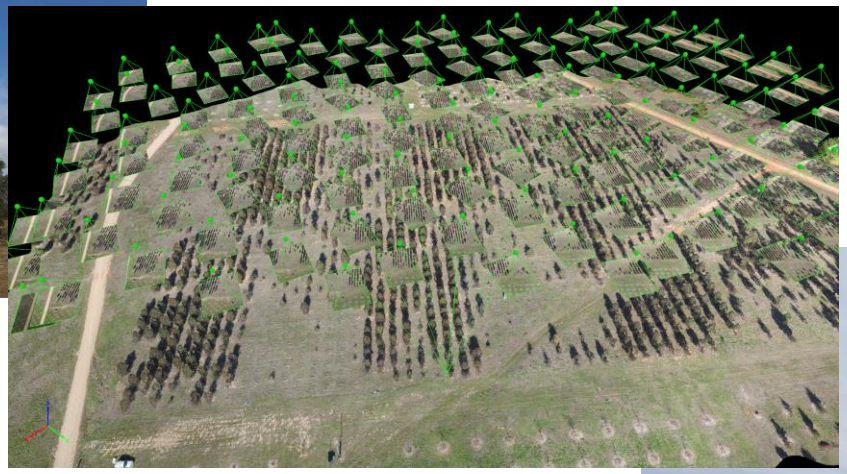
From pixels to point clouds - Using drones, game engines and virtual reality to model and map the National Arboretum in Canberra



Tim Brown, PhD
Director, Australian Plant Phenomics Facility (APPF), ANU
Research Fellow: ARC Centre for Plant Energy Biology, ANU

Ellen Levingston; Gareth Dunstone; Argyl McGhie, Aly Weirman, Zac Hatfield-Dodds,
Justin Borevitz – Borevitz Lab, CoE PEB, ANU Research School of Biology
Darrell Burkey - ProUav

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plant energy biology ARC CENTRE OF EXCELLENCE

Drones (UAV's UAS) are key part of the emerging toolset for "NextGen" monitoring of the environment

1. UAV's (drones)
2. New Sensors: Mesh-networks, Hyperspectral, thermal, micron-resolution dendrometers; Raspberry Pi-based phenocams & sensors
3. Gigapixel imaging – billion pixel resolution panoramic timelapse images
4. LiDAR – aerial and ground based

Measure the **E** in the field for Genetics x **Environment** = Phenotype

UAV Hardware

- Quad/Hexrotor with RGB imaging
  - ~$1,200 - $8,000AUD
  - 15-25 mn flight time, 0.250 – 10KG payload
  - Typically 12MP 4K camera

DJI Phantom 4 (2016)

DJI Mavic Pro (2017)

- Fixed wing (30-60min flight time)
  - TurnKey: eBee ($25-30K USD) ; <0.5kg payload
  - DIY: <$1000
  - Huge variations from small foam craft to multi-kilo gas plane

- NEW: VTOL systems – combines benefits of fixed wing and ‘copter
  - Ideal platform for digital agriculture?
  - <$5K
  - Vertical takeoff/landing (no runway)
  - Gas powered flight after takeoff /quad rotor backup for safety
  - 6kg payload / likely ~1hr forward flight

Camera options

- RGB
  - Many options from onboard (Phantom – 12MP) -> GoPro's -> DIY Raspberry pi -> DSLR's
  - Can't use any camera – watch for rolling shutter

- Multi-spectral (NDVI): MicaSense Sequoia ($3,500USD)/ RedEdge ($5900)

Other sensors (Expensive & produce more challenging data)

- Hyperspectral:
  - Headwall Nano ~ $53K AUD (~$5-$8K quadcopter to fly it)
  - *Line scanner (~800 bands)*
  - Spectra: ~400 – 1000nm
- Thermal: ~750 – 1300nm

Sequoia NDVI

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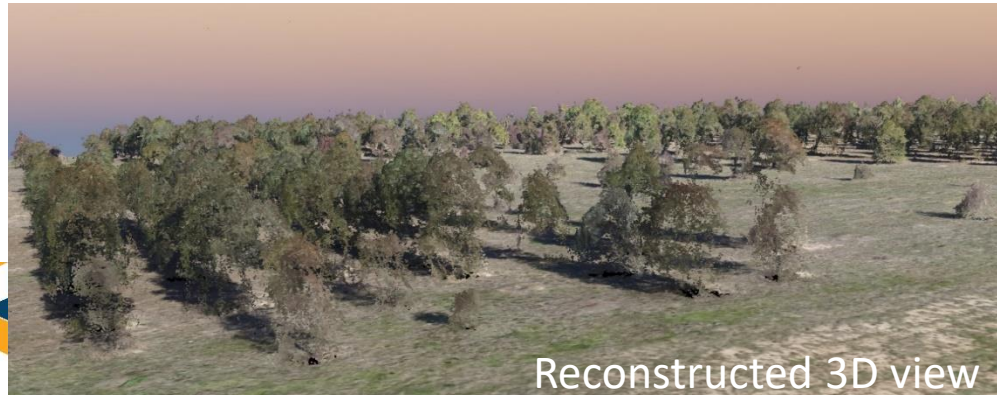
3D reconstruction software

Typical outputs:

- Orthomosaic images /map layers (google maps, mapbox, etc)
- DEM/Geotiffs
- (semi) classified outputs (i.e. ground removal for trees)
- RGB, multispectral and NDVI indices
- 3D point clouds
- Meshed 3D models


DJI Inspire @ National Arboretum


Reconstructed 3D view

3D reconstruction software options

- Desktop processing typically requires min. ~ $1500 AUD PC
- Pix4dMapper Pro: ~$2,000USD (academic); $8,700USD commercial (or $3500/yr)
  - Academic ~$1,000E/yr support license required after first year (2016 cost)
  - Windows only
  - Pro license required to automate or run on linux server or cloud (e.g. amazon)
- Agisoft photoscan ($60 - $550 USD - Academic)
  - Windows, Mac OS X, Debian/Ubuntu
  - (Python) scripting possible in Pro version and cloud
- Mosaic Mill RapidTerrain (~ € 4,500 [2013 pricing])
- VisualFSM - Free; Win/Mac/Linux; Scriptable

(more on 3D reconstruction later)

Online Options (Great for testing; smaller areas or occasional flights; low costs for single flights; fast processing)

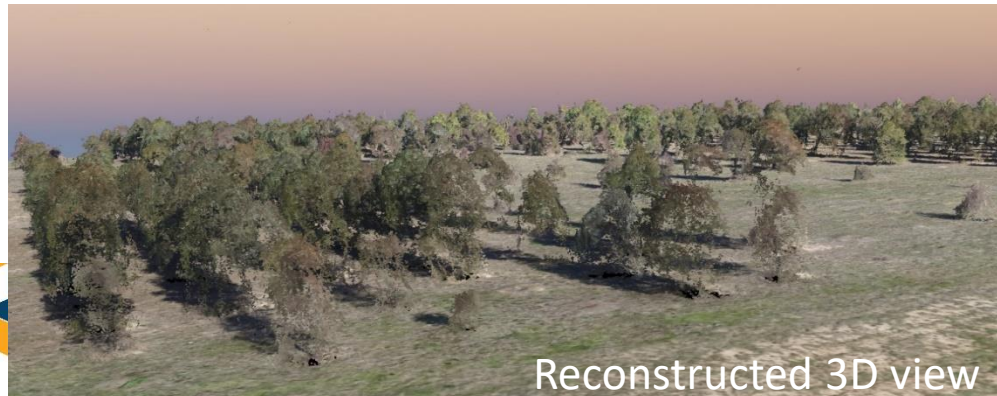
- https://www.skycatch.com/
- https://dronemapper.com/
- https://www.dronedeploy.com

Disclaimer

- *This is not a complete list!*
- *Prices vary by features &*

change frequently – check vendors for current pricing

DJI Inspire @ National Arboretum



Reconstructed 3D view

Putting all the tools together:
National Arboretum Phenomic & Environmental Sensor Array

National Arboretum, Canberra, Australia

Collaboration with Cris Brack, Albert Van Dijk (ANU Fenner school); Borevitz Lab

- Ideal location
  - 5km from ANU (64 Mbps Wi-Fi) and near many research institutions
- Great site for testing experimental monitoring systems prior to more remote deployments
- Forest is only ~7 yrs. old
  - Chance to monitor it from birth into the future!

National Arboretum Sensor Array

- 20-node Wireless mesh sensor network (10min sample interval)
  - Temp, Humidity
  - Sunlight (PAR)
  - Soil Temp and moisture @ 20cm depth
  - uM resolution dendrometers on 20 trees
- Campbell weather stations (baseline data for verification)

Environment

- Two Gigapixel timelapse cameras:
  - Leaf/growth phenology for > 1,000 trees
- LIDAR: DWEL / Zebedee
- UAV overflights (~monthly)
  - Georectified image layers
  - High resolution DEM
  - 3D point cloud of site in time-series

2017: Hyperspectral and Thermal PTZ

Phenotype

- Sequence tree genomes

Genetics

Arboretum Video

https://www.youtube.com/watch?v=YanOqSIW7yE

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ANU research forest drone monitoring

- Goals
  - Test and develop time-series drone monitoring program

  Outputs:
  - Time-series of
    - Georectified image layers
    - High resolution 3D point cloud
    - Phenotypes:
      - Tree height
      - “Area”
      - Color data

- Forest stats:
  - 12 forests of Spotted gum *C. maculata* & Iron Bark (*Euc. Tricarpa*)
  - Planted ~ 2012
  - ~ 4 Hectares

We've come a long way

April 2013
Cell phone duct taped
To my home made drone

March 2017
Darrell Burkey (ProUAV)
Matrice 600 Pro
16MP camera & Sequoia multispec camera

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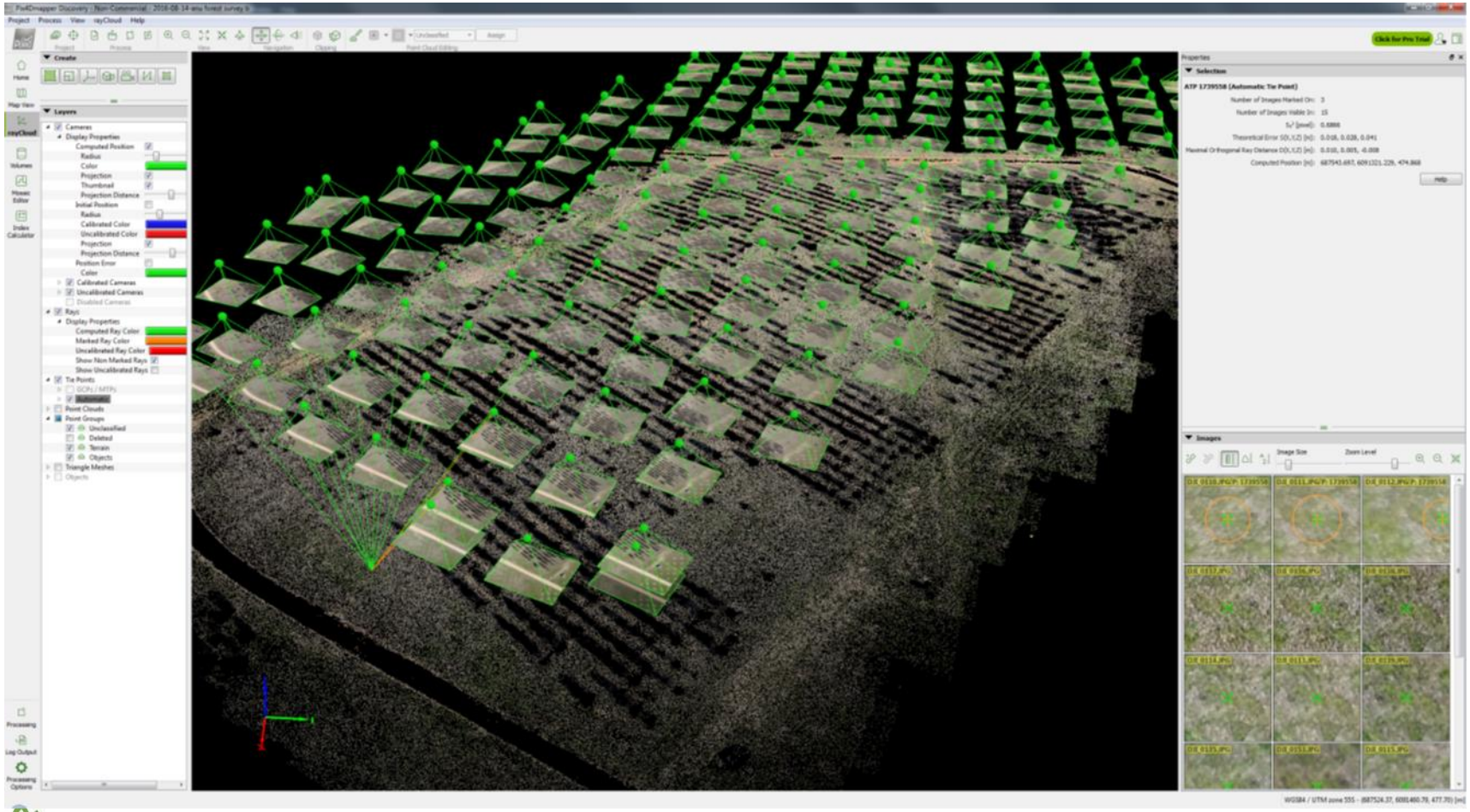
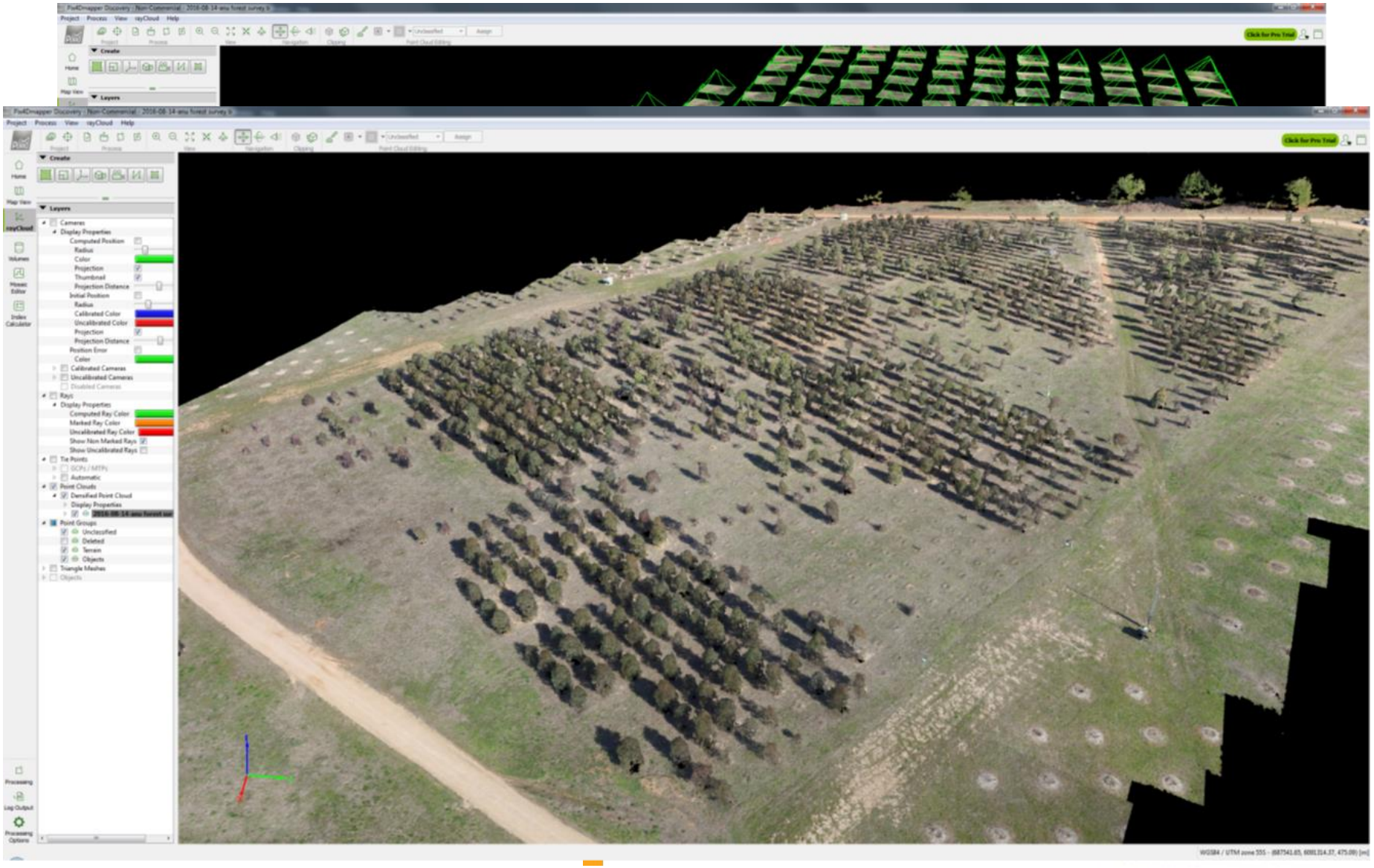
Workflow – Pix4D

1. Detect aerial position of every image
2. Calculate matching “control points” in overlapping images



Workflow – Pix4D

- Create 3D “point cloud”

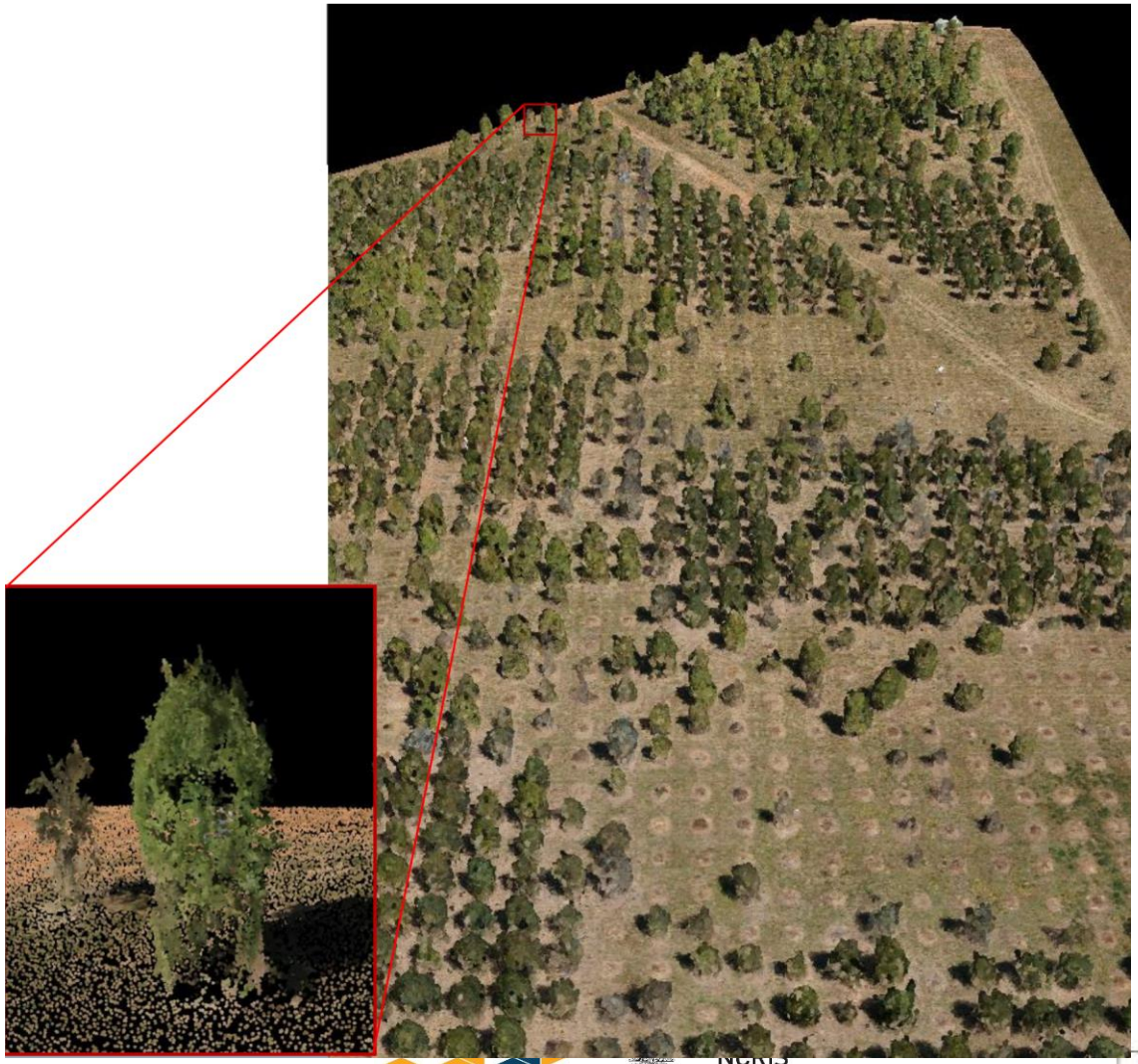


Workflow – Pix4D

- Total processing time is very hardware dependent (<3 to >12hrs)

Workflow – Pix4D

Point clouds to trees

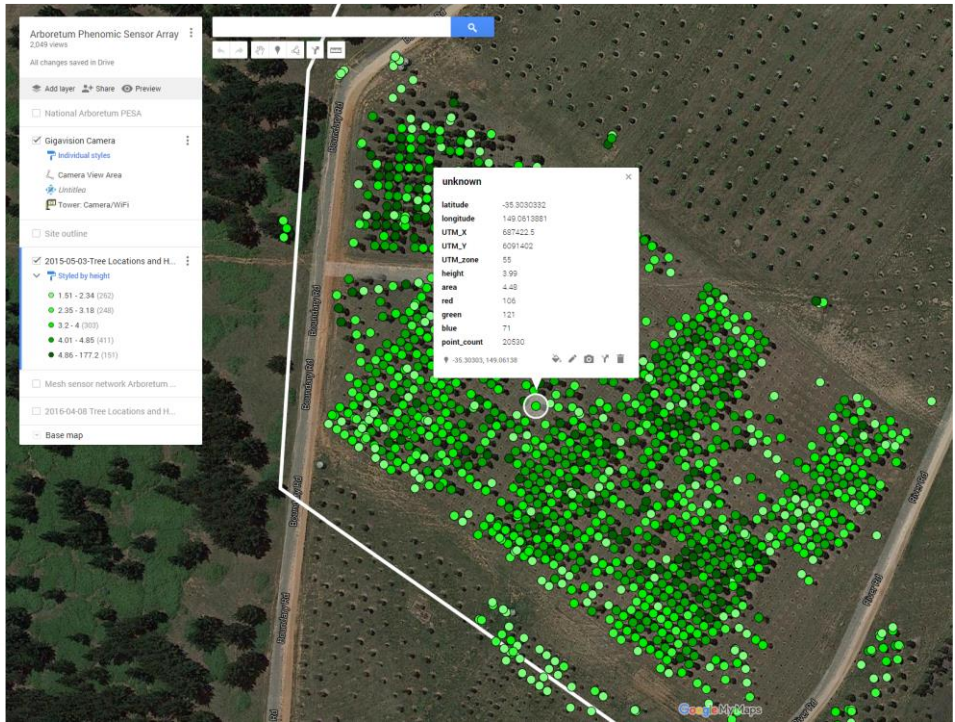


Forestutils – Point clouds to trees

20min drone flight (~200 images) + 3hrs processing (pix4d) => 3D forest

3D Point clouds online: http://traitcapture.org/pointclouds

- Forestutils software (Tim Brown, Zac Hattfield-dodds) https://pypi.python.org/pypi/forestutils
- Group pixels per tree
  - Assumes open canopy (until tree locations are known)
- Output:
  - Tree height, top-down area, location, RGB colors, “point count”
  - CSV of tree data -> google maps online



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Data management

- Decide on your data management plan BEORE you start surveys
- Consider the entire workflow
  - Who will do the surveys
  - If more than one person or airframe, how does the data get to you
  - What then?
  - How do you name things?
  - If people are uploading data, how do you assure it all made it?
  - If you have to duplicate projects (i.e. move to a processing computer or SSD) – how do you track this and name things?
  - *Best to enforce rigorous note taking – shared gdocs and notepad++ are handy*

anu.edu.au) (X:) › _NationalArboretum › mapping › _UAV ›

Name	Date modified	Type	Size
_SORT-From Tim Laptop			
2015-02-03-nac-anuf-tim			
2015-02-09-nac-anuf-prouav-DU			
2015-02-13 UAV demo			
2015-02-25-nac-anuf-tim			
2015-03-11-nac-anuf-tim			
2015-03-11-nac-anuf-tim-DU-copied back			
2015-05-01-nac-anuf-prouav			
2015-05-03-nac-anuf-prouav			
2015-10-nac-all-ir-aerial_image_works			
2015-12-03-nac-anuf-prouav			
2015-12-12-nac-anuf-prouav			
2016-04-08-nac-anuf-prouav			
2016-08-14-nac-anuf-prouav			
2016-08-14-nac-anuf-prouav-DU			
2016-10-27-nac-anuf-tim			
2016-12-03-nac-anuf-prouav			
2017-02-17-nac-all-prouav	5/6/2017 2:38 PM	File folder	
2017-03-15-nac-all-prouav (sequoia)	5/6/2017 2:38 PM	File folder	
2017-03-16-nac-all-prouav-currently processing	6/14/2017 11:09 AM	File folder	
2017-04-30-nac-anuf-tim-PSU	5/6/2017 2:38 PM	File folder	
2015-04-16 UAV survey GPS control points	5/4/2015 4:29 PM	KMZ File	41,411 KB
2015-05-03-ProUAV-NationalArboretum	11/13/2016 5:48 PM	Compressed (zipp...	1,523,154 KB
NationalArboretumANUForest-Quad-2016-08-14-A	8/18/2016 3:50 PM	Compressed (zipp...	1,002,236 KB
Pix4D parameter notes	5/12/2015 8:40 AM	TXT File	2 KB

yyyy-mm-mm-location-site-whocaptured-status

- Nac = National Arboretum Canberra
- anuf = ANU Forest plot
- Tim = I captured it
- DU = Done and uploaded

<u>But these filenames are too long for windows!</u>

Other options

- Readme files – but you need to maintain them
- Shared google docs are good

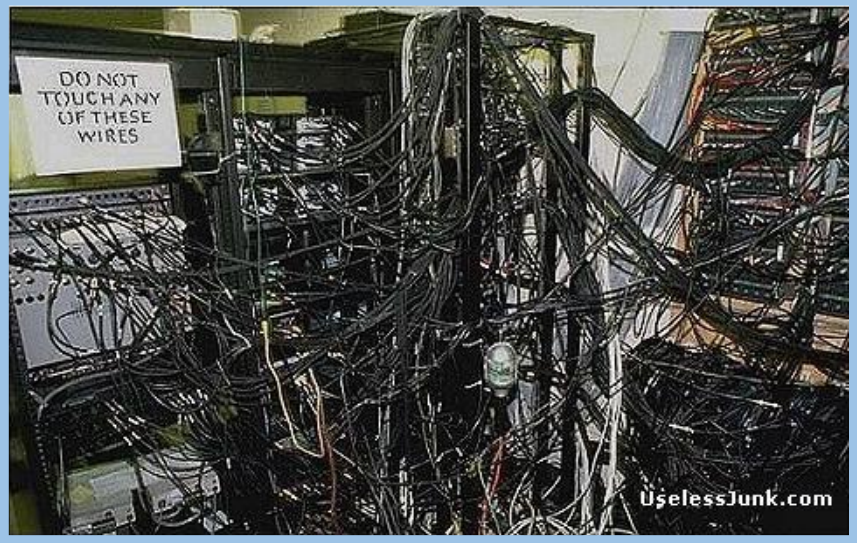
Australian Plant Phenomic

Data management

- Don’t panic! - this is not easy for anyone
- You won’t get things right the first time, just keep working at it, <u>but don’t wait too long to fix things</u>

Data Management

VISION



Reality

Some challenges with drone data

- Processing settings and ground truthing
  - Much of this data has never been collected before – how do we know what we are measuring and tie data values to biologically meaningful things
  - How do you ground-truth a 3D point cloud of a tree?
  - Different settings produce very different outputs, what do they mean?
  - And outputs change with each software update!

Table: Outputs from various Pix4D settings using the same initial images

Time for Point Cloud Densification	16m:11s	16m:12s	16m:10s	16m:36s	05m:42s	05m:45s	14m:59s	**05m:25s**	**55m:08s**	43m:15s	42m:38s	43m:33s	14m:14s
Number of 3D Densified Points	11,754,319	11742976	11805987	11780055	2826949	3032111	8736144	2824205	44,070,407	44011684	43718764	43932956	11727714
Average Density per m	1000.17	993.56	1022.85	1020.6	311.48	318.51	999.33	301.44	2016.22	1967.43	1818.92	1879.37	953.39

Choosing the right tool for the job

- Drones (particularly for point clouds) are best suited for smaller areas (<20Hectares).
- Example – Full arboretum survey - 250 Hectares
  - Many week planning
  - 4 flight days
    - Requires multiple staff on site and 5-10 volunteers
  - 8,800 RGB images
  - >12,000 Sequoia images
  - Outputs
    - 2months manual processing (couldn't run on any machines)
    - Point cloud: 584 million points
- Consider weather, distance to site, accessibility, time of day, etc.
  - Sometimes a camera is a better option; or satellite!
- Also, if you have a lot of sites it may be cheaper to hire a helicopter or plane…

The full arboretum point cloud

- Download here: https://traitcapture.org/pointclouds/by-id/59363e0fb43fdd50b9c08395 (or go to traitcapture.org/pointclouds)

Choose the right tool for the job

	Manned aerial surveys	UAS surveys
Notes 1. Surveys were conducted by the National Oceanic and Atmospheric Administration.		
Purpose of surveys	Estimate the abundance of Steller sea lions in the inner Aleutians	Estimate the abundance of Steller sea lions in the outer Aleutians
Cost per day	$4700 per day including fuel and pilot, or ***$400 per site***	$3000 per day based on the cost of vessel support, or ***$1700 per site***
Type of aircraft	NOAA Twin Otter	APH-22 hexacopter
Distance/area surveyed	***2500 km of coastline***, including the Gulf of Alaska and part of Aleutians; ***210 sites surveyed***	***400 km of coastline*** along the western Aleutian chain, ***30 sites surveyed;*** maximum distance from the vessel was 634 m, longest flight was 16 minutes

Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. Front Ecol Environ 2016; 14(5): 241–251, doi:10.1002/fee.1281

The future…

- Self driving drone swarms – fly your forest or field daily
  - All data uploaded and processed in the cloud
  - Near realtime analytics and reporting to the end user
- Xaircraft.cn and revolutionag.com.au

Super future

- Micro drones may be more feasible and safer

Developing a drone program

Drones and sensors are a crucial component for field monitoring and phenotyping but launching a good drone program is hard

- Lots of technologies available so it is important to focus on deliverables:
  - Who are your stakeholders / “customers”
  - What do they need to know? - What would be “actionable information” for them
- Working back from the deliverables, what is required?
  - Make sure to do full costing: Hardware is pretty cheap but this isn’t the full cost
  - How big is the area to cover? If multiple areas, how far apart are they?
  - How frequently do you need to survey?
  - If using custom or expensive hardware – does it work? What are the processing pipelines? Is it insured? Repairable?
  - What is the weather like; what other access or similar issues might you have
  - Don’t forget the details: Basics like disk space (both in the field and lab) and battery charging are very important
- Start small and get your pipeline <u>working</u> and <u>documented</u> before doing larger projects
  - Make checklists and data flows
  - Do some dry runs before scaling up
- UAV hardware
  - Is a UAV the correct tech? If so, which one?
  - Do you buy your our own hardware or just subcontract?
- Processing data:
  - Outsource or do it yourself?
  - If you need to develop novel tools, can you collaborate with groups? Share it with others?
- Data management
  - Don’t underestimate how hard this is
  - Have a data management plan in place at the start

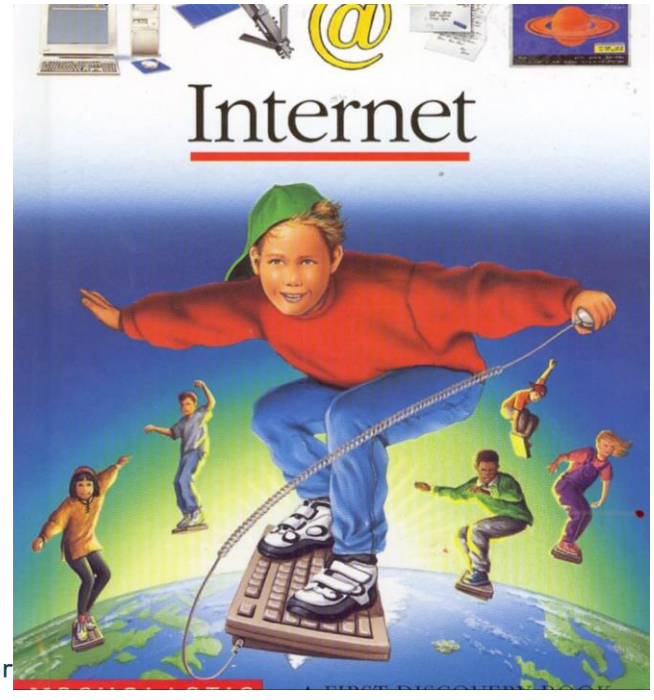
Future Vision

- Data standards and open data are very important
- Imagine what we could do with a searchable system that pulled from every drone flights, field trial and data layer we had and then all those available internationally
- Cross-global integrated search (https://search.descarteslabs.com/)
  - This is for image patterns, but it could just as well be for any *GxExP* indices we can come up with measure
  - This requires:
    - Open data
    - Open standards and open code
    - Very aggressive pursuit of collaborations and building networks with other national-scale monitoring networks to develop open data standards and interoperable web-services globally

The Future – NexGen visualization

"OK, so we have all this data, now how do we see it?"

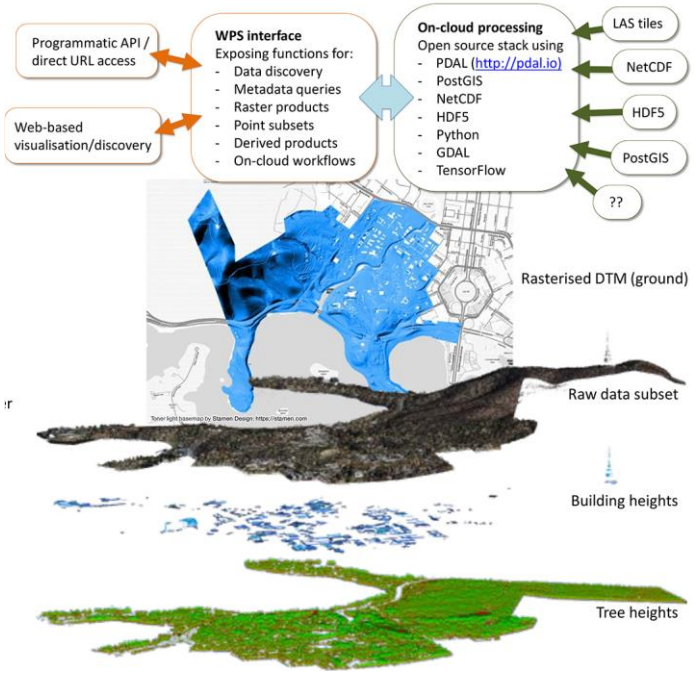
- Our current tools for data visualization and management (e.g. Excel, Matlab, R, GIS) aren't sufficient for Phenomics datasets
- Phenomics / HTP data is
  - Time-series
  - Geospatial and 3D
  - Highly varied: pixels, numeric timeseries, point clouds, hyperspectral, genetics
  - Highly dense: 100s' – 1000s of data layers / pixel / leaf
- Human insight is amazing but only if your data is in a format that lets you think about it clearly
- Many of the current challenges in HTP derive from lack of tools that lets us best use this data



Point cloud viewing tools in development

Ajay Limaye (developer of Drishti) @ NCI VisLab:

- Timelapse co-located pointcloud viewer: Windows and in VR
  - Visualize time-series point clouds of any type in any resolution
  - Co-visualization of many datasets if GPS is correct
- Adam Steer et al – Realtime Point cloud viewing online via OGC and open source software stack



See: *Steer, Adam, et al. "An open, interoperable, transdisciplinary approach to a point cloud data service using OGC standards and open source software." EGU Vol. 19. 2017.*

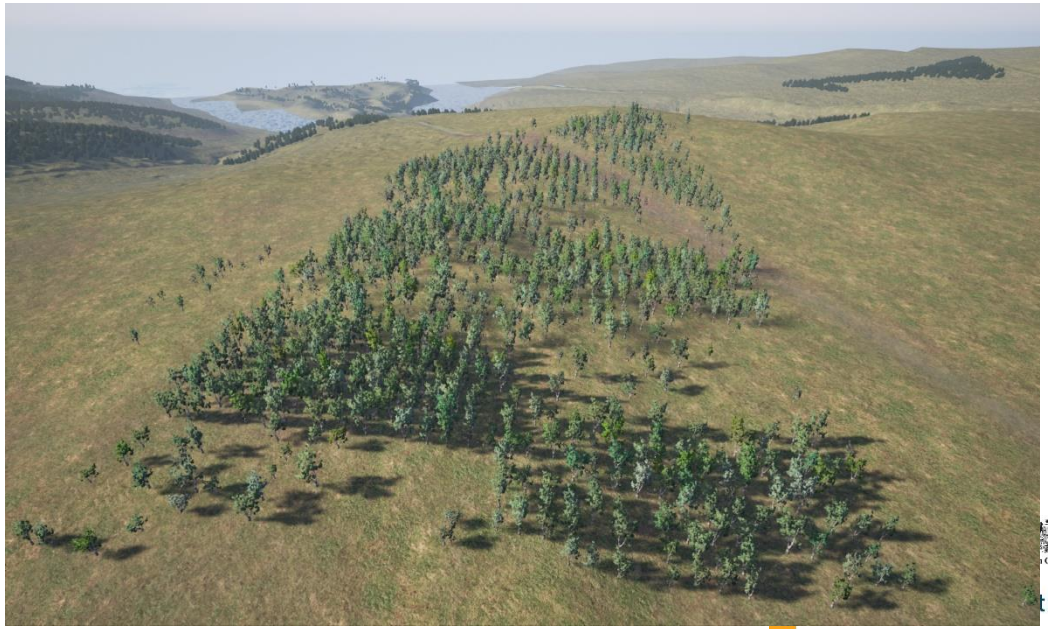
http://pointclouds.nci.org.au/pointwps.howto.html

NCI
NATIONAL COMPUTATIONAL INFRASTRUCTURE

EcoVR: Virtual 3D Ecosystems Project
GIS for 3D “time-series data”

Goal: Use modern gaming software to explore new methods for visualizing time-series environmental data

- Collaboration with
  - ANU Computer Science Dept. TechLauncher students
  - Stuart Ramsden & Ayjay Limaye, ANU VISlab
- Historic and real-time data layers integrated into persistent 3D model of the national arboretum in the Unreal gaming engine
- Visualize any field site with GPS and time-series data



UNREAL ENGINE

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Future-Tech

Virtual Reality (VR) and Augmented Reality (AR)

- Virtual Reality (VR) and Augmented Reality (AR) will radically change how we interact with our data
- VR (Oculus, VIVE, etc): View your field site virtually
- AR/MR (Hololens, Magic Leap): Add virtual content to the real world = view your field site on your desk & view data on your plants in the field
  - Magic Leap:
    - Est. value 2015: $500M USD; 2016: $4.5 billion; 2017: $8 Billion

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Search: "Magic Leap Wired"

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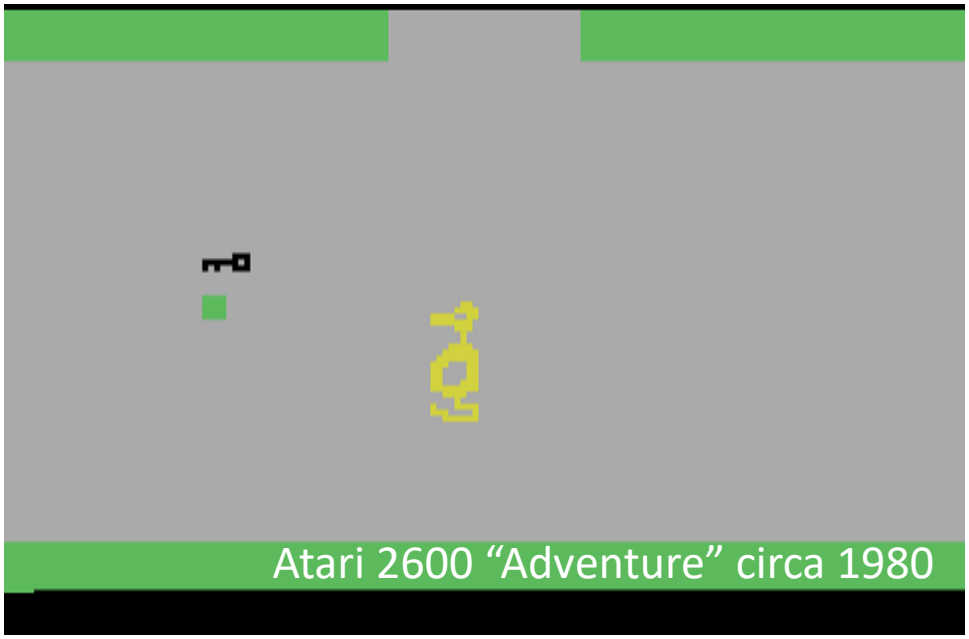
Gaming and animation software for data visualization

- Hollywood and the gaming industry have spent billions of dollars creating tools for generating realistic environments
- We can use these tools for data visualization
- Houdini software:

https://www.youtube.com/watch?v=R_8YHsvN9t4

This is just the beginning



We are at the “ATARI” stage in VR

Our ability to measure the world continuously in 3D has just started

In 10 years, VR/AR will be indistinguishable from reality.

What will we do with these tools?

How will we create the new interfaces that enable the next generation of ecosystem research

Thanks and Contacts

Justin Borevitz – Lab Leader Lab web page: http://borevitzlab.anu.edu.au

Code: **http://github.com/borevitzlab**

- Funding:
  - APPF / NCRIS
  - ARC Center of Excellence in Planet Energy Biology | ARC Linkage 2014
  - Arboretum ANU Major Equipment Grant: 2014, 2016

- TraitCapture:
  - ***Gareth Dunstone***
  - *Sarah Namin*
  - *Mohammad Esmaeilzadeh*
  - *Chuong Nguyen; Joel Granados; Kevin Murray; Jiri Fajkus*
  - *Jordan Braiuka*
  - *Pip Wilson; Keng Rugrat; Borevitz Lab*
- Arboretum
  - http://bit.ly/PESA2014
  - **Ellen Levingston (drone data processing)**
  - Cris Brack, Albert VanDijk, Justin Borevitz (PESA Project PI's)
  - UAV data: Darrell Burkey, ProUAV
  - 3D site modelling: Pix4D.com / Zac Hatfield Dodds / ANUVR team
  - Dendrometers & site infrastructure" Darius Culvenor: *Environmental Sensing Syste*
  - Mesh sensors: EnviroStatus, Alberta, CA
  - *Gigavision: Jack Adamson*
- ANUVR Team
  - Yuhao Lui, Zhuoqi Qui, Abishek Kookana, Andrew Kock, Thomas Urwin [2016/17 Team]
  - Zena Wolba; Alex Alex Jansons; Isobel Stobo; David Wai [2015/16 Team]

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Australian Government
Australian Research Council

PIX4D

ProUAV AUSTRALIA
Aerial Photographic Services

heliospectra

Photon Systems Instruments