Intelligent Sensing Devices in Real World Applications

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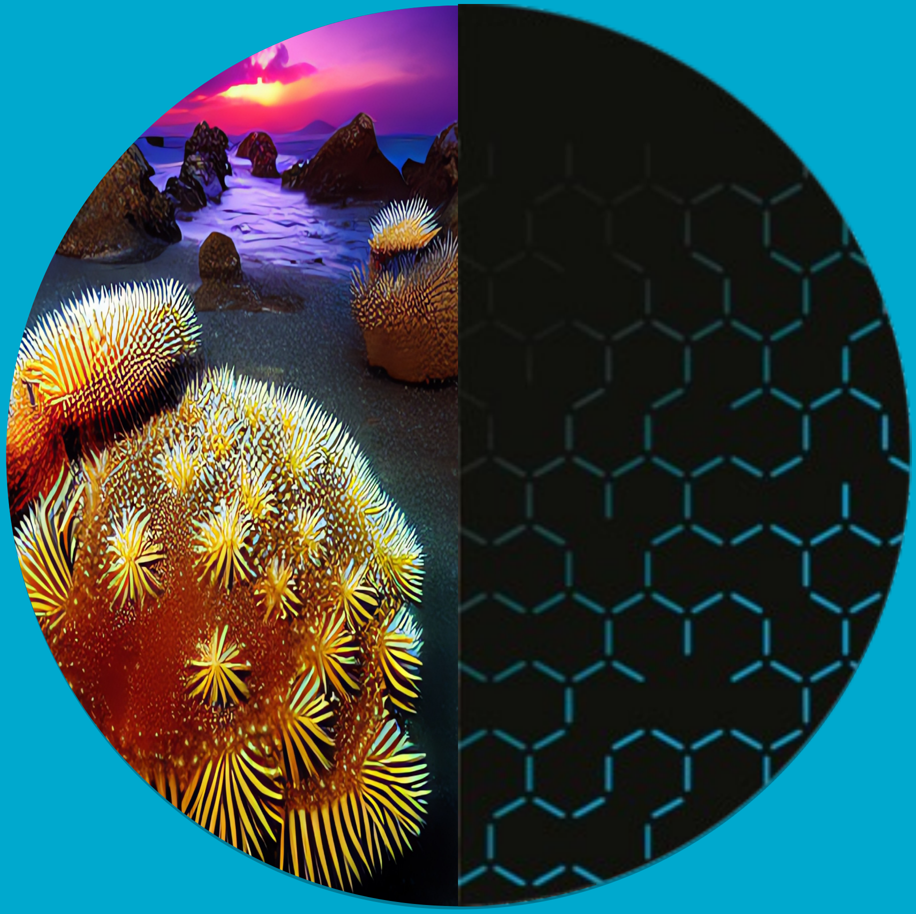
| 24-Jul-2023

Australia's National Science Agency



My Research Group: Distributed Sensing Systems

Building distributed systems consisting of small, low-power nodes capable of sensing, processing, and wireless communications

Capability

- Broad IoT technology expertise
  - IoT hardware and software, cloud, digital twins
  - IoT data analytics and models
- Applied Real-world R&D: testbeds, field work
- R&D Focus
  - Intelligence: on-device analytics/ML
  - Interactive methods: user/AI co-learning
  - Scalability and sustainability

Application Domains

- ***Agriculture***: livestock management, yield forecasting
- ***Biodiversity, biosecurity***: species detection/classification
- ***Energy***: building systems, control
- ***Terrestrial***: water management, animal-born diseases
- ***Oceans***: broadscale coastal surveys, digital aquaculture

Environmental/societal Impact

Micro-climate
Springbrook NP
Boorroowa

Wildlife
Flying foxes
Feral buffalos

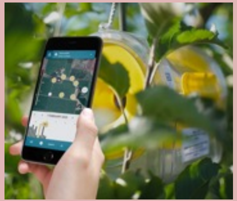
Ecological Surveys
Crown of Thorns,
Blue Carbon

Landscape Digital Twins
Basin Futures,
Wheatcast

Commercial Impact

CERES TAG

RapidAIM

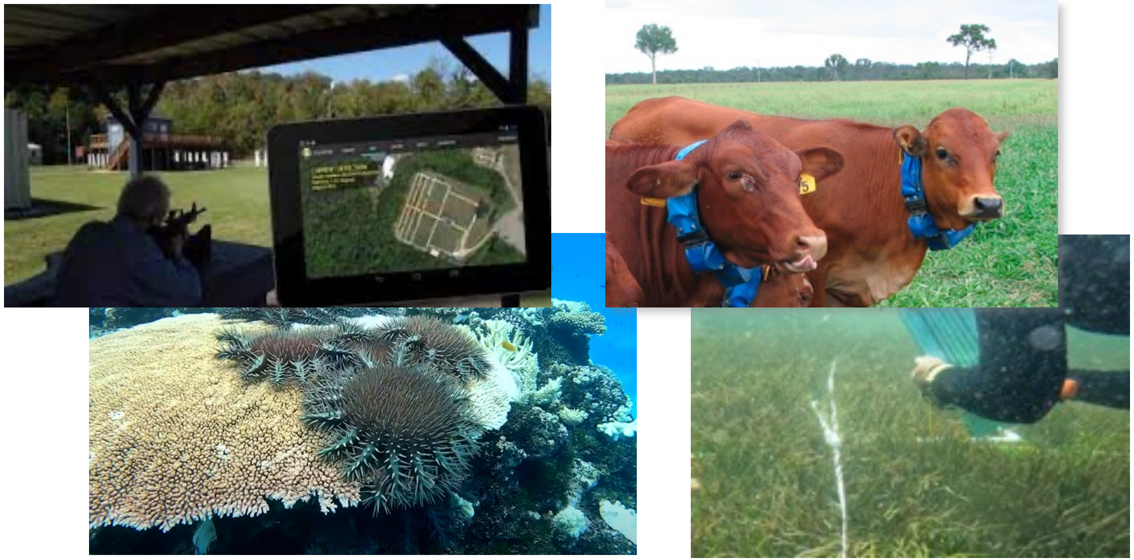


YNOMIA

What is This Lecture About?

Show you examples of real-world research impact of IoT technology.
Increasingly AI plays an important role, but not without challenges.

Quick Knowledge Review



Use-case Studies

Edge Computing vs Edge AI

IoT

IoT – network of physical objects or “things” embedded with sensors and software

Not just phones, tablets: vehicles, home appliances, machinery, …

Make our devices smarter through connectivity and ML: help us make smart decisions, automate tasks

Edge Computing

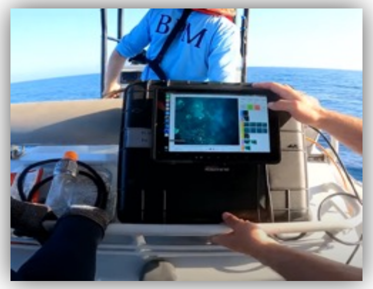
Distributed computing paradigm where data and compute are located close to data source. Sensor networks and IoT are an instance of edge computing

Benefits

Faster Response, Energy Efficiency, Scalable, Secure

Challenges

Interaction with users, Compute constraints, Unknown operating conditions / domain-shift



Edge AI

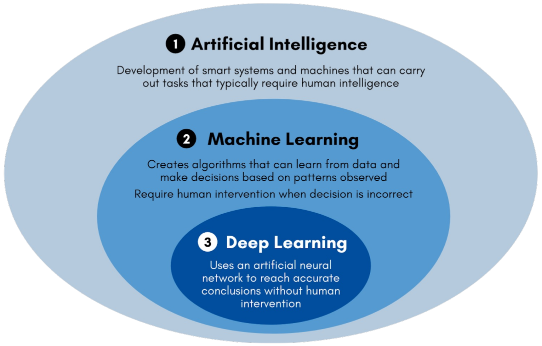
Compute efficient machine learning algorithms and compute/hardware to accelerate ML ops.

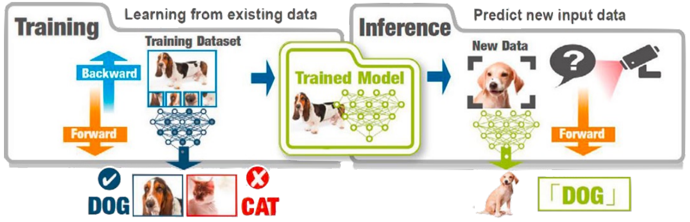
Xavier - 30W

Coral - 5W

NRF52 – 6mW

Machine learning





Artificial Intelligence (AI):

- Creating machines and software capable of intelligent behavior
- Two general methods
  - Machine learning – learn from experience, make decisions and predictions based ***on data***
  - Knowledge Engineering – follow predefined rules and logic

Training:

- Understand patterns on input data, requires labels
- Adjust internal parameters to minimize prediction error

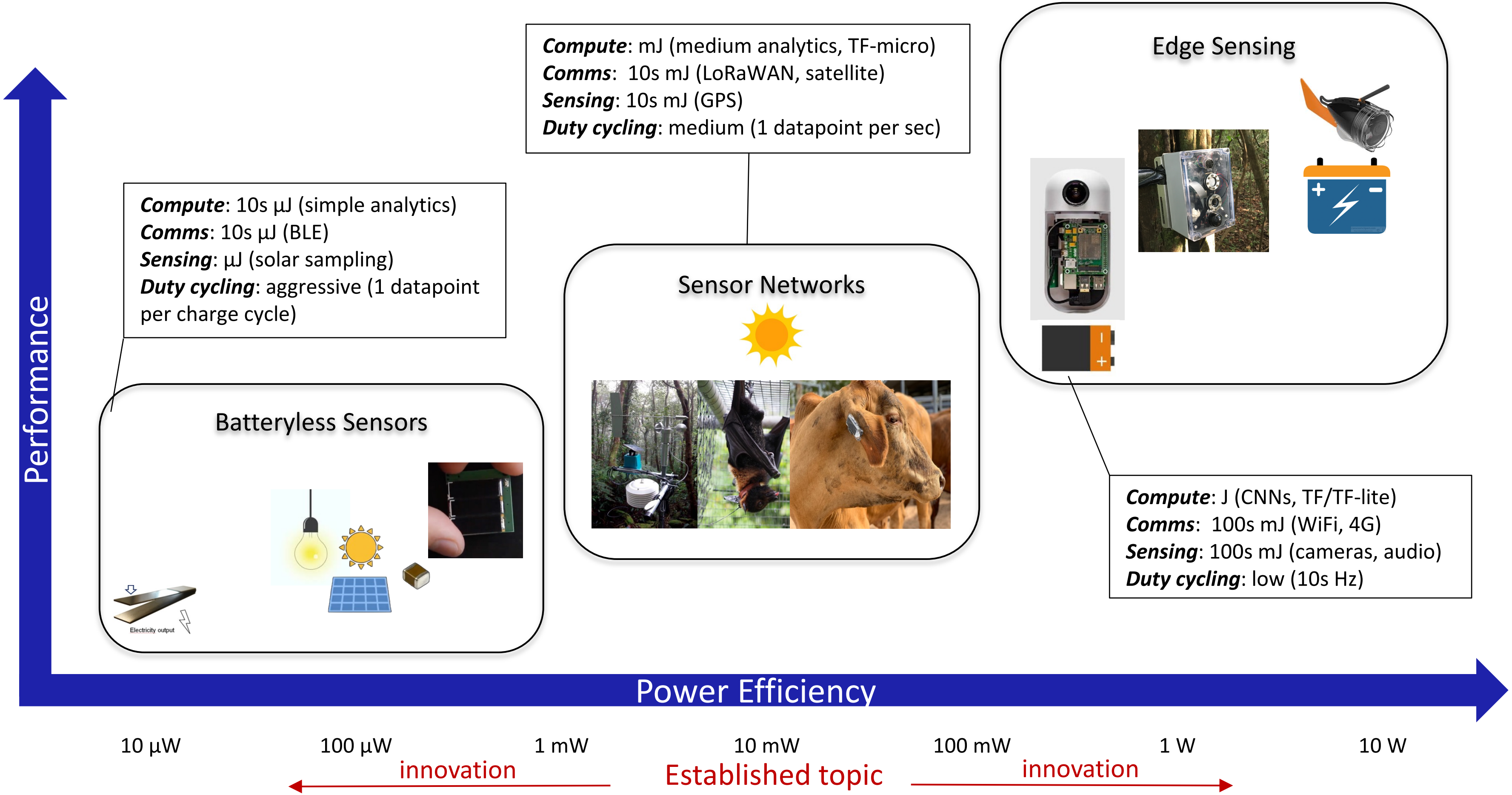
Inference:

- Trained model makes predictions on new data

Domain Shift:

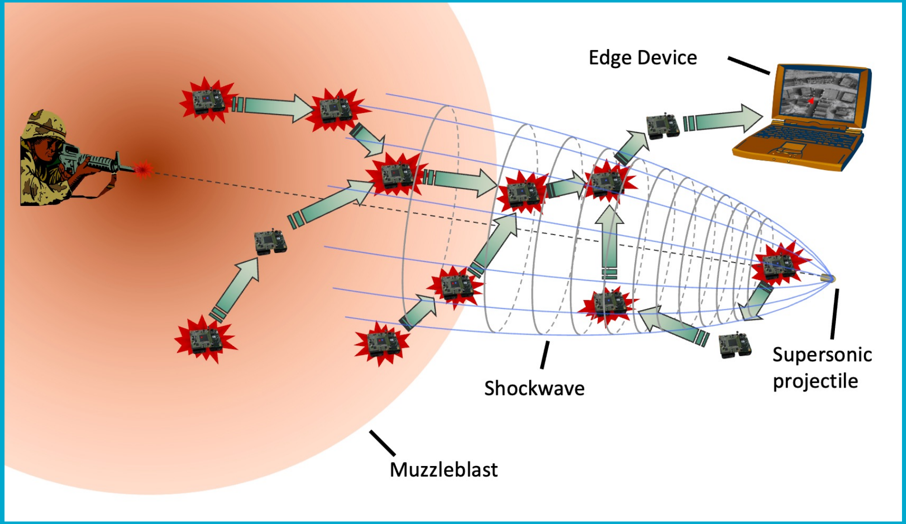
- A major challenge in machine learning
- Occurs when the distribution of data changes between the training and the inference phase
- E.g., Change in lighting condition, change of camera parameters, …

Different Types of Embedded Systems



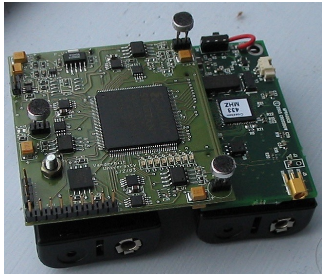
Case Study

Shooter Localization System



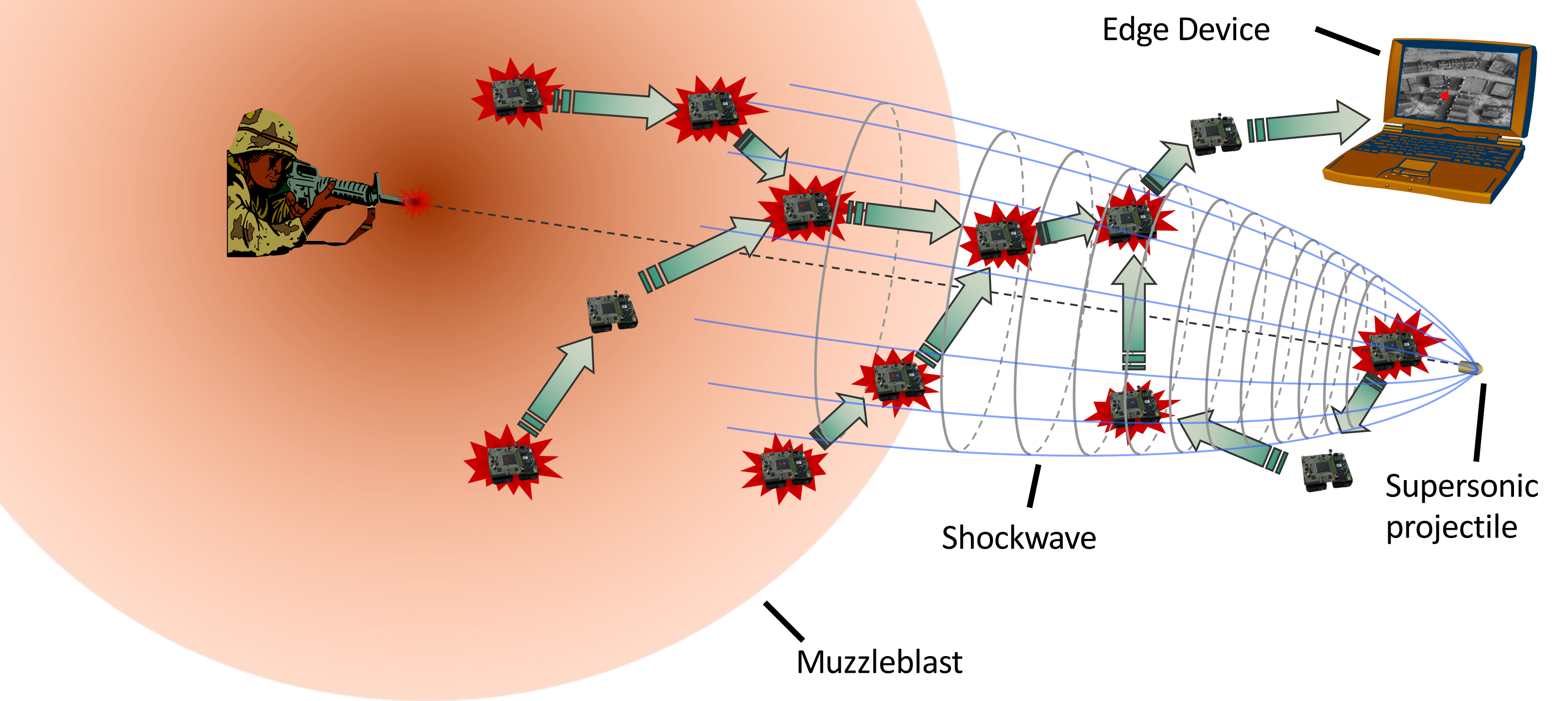
Case Study: Shooter Location System

- Task:
  - Localize a shooter in urban environment in real time
  - Hard problem due to multipath and limited line of sight (shots inside buildings, behind cars, …)
- Deployment:
  - 60 acoustic sensors covering 100x40m
  - Ft. Benning, GA, USA
- Performance (in 2005):
  - 1m (3D), 0.6m (2D), 2 sec latency

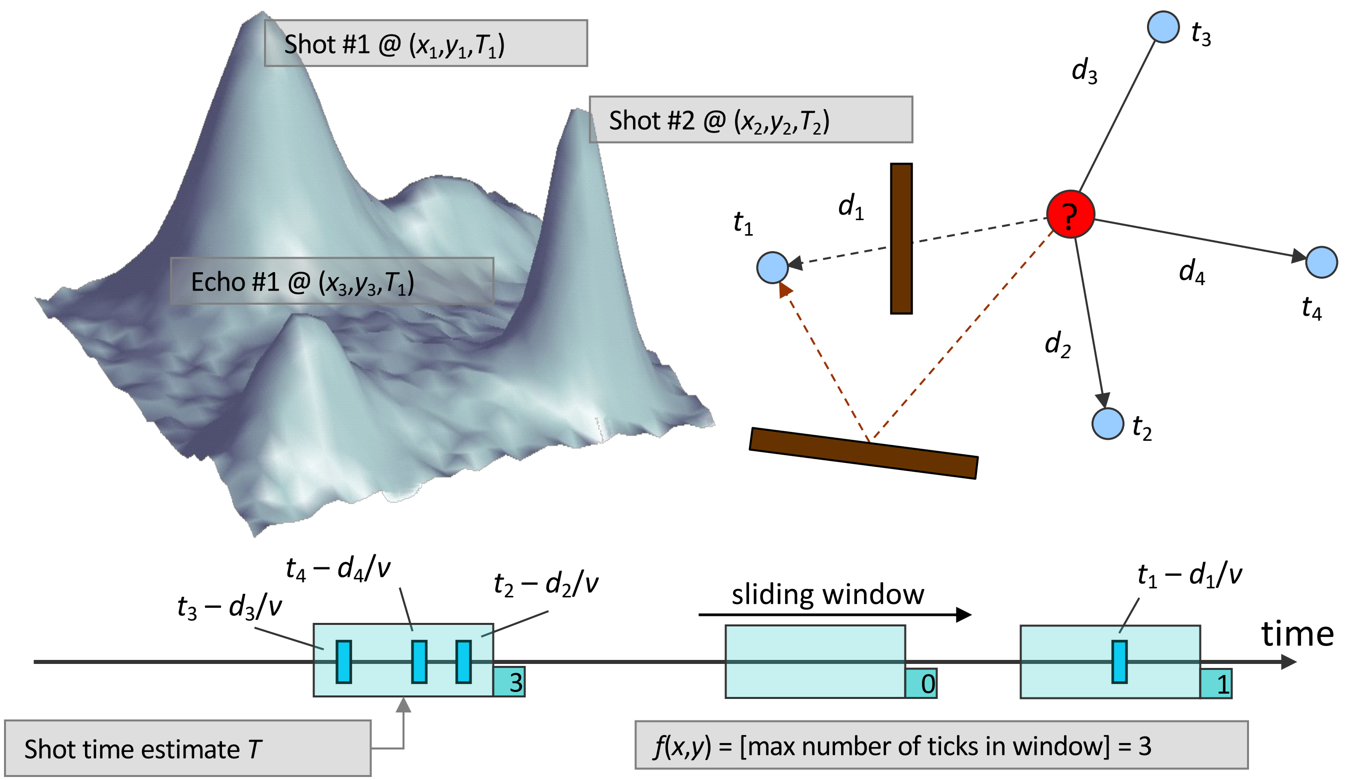


- Acoustic IoT sensors
  - Detect shots and record time and location
  - Proprietary acoustic board for shot detection
- Edge device (laptop + IoT gateway)
  - Data fusion, shot location estimation

Technical Overview



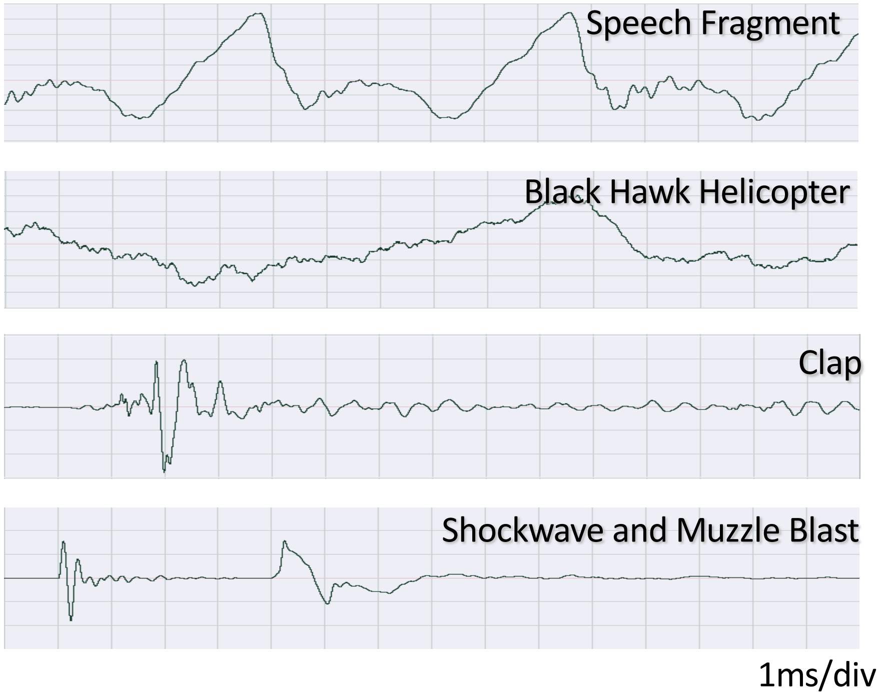
Sensor Fusion



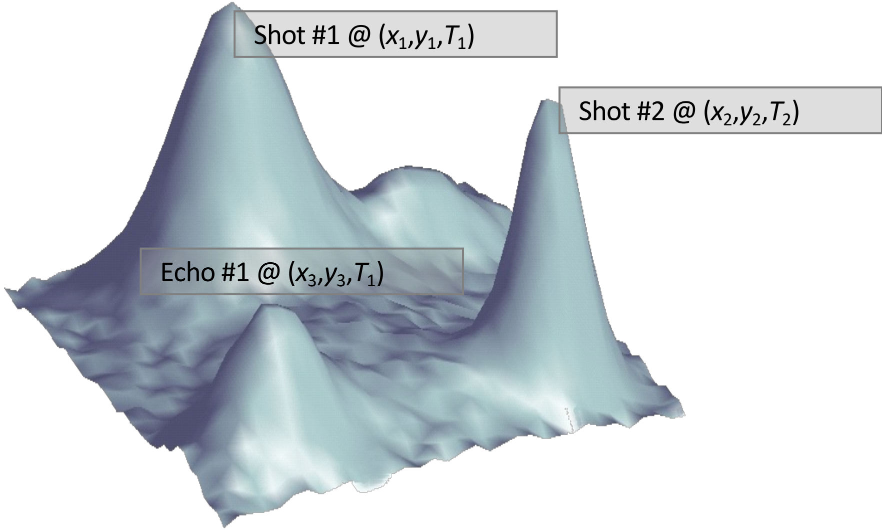
2.5D Display, Single shot

Intelligence/Summary: Mostly Knowledge Engineering

On Device – Shot Classifier



On Edge – Data Fusion



Case Study

Animal Behavior Classification

Australia's National Science Agency

Use Case I: Automated Phenotyping

Task – Automate Genetic Selection in Cattle Industry

- Measure inputs: pasture intake at a location
- Against outputs: weight gain, GHG emissions

Method – Measure Detailed Food Intake

Dry Matter Intake (DMI) = grazing(t) x bite_rate(t) x bite_size(t)

Data

- Collar tags for cattle, deployed for 1 month
- Sensors: 9-axis IMU @50Hz, GPS @1Hz
- Manual annotations: 4 activities, bite rate

Use Case I: Intake Estimation (Shallow Classifier)

Random Forests

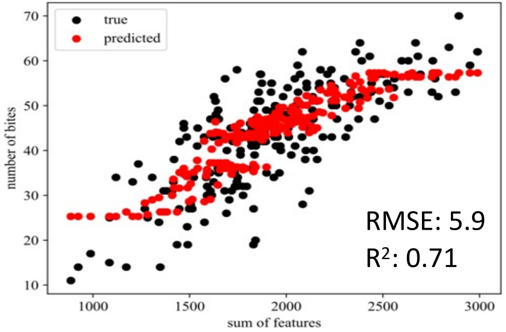
- High accuracy
- Low computation and model's size
- Higher compute required for training

Implementation

- CC2650 (cortex-m3), 48 MHz, 28 KB RAM
- Sklearn-porter (adapted to integer arithm)
- Feature calculation: ~900 CPU cycles
- Inference: ~1000 CPU cycles

=> DUTY CYCLE <0.1%

true \ predicted	grazing	ruminating	resting	other	precision(%)	recall(%)
grazing	2158	5	6	11	95.96	98.97
ruminating	3	679	104	1	84.00	86.28
resting	24	109	840	6	86.34	85.82
other	64	15	23	24	57.12	19.21



RMSE: 5.9
R^2: 0.71

Use-case I: Intake Estimation (Naïve Bayes)

Histogram-based Implementation

- Good accuracy
- Allows online training

Implementation

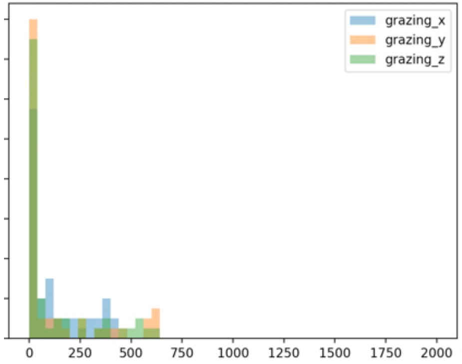
- Model size 600b per class, i.e., 2.5kb total
- Computation (CPU cycles):

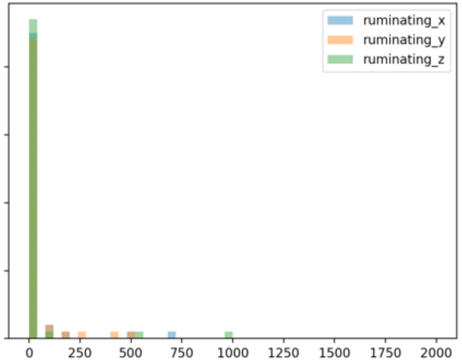
  Inference (float): 5969

  Inference (int32): 4039

  Training (int32): 869

- Error rate: 7.4%, weighted recall: 93%, weighted precision: 93%



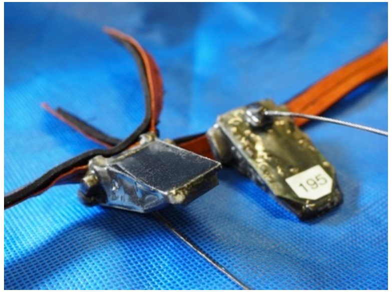


activity	Precision (%)	Recall (%)
grazing	98	99
ruminating	91	92
resting	82	82
other	60	48

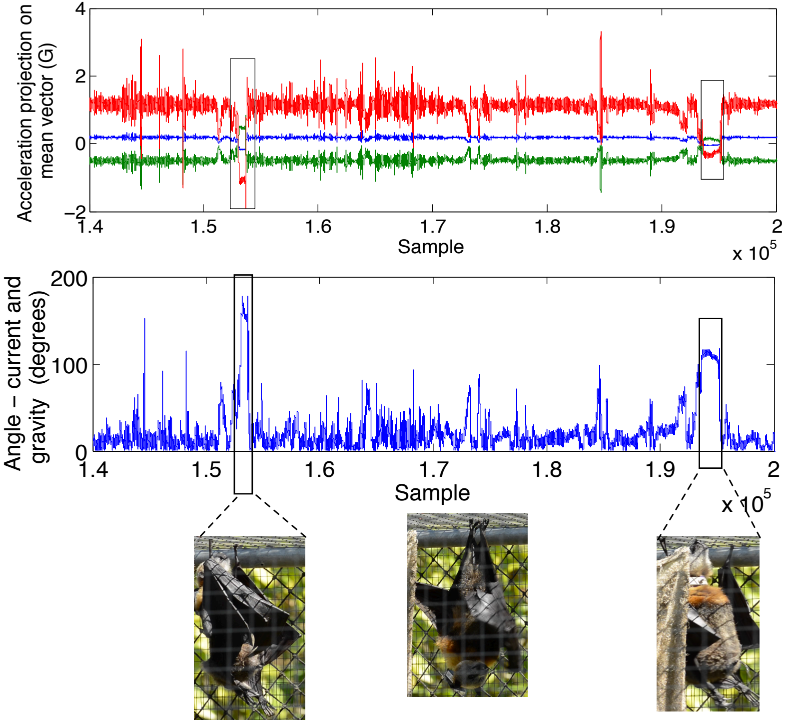
Use Case II: Behavior of Flying Foxes

Hardware Platform Constraints

- Weight limit: 20-30 g (5% of body weight)
- Long-term operation (months to years)
- Delay tolerant networking
- GPS tracking
- Context (inertial, audio, environmental)



On-board 3-axis acceleration sensor

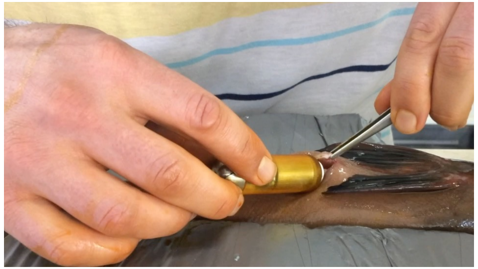


Events of Interest:

- Flying
- Feeding
- Sleeping
- Defecating
- Urinating
- Fighting

R. Jurdak, P. Sommer, B. Kusy, et al. "Multimodal Activity-based GPS Sampling," IPSN/SPOTS 2013.

Use Case III: In-situ Physiology of Coral Trout

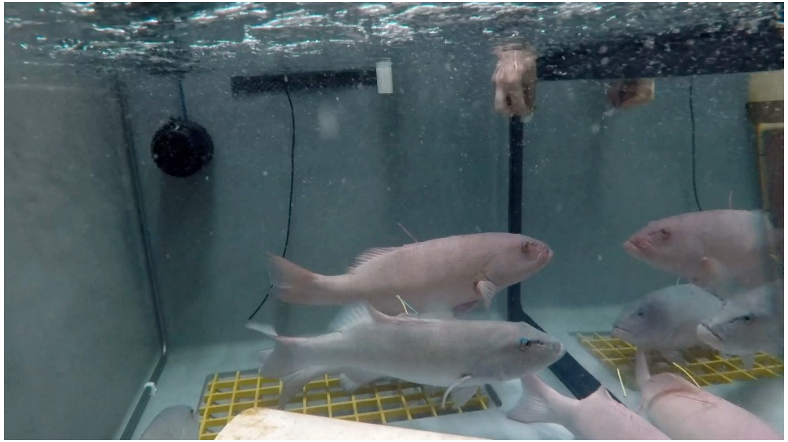


Task

- Health/condition inference – linkage to stressors (climate change, industrial pollution, tourism)

Method – Measure heart rate increase during feeding

Energy consumed=Metabolism/Respiration/Motion + Waste + Growth



Data

- Implanted sensors, deployed for 10 weeks, controlled feeding experiments
- Sensors: ECG and 3-axis ACC @50Hz, Temp/Depth @1Hz
- Manual annotations: collected paper records, video recordings of feeding

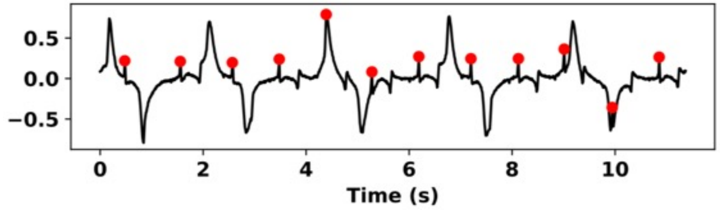
Use Case II: Feeding Classifier for Fish

Fish Feeding and Heart Rate

- Fish is exothermal, increases metabolism to digest food
- Feeding signature is different from fight/flight/etc
- Challenges - biosignals are messy, ECG reflects all motion

Heart Rate

- filtering, ECG peak augmentation/detection
- HR estimation, post-filtering

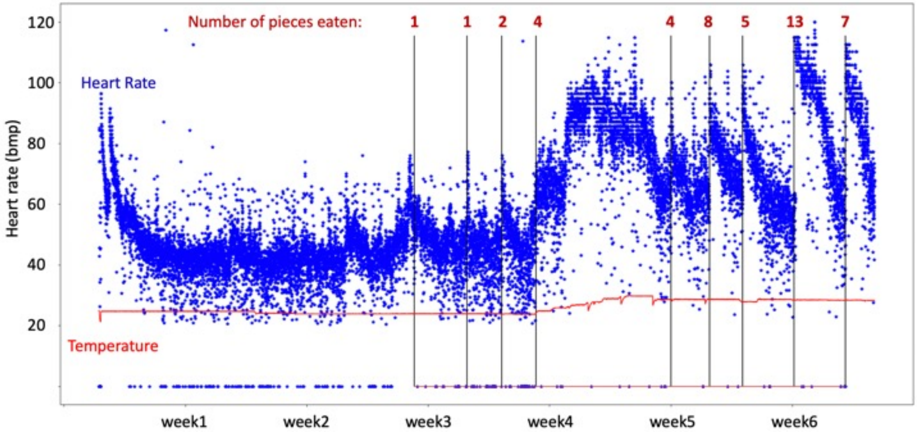


Raw ECG signal

Feeding Classifier

Long-term statistical change detection

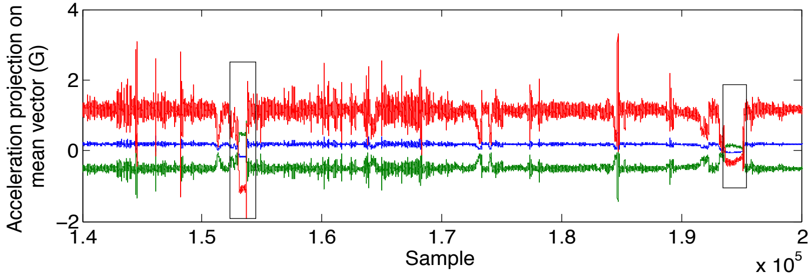
Balanced FPR/FNR of 23%, accuracy 77%

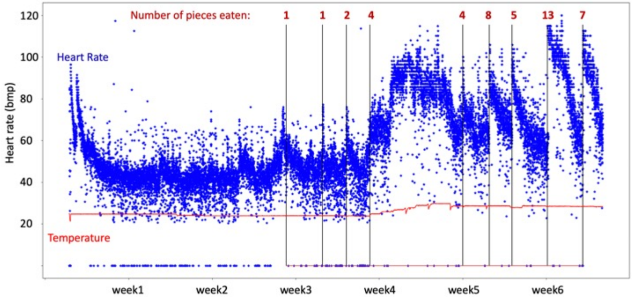


Heart Rate, temperature, and feeding events

Intelligence/Summary: Combination of Knowledge Engineering and Machine Learning

Features are Hand-Engineered

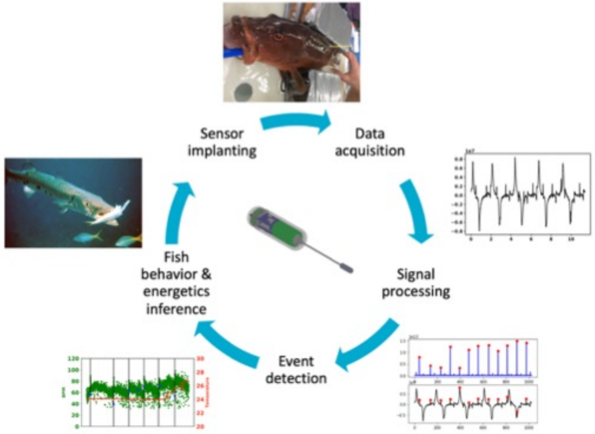




ML – Classification Algorithms

LiDAR LiDAR (Filtered) RGB Camera Accelerometer GNSS

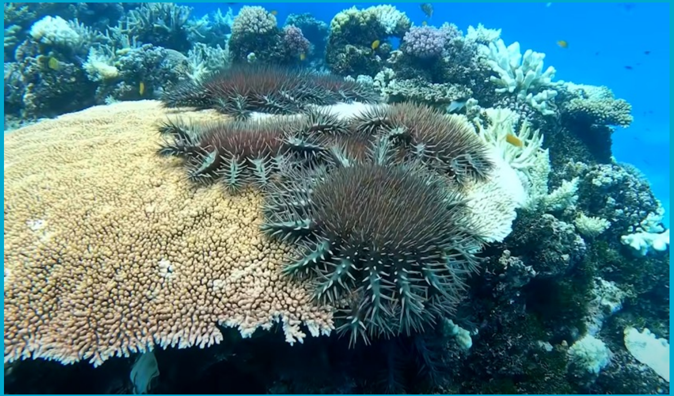
Cattle behavior



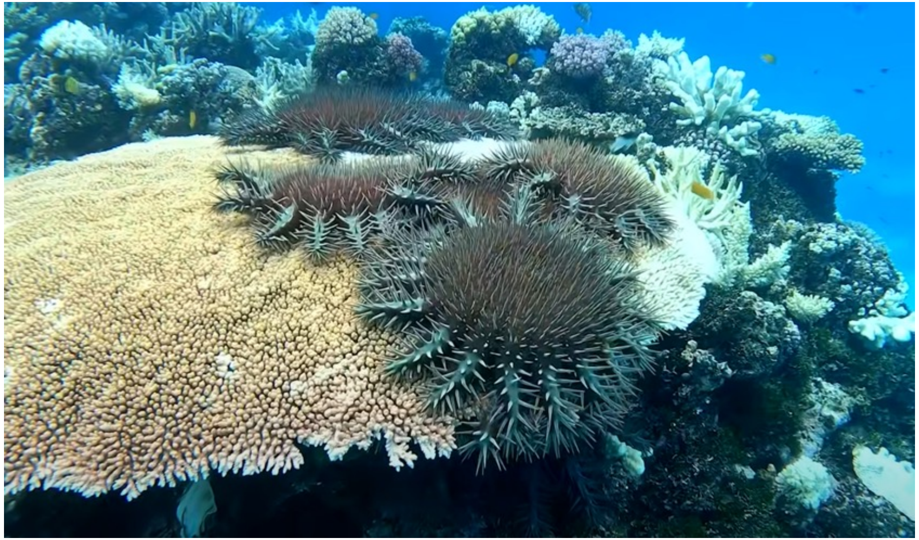
energetics

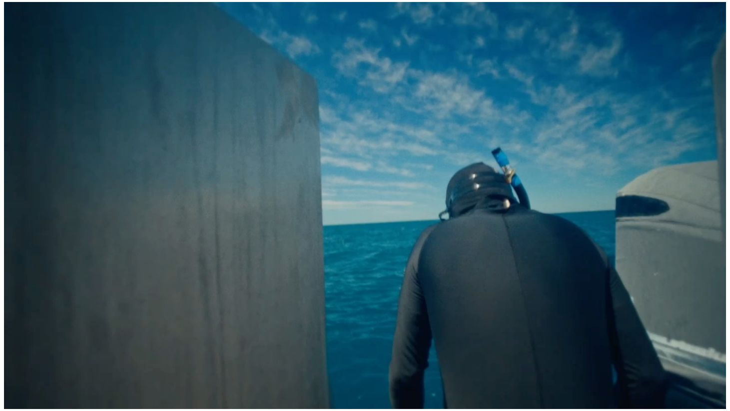
Case Study

Broadscale Coastal Surveys

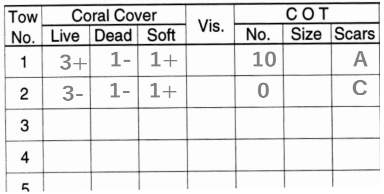


Crown-of-Thorns Starfish (COTS)



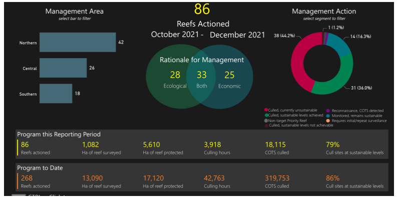


Manta Tow method



Tow No.	Coral Cover Live	Dead	Soft	Vis.	COT No.	Size	Scars
1	3+	1-	1+		10		A
2	3-	1-	1+		0		C
3							
4							
5							

Scoring Sheet



COTS Data Dashboard

Crown of Thorns Starfish (Acanthaster planci) : a large starfish that preys on hard coral, leaving behind white carbonate skeleton

COTS population outbreaks are a major cause of coral decline.

Government-funded COTS control program actively controls starfish populations on the Great Barrier Reef. Starfish are surveyed using the Manta Tow method.

Annual manta tow surveys for CoTS:

- 5 vessels, 100 employees, 8070 in-water surveys
- 106 reefs per year, 1577km of reef-margin transects

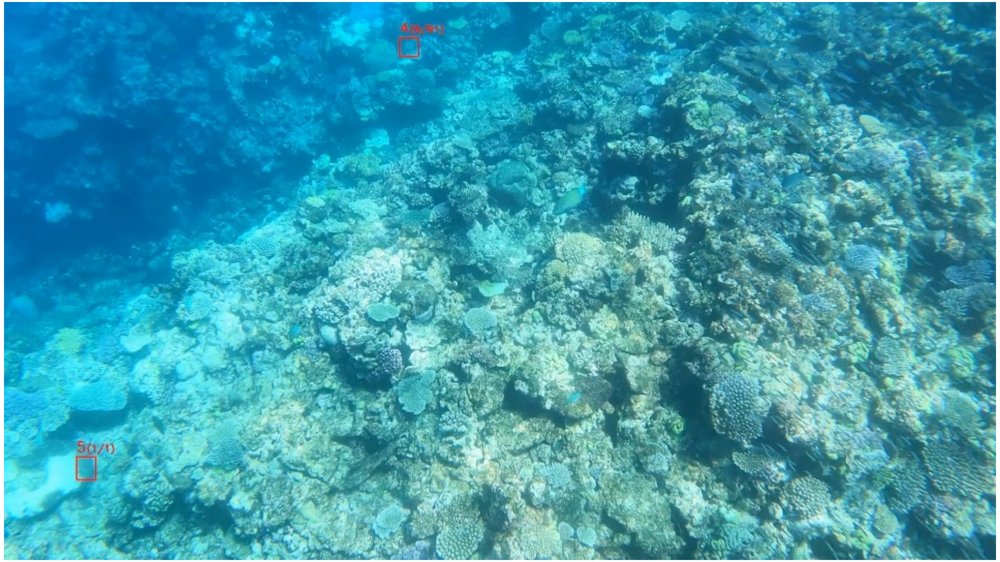
COTS Innovation Program

Use computer vision platforms and machine learning technology to automate detection, counting, and mapping of COTS on coral reefs

Manta Board with Cameras →

Autonomous Platform

COTS ML Detector Tracker, Edge AI



→ Real-time Maps/Stats

→ COTS Data Dashboard

Funding by Google Tensorflow/DFI, GBRF CCIP, in-kind by GBRMPA/operators

Blue Growth Project

Next generation methodologies/tools to accelerate and scale coastal surveys

Scalable Sensing Platforms for Image Transects

Machine Learning Models for Analyzing Images

Interactive Edge AI Platform

Imaging Platforms

Commercial

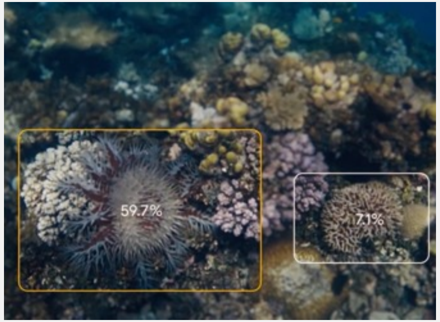
Bespoke

Navigation Software

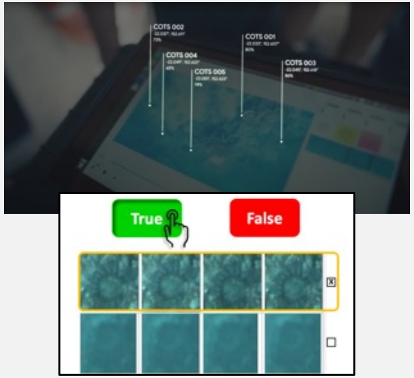
Pilot GUI

Map/ML GUI

ML Models



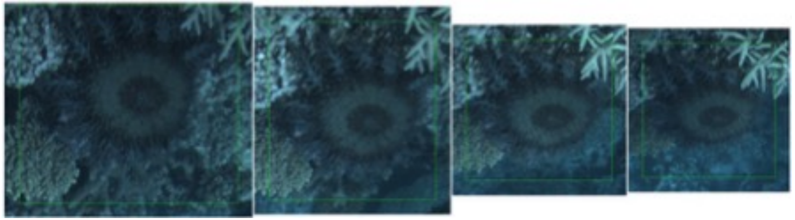
User Interaction



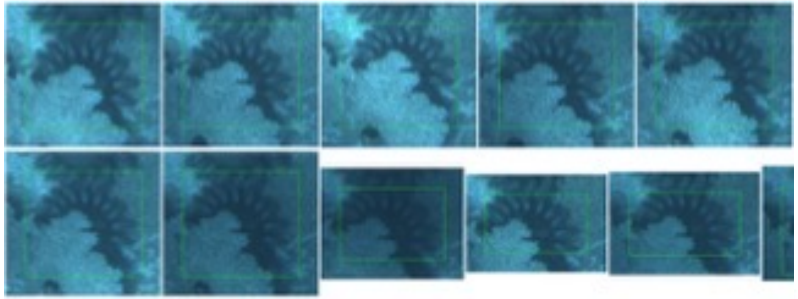
Collect Data at Scale

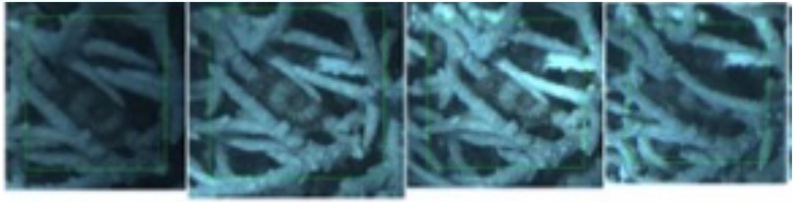
Insights in Real-time

Examples: CoTS Detections by ML



Shallow





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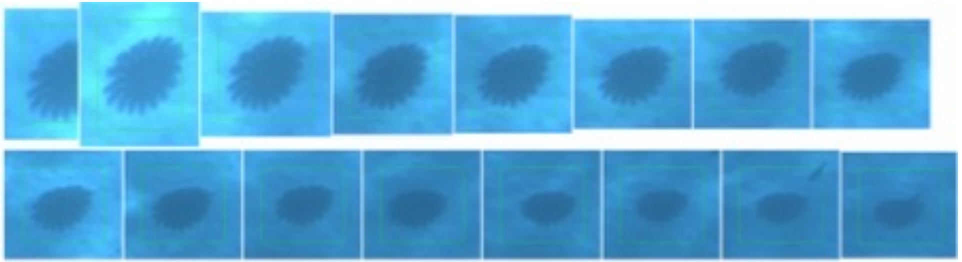
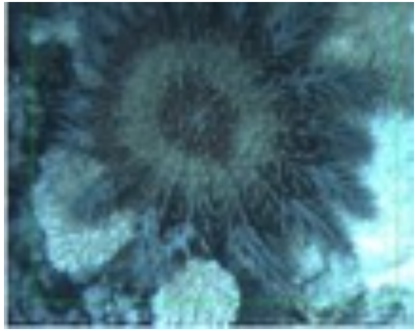


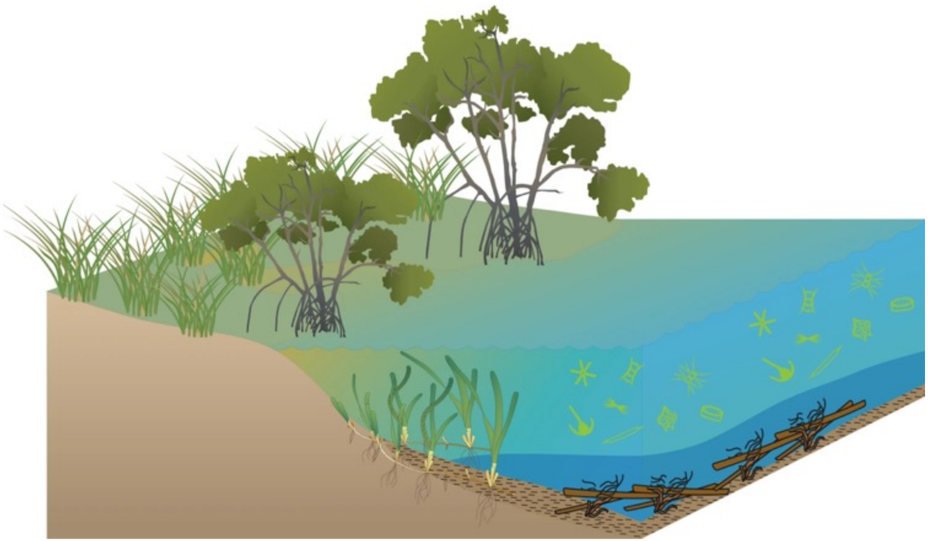
Deep



Top-down

Sideways

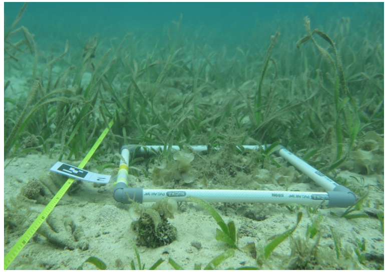
Blue Carbon Ecosystems



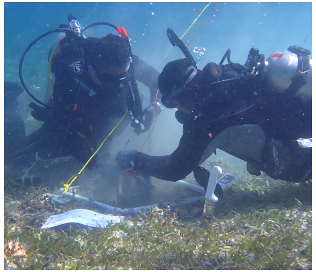
Blue Carbon coastal ecosystems provide important ecosystem services directly linked to sustainable livelihoods. For example, they can sequester carbon for millennia, through plant growth and the accumulation and burial of organic matter in the soil.

New scalable mapping and monitoring methods can provide a step change in our ability to tackle climate, prosperity, and livelihood challenges.

Existing methods for mapping and estimation of carbon sequestration potential.



Quadrat Visual Surveys



Soil samples

Drone Surveys

Seagrass Maps
Ecosystem Models

↓

Measurement
Management
Resilience

Pacific Blue Carbon Program

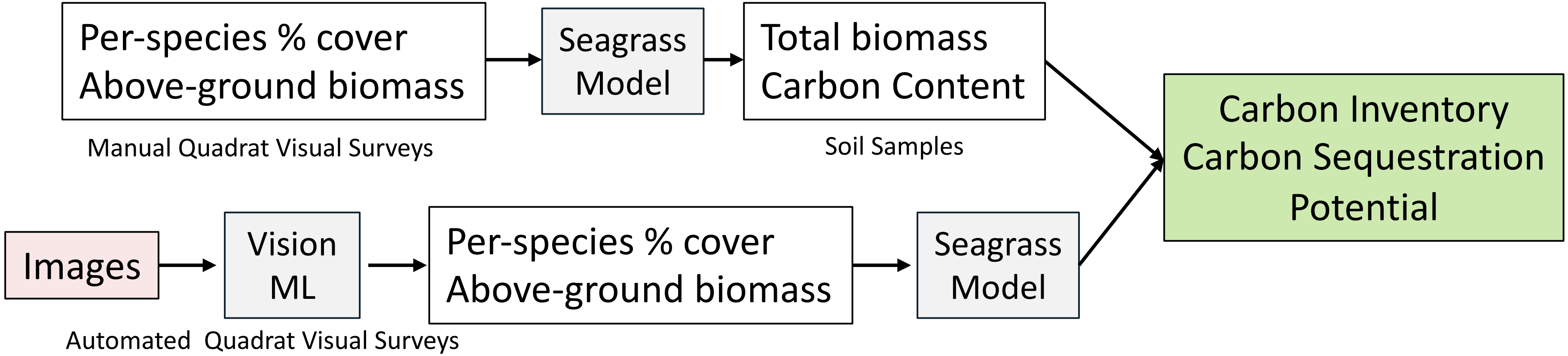
Motivation: Support national climate action and livelihoods through enhanced measurement, management and investment in coastal blue carbon ecosystems

Goal: Establish a blue carbon inventory and characterize controls on sequestration

Fiji
Indonesia
Australia

Step 1: Marine Science: relationship between Seagrass Species/Biomass Data and Soil Carbon

ML Research: train ML models to automate visual data processing



Funding by DFAT (SciTech4Climate), Google (DFI), in-country/Google-X in-kind

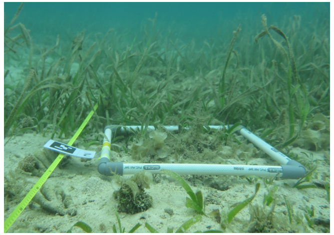
Pacific Blue Carbon Program

Fiji
Indonesia
Australia

Motivation: Support national climate action and livelihoods through enhanced measurement, management and investment in coastal blue carbon ecosystems

Goal: Establish a blue carbon inventory and characterize controls on sequestration

Step 2: Deploy the measurement method with in-country collaborators



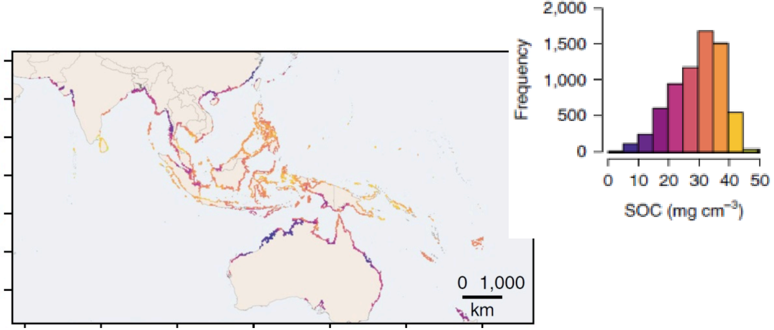
Quadrat Image Surveys
(In-country Collaborators)

→

iBenthos Cloud Tool

- Vision ML
- Seagrass Model

→



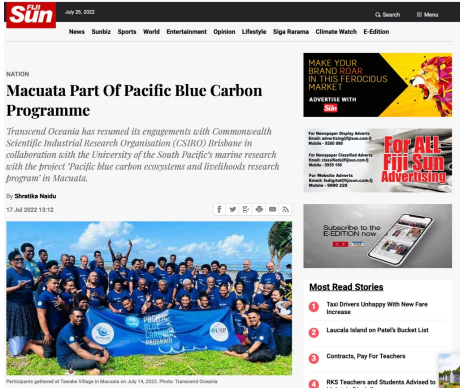
Maps – predicted SOC stocks

Funding by DFAT (SciTech4Climate), Google (DFI), in-country/Google-X in-kind

Fiji Lau Group Field Trip

Indonesia Komodo

Fiji Lau Group Field Trip



July 25, 2022

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NATION

Macuata Part Of Pacific Blue Carbon Programme

Transcend Oceania has resumed its engagements with Commonwealth Scientific Industrial Research Organisation (CSIRO) Brisbane in collaboration with the University of the South Pacific's marine research with the project 'Pacific blue carbon ecosystems and livelihoods research program' in Macuata.

By Shratika Naidu

17 Jul 2022 13:12

Participants gathered at Tawake Village in Macuata on July 14, 2022. Photo: Transcend Oceania

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2. Laucala Island on Patel's Bucket List
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Pacific livelihoods blue carbon program

Intelligence/Summary – Machine Learning

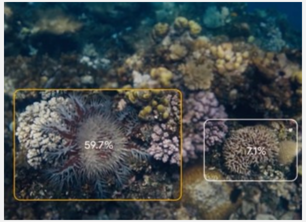
Scalable Sensing Platforms

Commercial

Bespoke

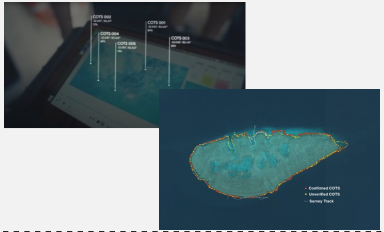
Collect Data at Scale

Machine Learning Models



Insights in Real-time

Interactive Edge/Cloud AI Platforms



- Rapid Response
- Trusted ML
- Continuous Improvement

The Key Machine Learning Challenge

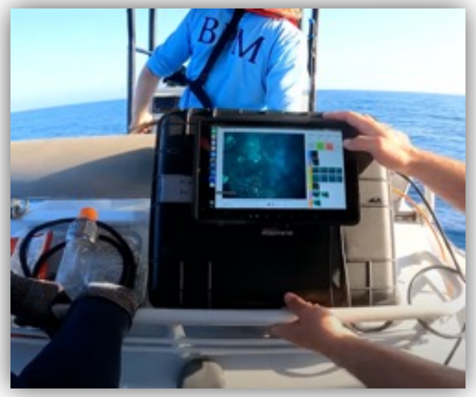
ML workflow is only as good as the underlying ML models

ML Models make mistakes

- Misclassification
- False Positive (Model detected an object that wasn't there)
- False Negative (Model hasn't detected an object that was there)

→ Outcomes/Insights will be wrong (maps, stats, counts)

Edge AI Platform – Continuous Learning from Experts



1) Powerful enough to run ML models in real-time (10fps HD video)
2) Small and efficient to carry on a small boat
3) Interactive GUI to learn from expert human operator

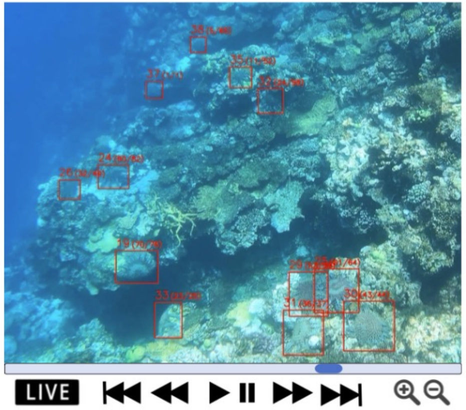


Figure 1: Live view of the camera feed super-imposed with ML outputs.

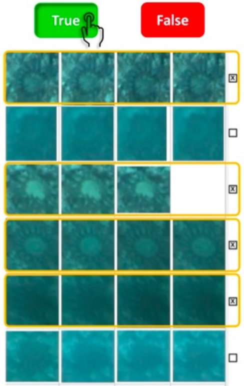


Figure 2: ML curation window: Rows correspond to objects detected over time, buttons at the top allow for quick curation of results.

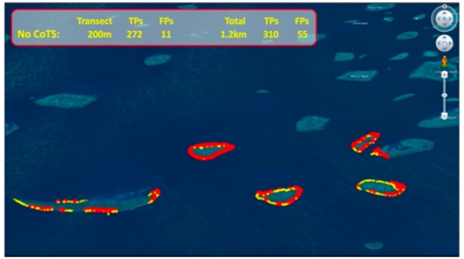
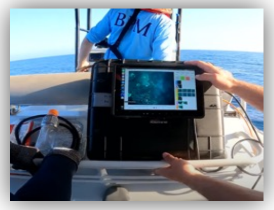


Figure 3: Map of several reefs overlayed with ML detections to show their spatial distribution.

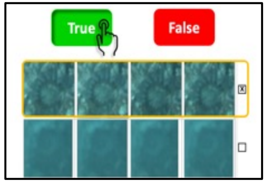
Continuous ML Refinement Lifecycle

We continuously validate and improve performance of ML algorithms



Edge AI Platform

curation

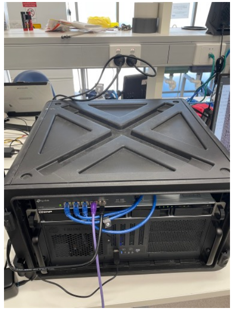


review

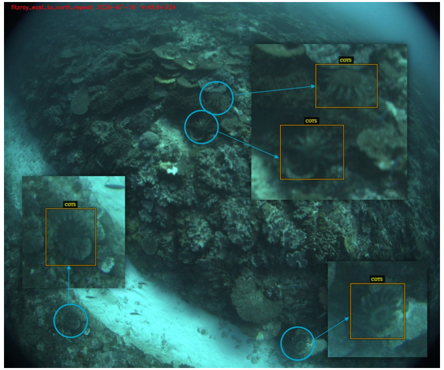
data

Real-time labels

Live Data Collection



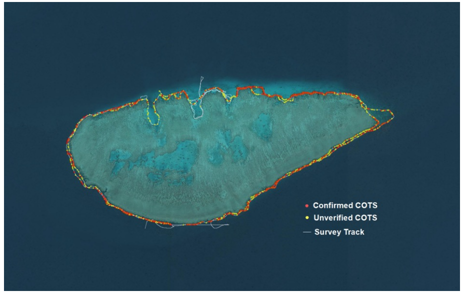
(Offline) Server with GPU



Model Retraining

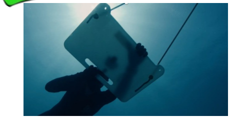
More Accurate Labels

Review, Curation by Humans



End-of-day Review/Analytics

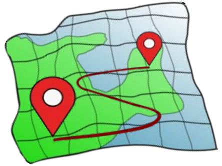
Innovating Broadscale Surveys



Manta tow

Quadrat

Biomass/Soil Cores



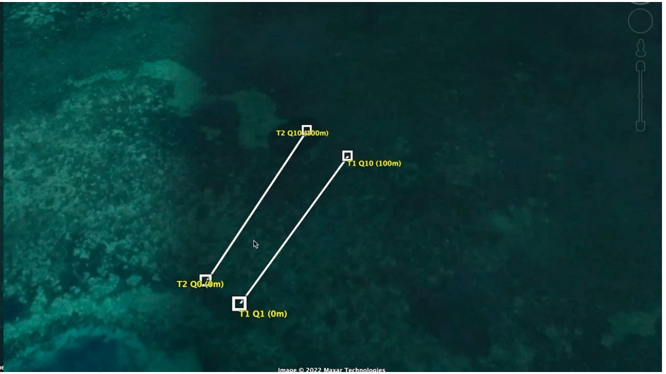
Video Transects

Today: Time-consuming data collection methods that require experts

Future: Scalable data collection by trained operators and fast data interpretation by AI

11-point transects per day

Local Scale: higher res



Regional Scale

Impact

- COTS
  - GBR Validation (2020-22): Capricorn bunkers, Swains NP
  - Reef Trust Partnership (2022-24): Collaboration with AIMS, GBRF, GBRMPA, boat operators
  - Google – Kaggle competition, Google I/O dev keynote

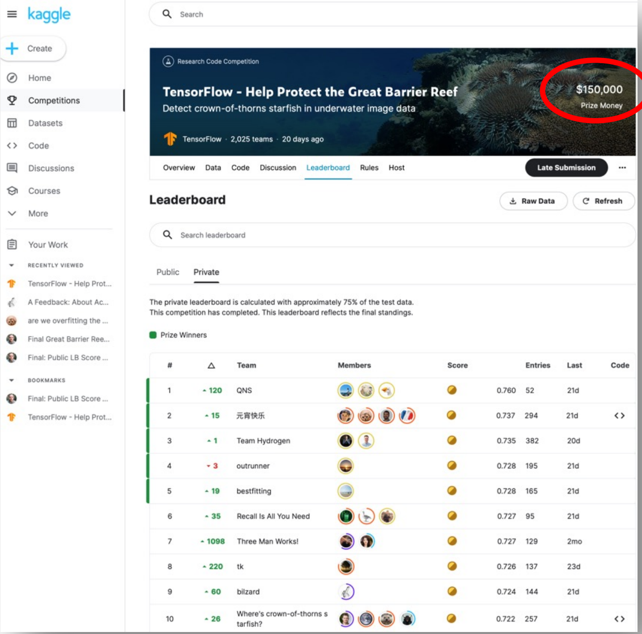
- Blue Carbon
  - Fiji Lau Group (jul’22): 6 islands, 18 transects
  - Indonesia Komodo (oct’22): 9 sites, 19 transects
  - Indonesia Sulawesi (jun’22): 16 sites, 30+ transects
  - Fiji/Indonesian government dept, academia

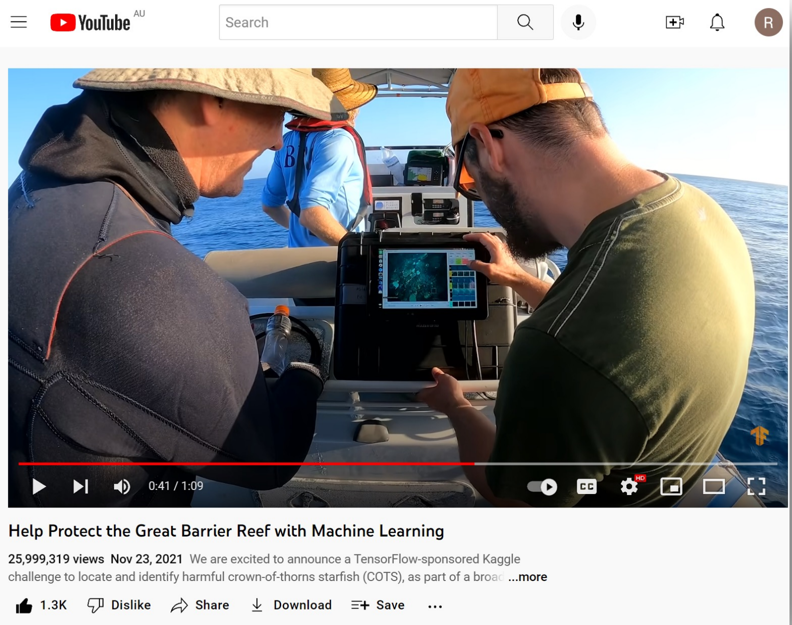
Google DFI Event (Nov’21)

Google-X (Sep’22, CSIRO CEO)

Kaggle is an online community of data scientists and machine learning practitioners:

- find and publish data sets
- explore and build models in a web-based data-science environment
- work with other data scientists and machine learning engineers
- enter competitions to solve data science challenges.





https://www.kaggle.com/c/tensorflow-great-barrier-reef


The CSIRO Crown-of-Thorn Starfish Detection Dataset

Figure 1: A COTS outbreak at the Swain Reefs, in North Queensland, Australia, October 2021.

ABSTRACT

1 INTRODUCTION

https://arxiv.org/abs/2111.14311

- Max team size: 5
- **14,549** registrations, **2,613** participants on **2,026** teams
- Submission limits: 5 per day, 4 final per team
- Average submissions (top 100): 123.5

Know Our Winners

Rank	Model Ensembles	Pipeline Summary	Augmentation	Further Remarks
1	Y: 6 Yolov5 models, 3 trained on 3648 images and 3 trained on 1536 image patches	Object detection + ensemble + augmentation + re-score + attention	hflip, vflip, transpose, 45° rotation and cutout	Trust local CrossValidation
3	Y: CenterNet, FasterRCNN, FCOS, EfficientDet, YoloV5	Ensemble with different detectors plus tracker		Label refinement; Trust local CrossValidation
5	Y: YOLOv5-S6, YOLOv5-M6, YOLOv5-L6, YOLOX-L, YOLOR-P6 and HRNetV2P-W18	Ensemble with different detectors plus tracker	"Copy-paste" with Possion blending	Trust local CrossValidation

Competition is Finalized - Congratulations to our Winners; Recap

https://www.kaggle.com/c/tensorflow-great-barrier-reef/discussion/308248

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