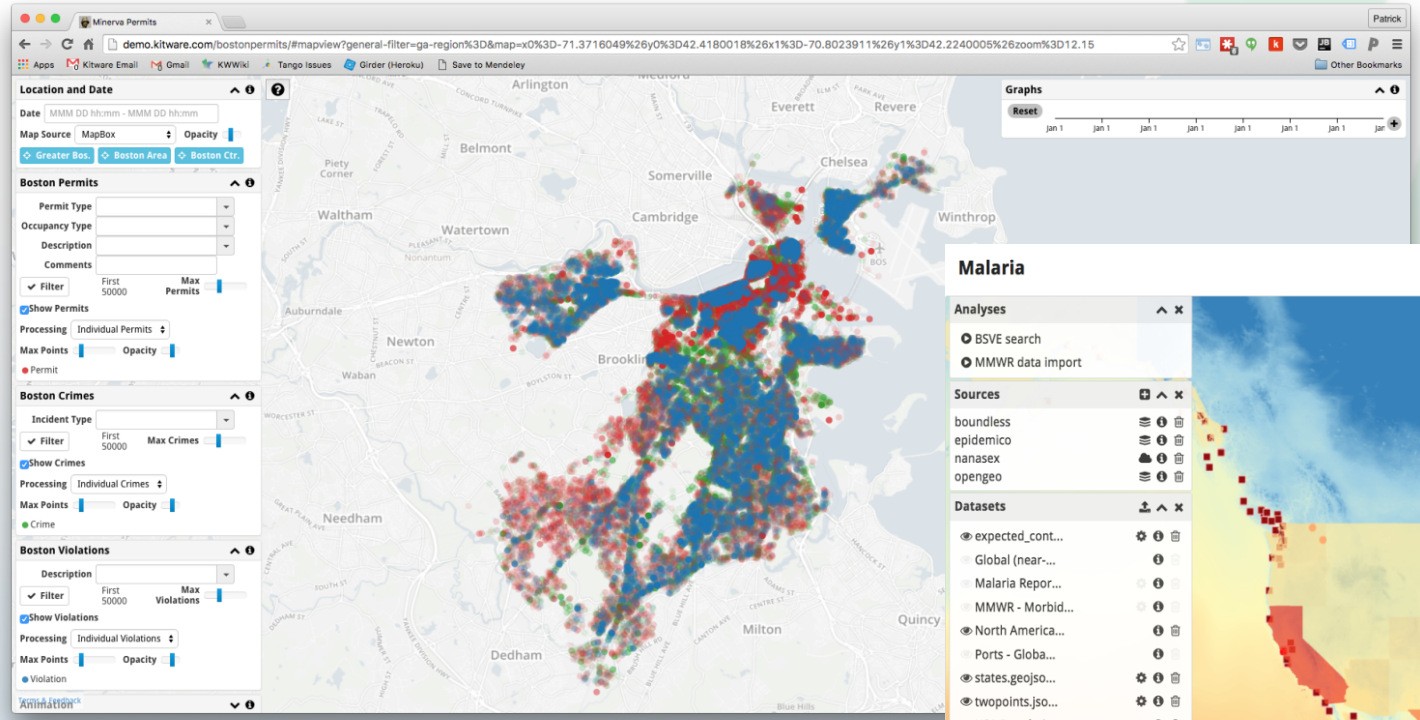




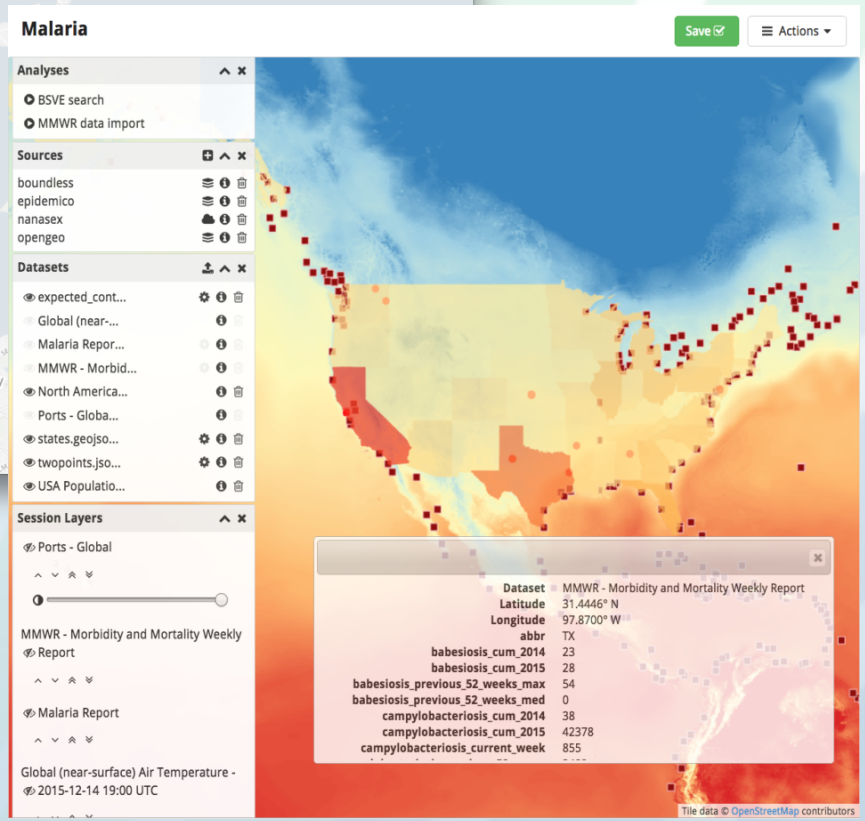


Kitware

Analytics Visualization



Web based visualization leveraging GeoJS and other Open Source visualization toolkits



Kitware

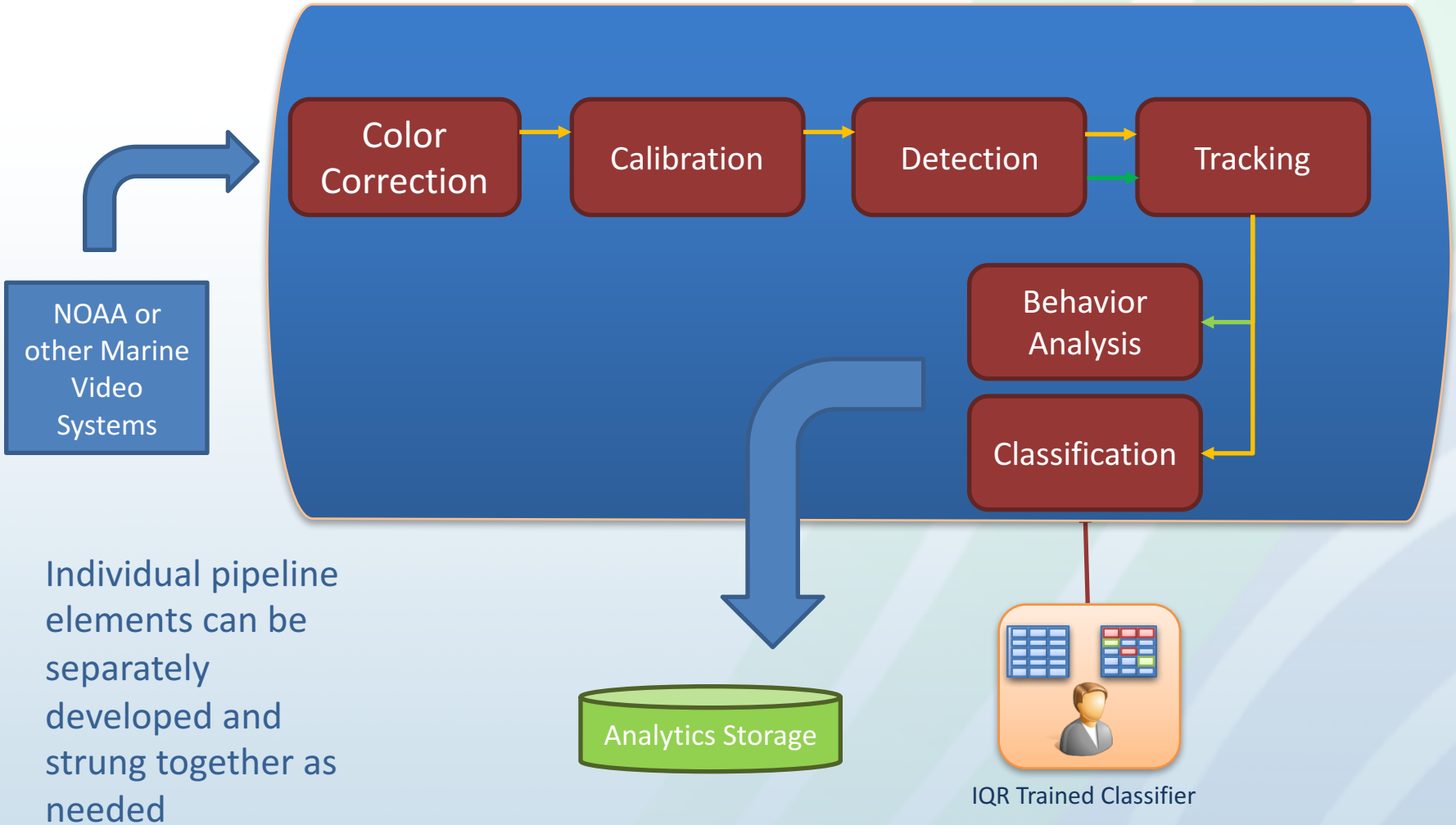
Topics

- Open-source software at Kitware
- KWIVER
- **VIAME Common Processing Environment**
- Additional KWIVER Capabilities

VIAME Common Programming Environment (CPE)

- Normalize and standardize data structures to facilitate integration
- Isolate system integration issues by providing test fixtures for remote development
- Encourage collaboration by providing a framework for data sharing and replay
- Encourage modular development with pipeline based architecture
- Leverage existing KWIVER and other Open Source Toolkits

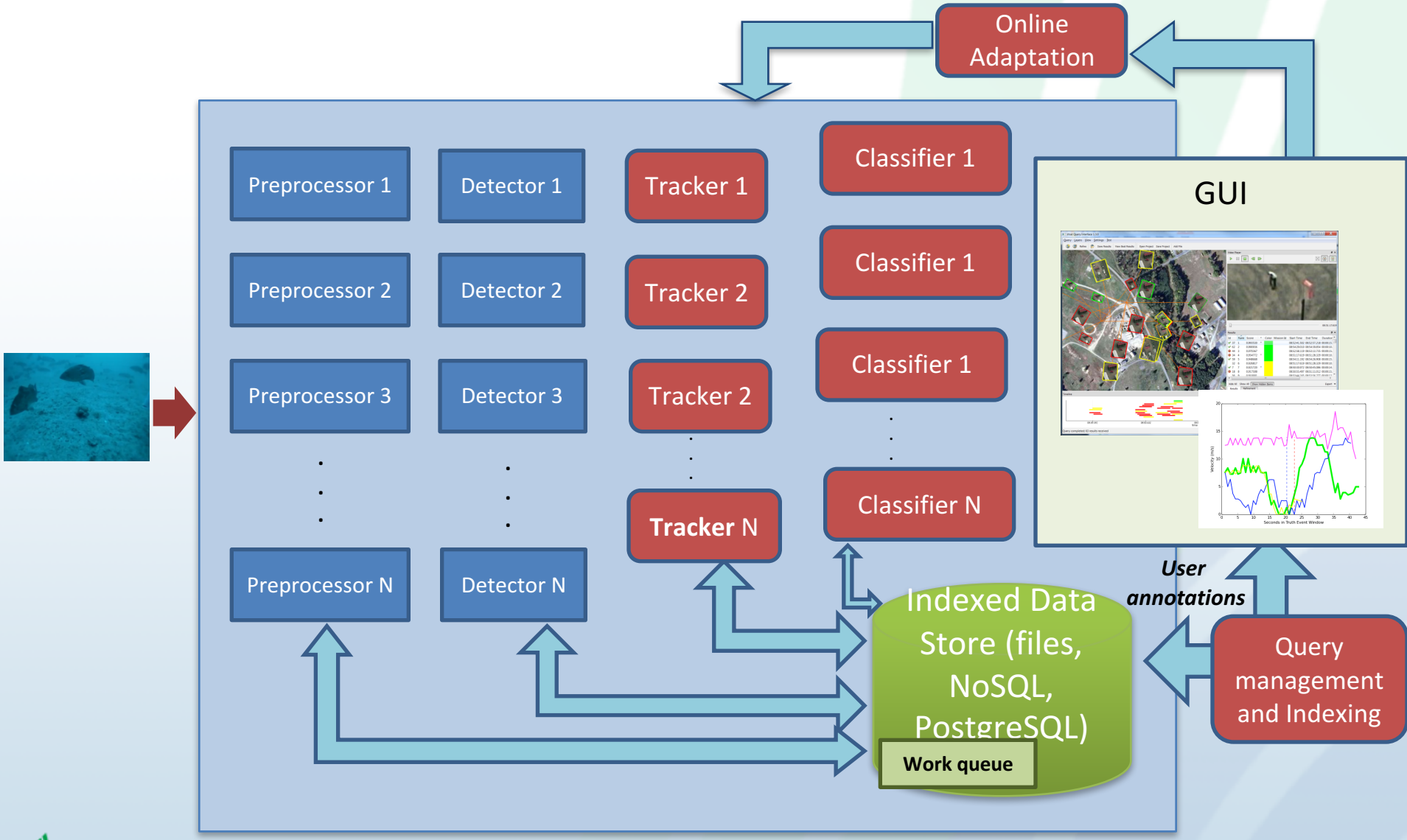
VIAME Pipeline



Individual pipeline elements can be separately developed and strung together as needed

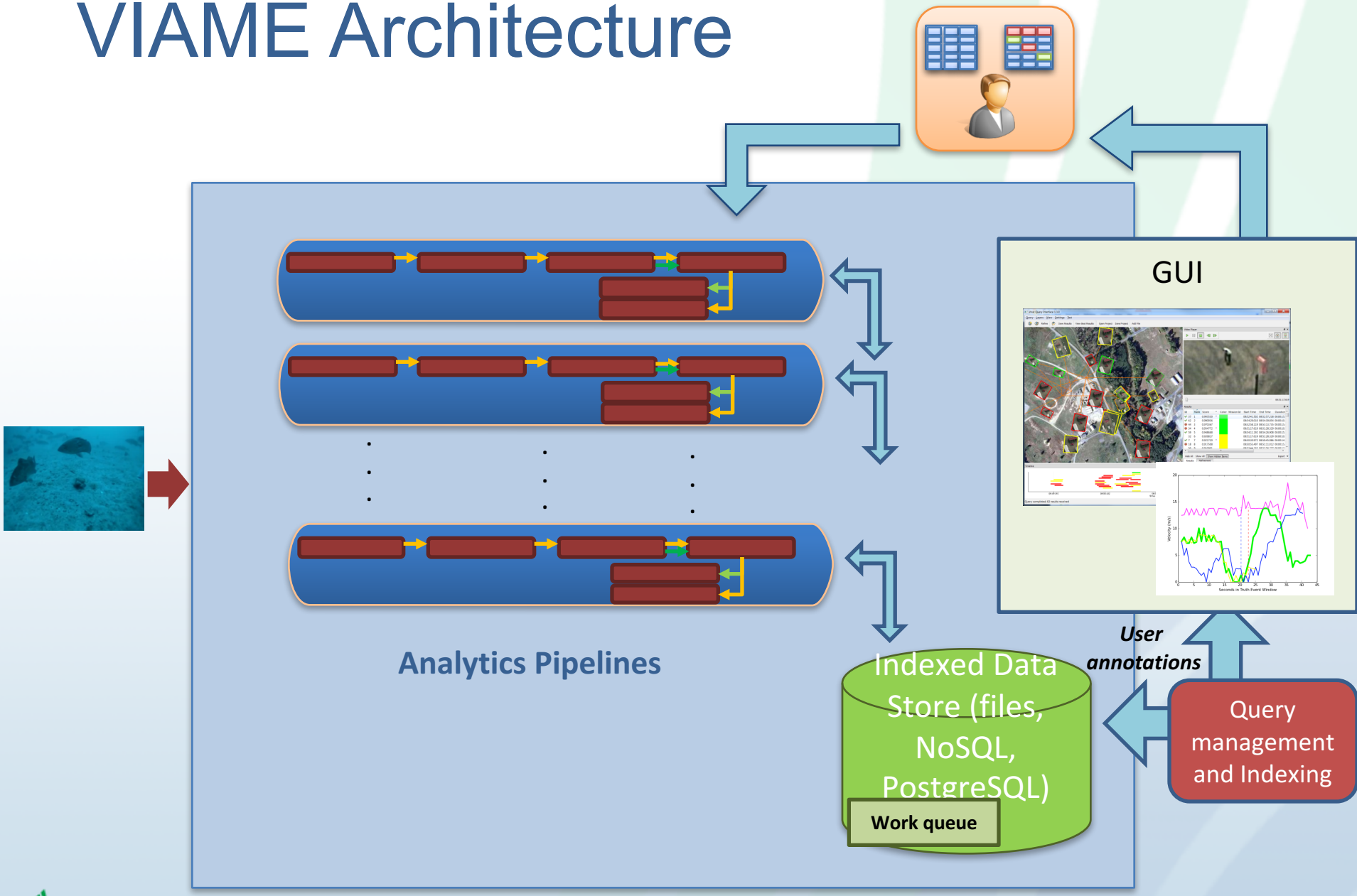
Kitware

VIAME Architecture



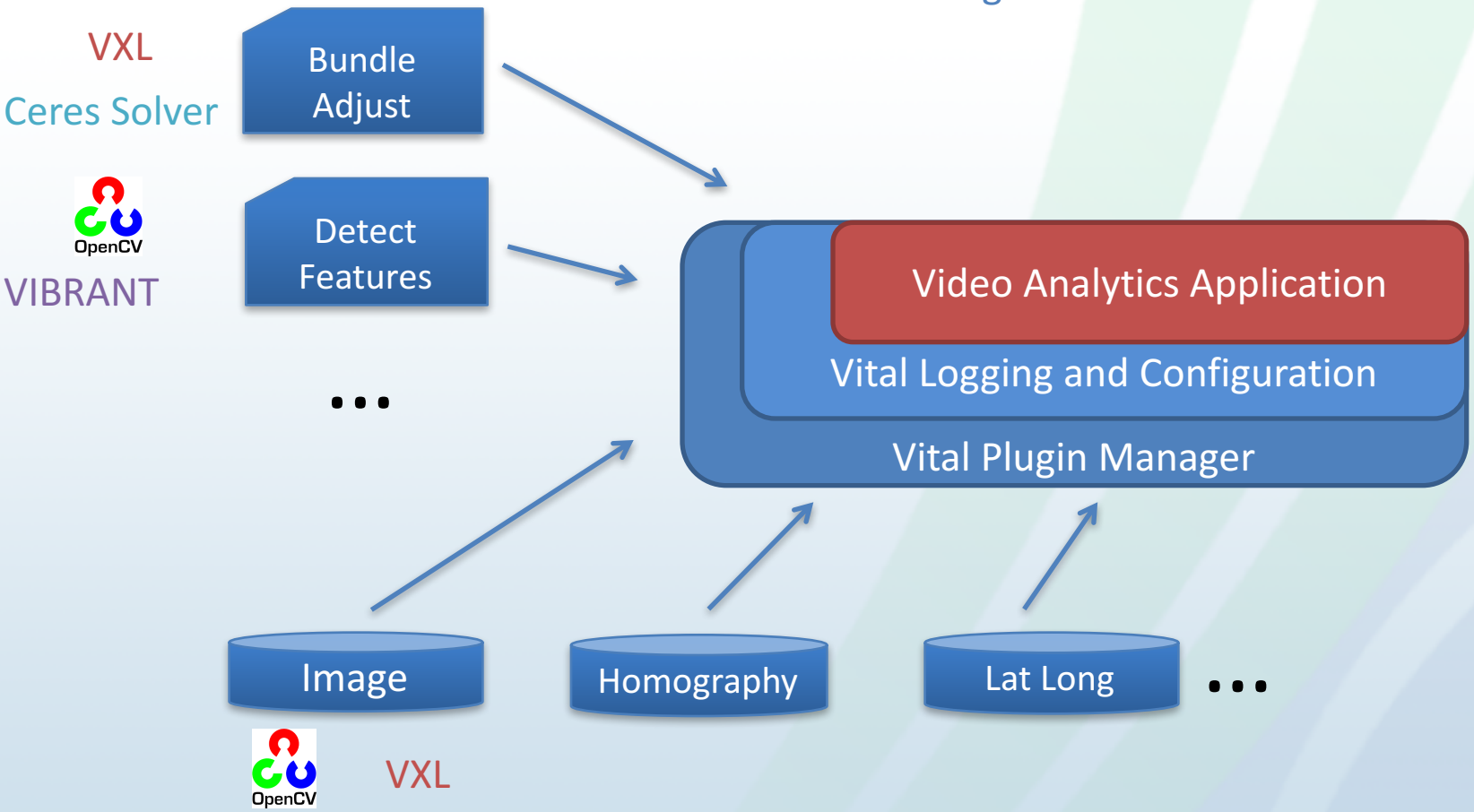
Kitware

VIAME Architecture



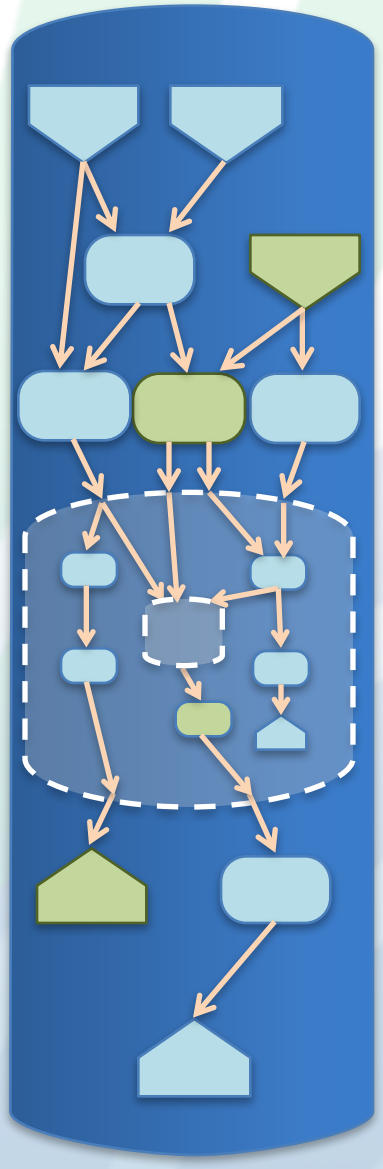
VITAL

Provides abstractions for algorithms and data types along with core services such as logging and configuration to help build cohesive systems. Many choices can be configured at *runtime*.



Sprokit – A Framework for Streaming Data Processing

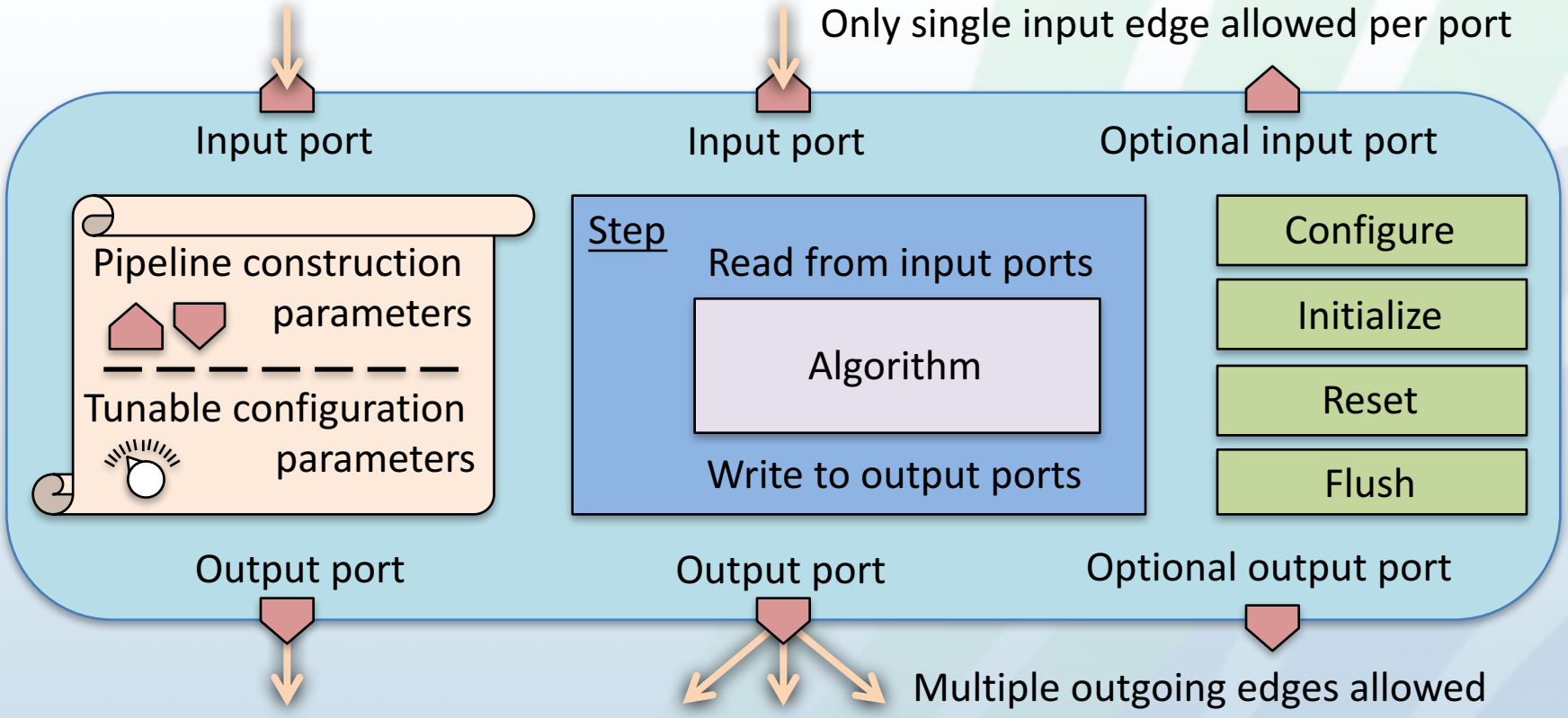
- What is Sprokit?
  - Plugin-based **streaming data processing engine** on which to build modular streaming data processing applications (especially video processing applications).
- What does Sprokit do?
  - Chains processing elements into a directed acyclic graph (DAG)
  - Executes a constructed pipeline on streaming data (e.g. video)
  - Manages data dependencies, flow, and synchronization
  - Distributes and balances processing load over CPU cores
  - Provides dynamic construction/configuration via configuration files
  - Allows reuse of preconfigured clusters of processes
  - Supports algorithms written in C++ and Python
  - Extends to custom processes, data types, and schedulers via plugins
- Why was Sprokit developed?
  - To build complex streaming algorithms from simple components
  - To replace an older, much more restrictive, pipeline framework
  - Because existing open source frameworks (e.g. Gstreamer, Ecto, etc.) did not meet all requirements in the list above.



Kitware

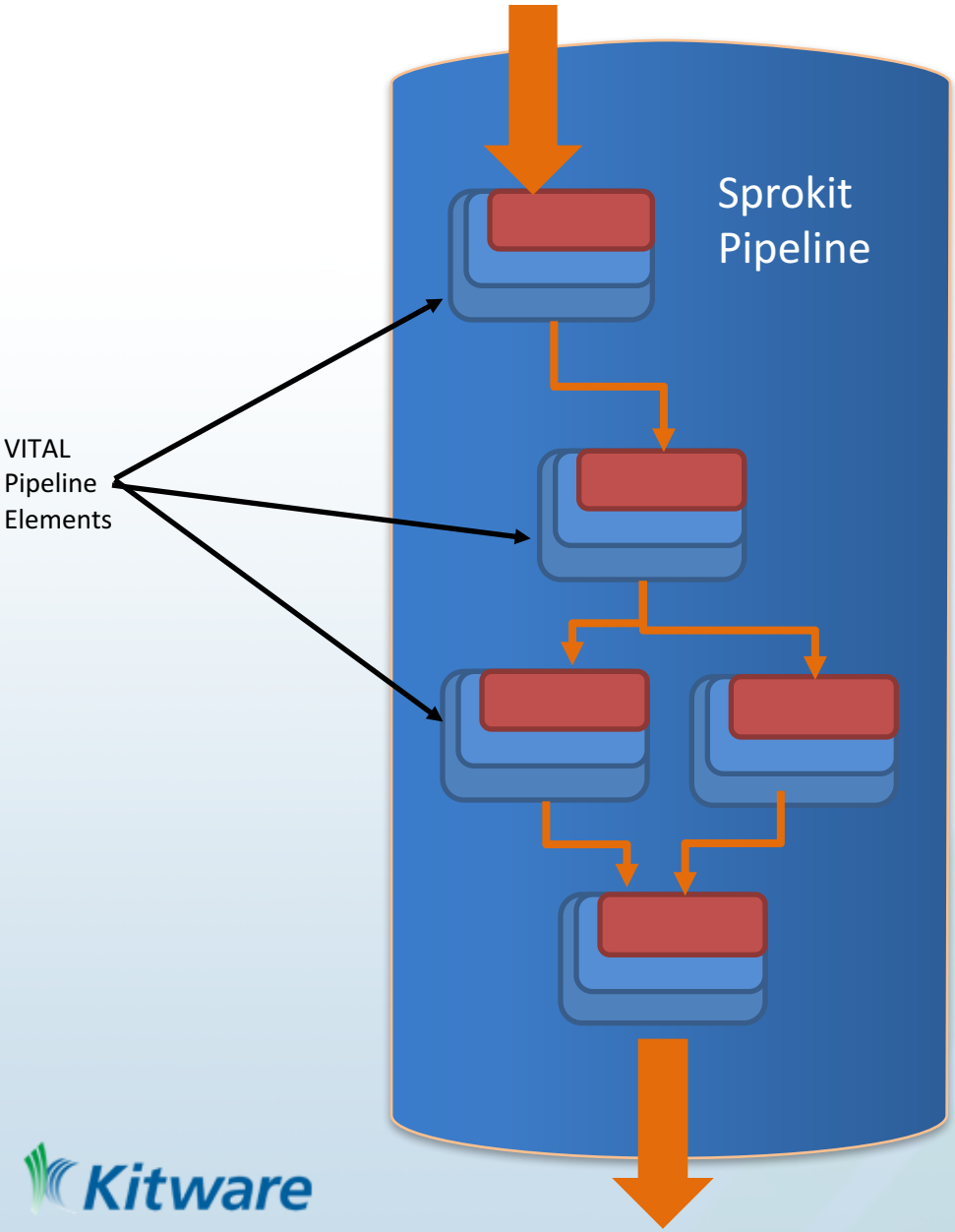
Anatomy of a Sprokit process

- User constructs a process by
  - Inheriting from C++ or Python base class
  - Calling functions in the constructor to define ports, configuration parameters, etc.
  - Overriding a virtual "step" function to read/write data from ports and run the algorithm
  - Optionally overriding other virtual functions to add more advance behavior



Kitware

VITAL and Sprokit



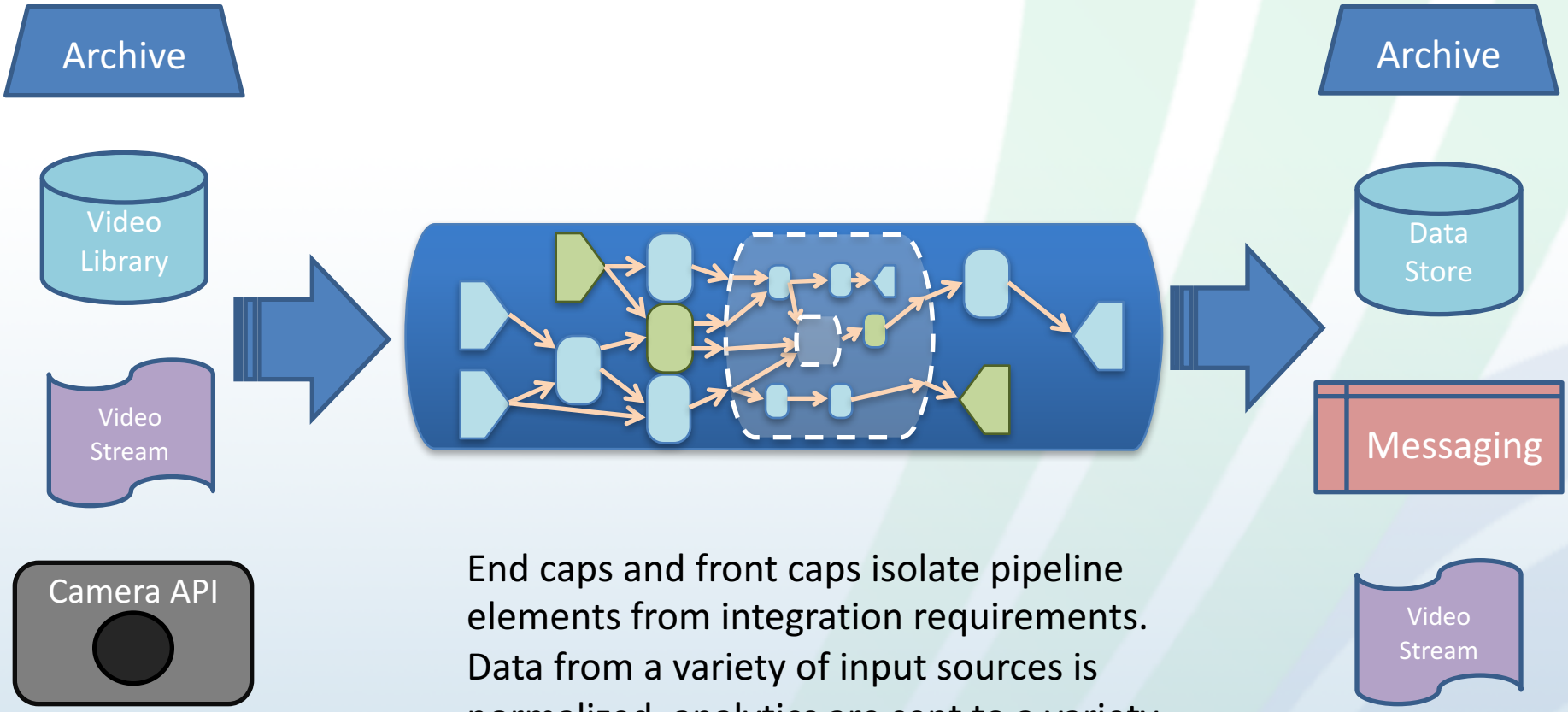
Taken together, VITAL and Sprokit provide the basis for a modular, dynamic environment for the development of a wide variety of video analytics systems.

Additional data types and data flows can be defined for domain specific efficiency as for video analytics in a marine environment.

Configurable pipelines and pluggable processing elements provide the most flexibility possible when developing a system.

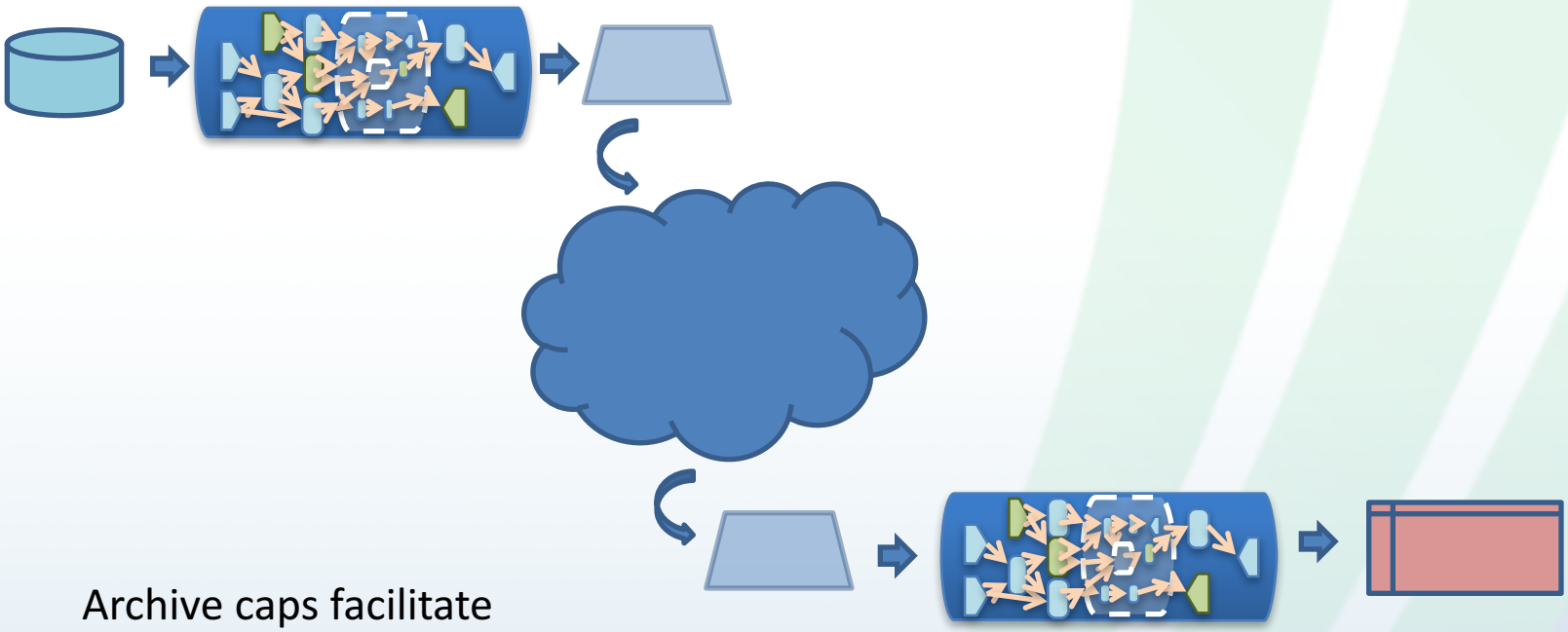
Kitware

Front Caps and End Caps



End caps and front caps isolate pipeline elements from integration requirements. Data from a variety of input sources is normalized, analytics are sent to a variety of destinations. Processing elements merely consume their inputs and produce their outputs.

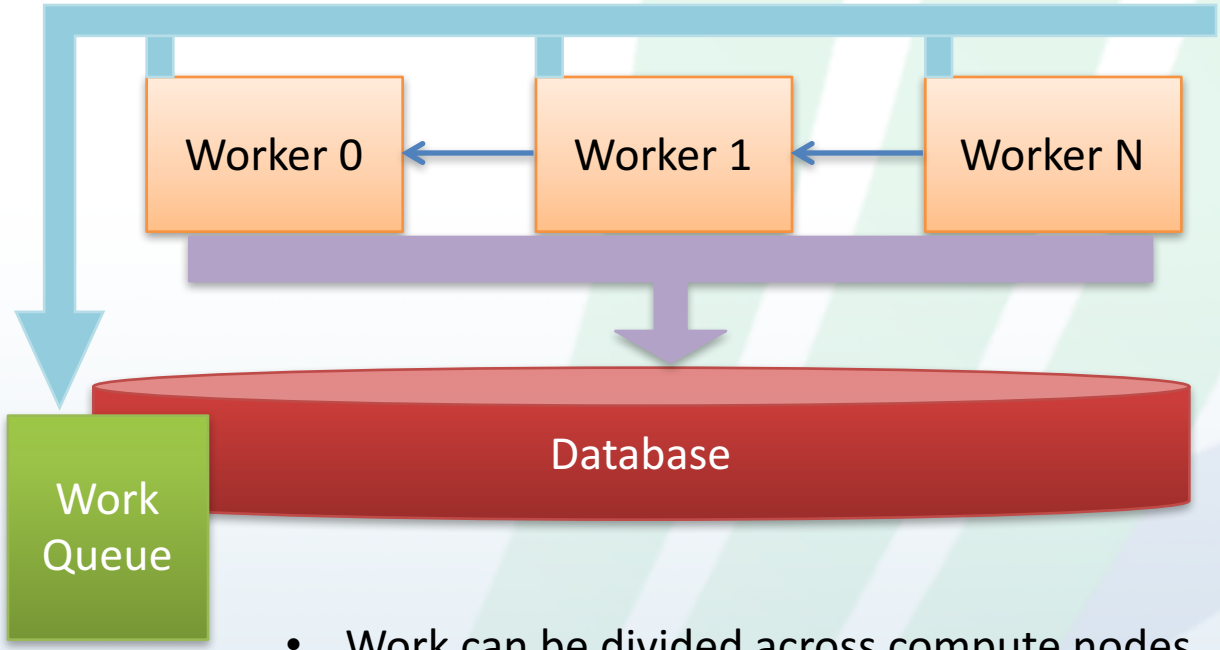
Archive Caps



Archive caps facilitate experimentation, remote development and collaboration. Pipeline data can be archived, transmitted and replayed later.

WorkQL – A Library for Multi-processing Synchronization

- Processing Dependency:
- Synchronization requests:
- Intra-worker data flow:



- Work can be divided across compute nodes
- Workers request next available data based on the productivity of their dependents
- Tasking stored in database for later replay and forensic analysis

Kitware

Fletch – A Computer Vision Tool Chest

Fletch uses CMake to fetch, configure and build a variety of Open Source Computer Vision, Machine Learning and C/C++ libraries, easing the set up of a KWIVER development environment

Fish Counting and Assessment

https://www.youtube.com/watch?feature=player_detailpage&v=wvMXhHwjB6Y

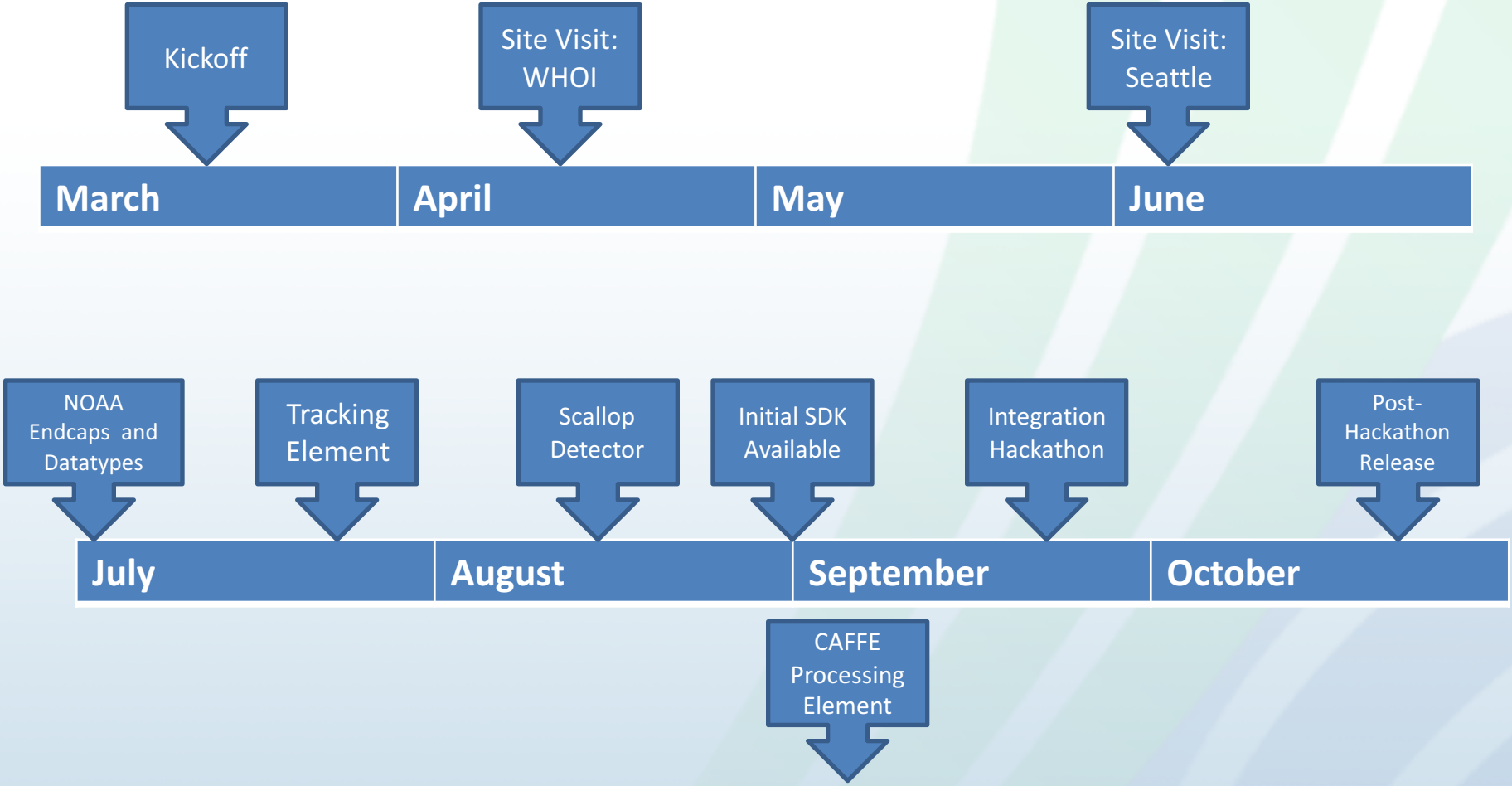
NOAA problem directly plugs into existing pipeline

Algorithms are similar but different

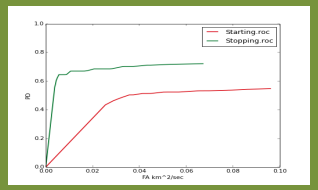
https://www.youtube.com/watch?v=kAbEzakam3Y&feature=player_detailpage

Kitware

Schedule & Milestones



VIAME Initial Release: Aug. 29



Detection Scoring and ROC Generation

Detection Overlays and Girdir Viz

Images (no video)

Analytics Pipelines

Scallop Detection

Indexed Data Store (files, NoSQL, PostgreSQL)

Work queue

User annotations

Query management and Indexing

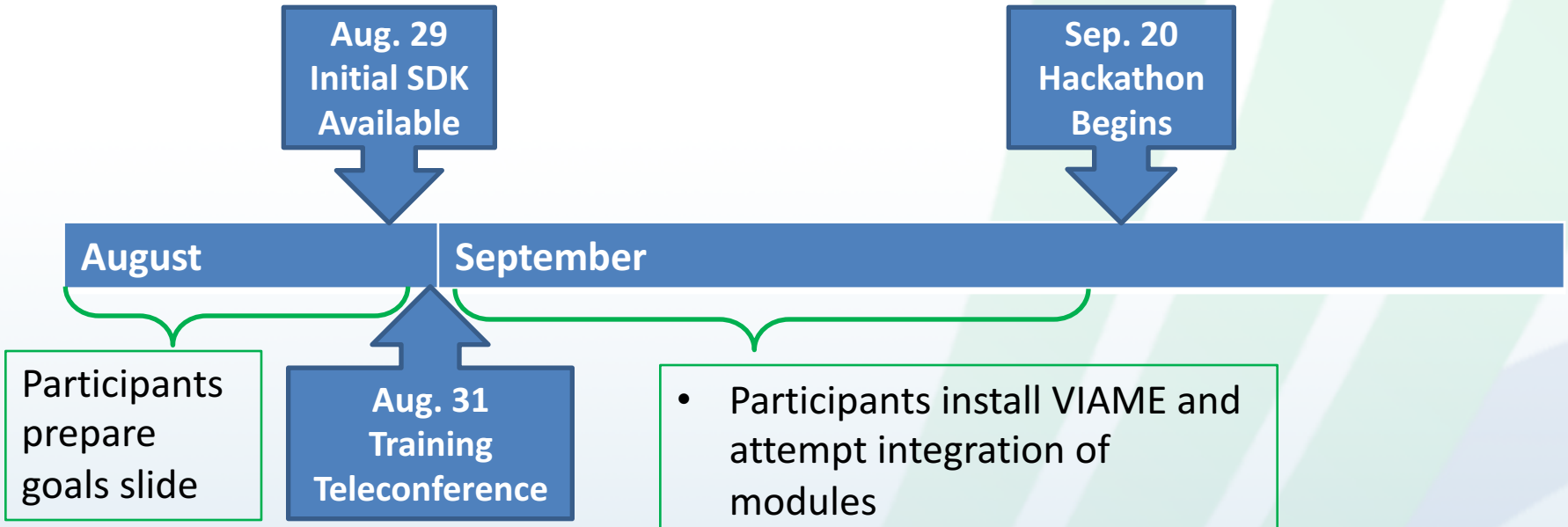
Kitware

API for C/C++, Python, Matlab

VIAME Hackathon

- September 20-23, 2016 at NOAA in Seattle
- Goals
  - Integrate detection modules to access VIAME scoring, ROC generation and data analysis tools
    - compare different algorithms doing same problem, e.g. multiple scallop detectors
  - Run integrated modules on data from other groups
  - Integrate multi-stage pipelines combining modules from different groups
    - E.g. color correction from A used by detector from B; detection from A feeds into classification from B.
  - Train and run deep learning (Caffe) detectors on existing annotated datasets through VIAME-Caffe interface
- Expecting 13+ participants from Alaska FSC, SW FSC, WHOI, U Washington, U Victoria, MBARI, LANL, SRI

Hackathon Preparation



VIAME in 2017

- Video processing
- Stereo processing
  - Calibration
  - Dense 3D reconstruction
- Anomaly detection and clustering
- Habitat classification
- Extend analytics and visualization
- Full Matlab interfaces
- Extend deep learning integration
- Database extensions