# NanoLambda:
## FaaS at All Resource Scales for IoT

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RACELab: https://sites.cs.ucsb.edu/~ckrintz/racelab.html

# Background

- IoT devices are increasingly prevalent producers of data
- Programming & processing data remains a challenge
  - On device processing:
    - Often difficult to implement
    - Portability, security, maintainability all are challenges
  - Cloud / Edge Cloud processing
    - Easy to program in high level languages
    - Tools such as FaaS provide a homogenous and scalable execution environment
    - Cloud introduces expensive network cost and latency
      - IoT devices will produce 80 zettabytes a year (*IDC) by 2025

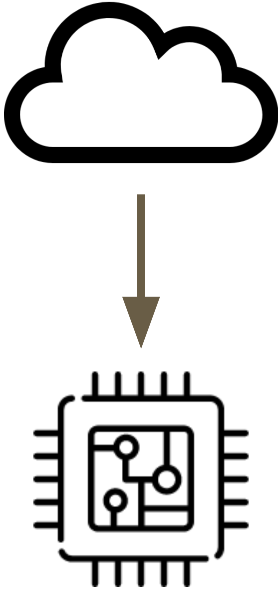
*IDC market analysis firm on IoT data [https://www.idc.com/getdoc.jsp?containerId=prUS45213219](https://www.idc.com/getdoc.jsp?containerId=prUS45213219)

# Background

*What if we could bring FaaS to the device?*

The challenge is that FaaS is currently limited to the Cloud or Edge*

- Data must be moved from device to data center
- *High power cost for low power devices to transmit over WiFi*
- Poor network infrastructure in rural areas
- Existing FaaS runtimes are limited to Linux-based edge systems



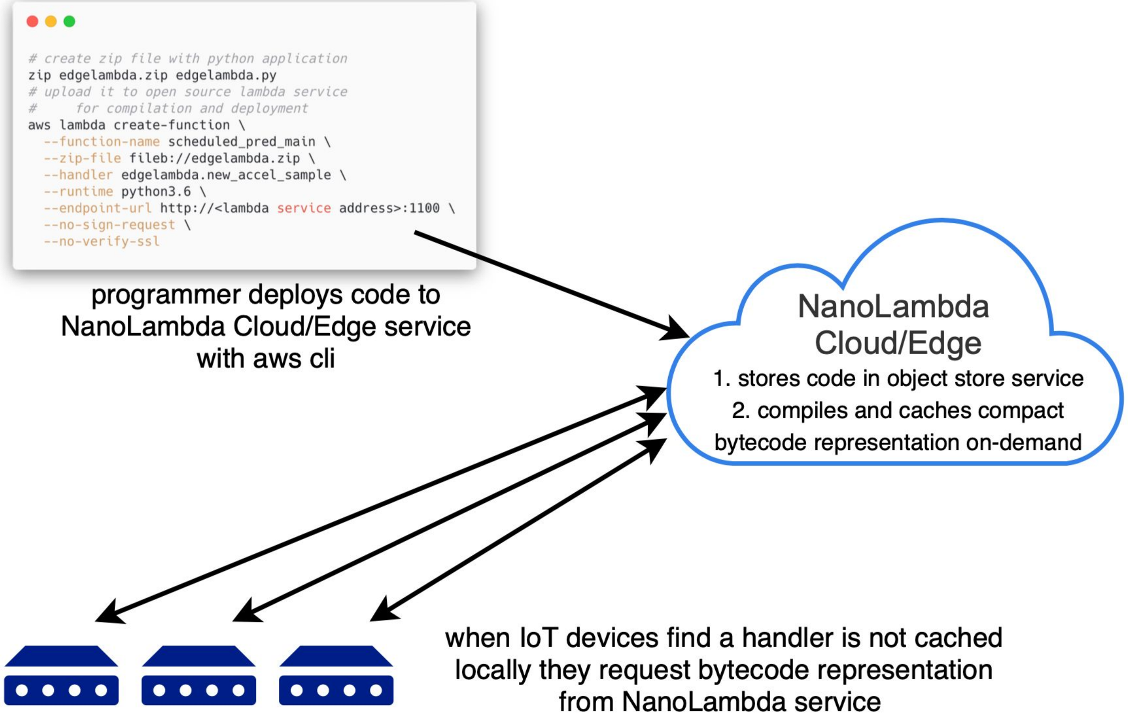
*AWS GreenGrass and similar services

# Introducing NanoLambda

- NanoLambda: platform for running FaaS handlers across all tiers
  - On Device
  - Cloud / Edge
  - Compatible with AWS Lambda
- Goals
  - **Ease of development**
  - **Portability**
  - **Small code and memory footprint**
  - **Security**
  - **Uniform programming methodology**
- At the smallest scales
  - ESP8266 with 96KB of ram and 512KB of program flash storage
  - CC3220SF with 256KB of ram and 1MB of program flash storage

ESP8266 development board

# Deploying FaaS Functions



```
# create zip file with python application
zip edgelambda.zip edgelambda.py
# upload it to open source lambda service
#     for compilation and deployment
aws lambda create-function \
  --function-name scheduled_pred_main \
  --zip-file fileb://edgelambda.zip \
  --handler edgelambda.new_accel_sample \
  --runtime python3.6 \
  --endpoint-url http://<lambda service address>:1100 \
  --no-sign-request \
  --no-verify-ssl
```

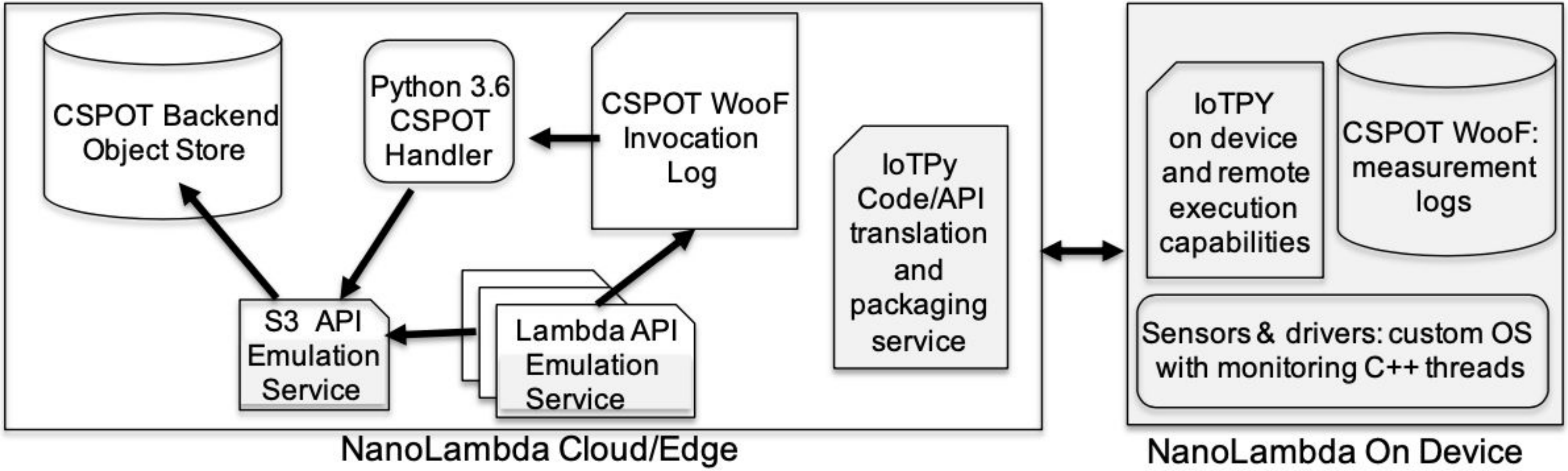
programmer deploys code to NanoLambda Cloud/Edge service with aws cli

NanoLambda Cloud/Edge

1. stores code in object store service
2. compiles and caches compact bytecode representation on-demand

when IoT devices find a handler is not cached locally they request bytecode representation from NanoLambda service

# NanoLambda Architecture



CSPOT Backend Object Store

Python 3.6 CSPOT Handler

CSPOT WooF Invocation Log

S3 API Emulation Service

Lambda API Emulation Service

IoTPy Code/API translation and packaging service

NanoLambda Cloud/Edge

IoTPY on device and remote execution capabilities

CSPOT WooF: measurement logs

Sensors & drivers: custom OS with monitoring C++ threads

NanoLambda On Device

# NanoLambda Architecture

Comprised of two core systems

- NanoLambda Cloud/Edge
  - FaaS handler registry & edge execution environment
  - Remote code compilation and bytecode delivery to IoT devices
- NanoLambda On Device
  - Provides on-device handler execution capabilities with *IoTPy*
  - Leverages Python VM isolation to provide isolation

# IoTPy Design

- Why python?
- Why not an existing interpreter like micropython?
  - Lacks key embedding features
  - Binary size - micropython 620KB binary vs IoTPy 290KB binary
- IoTPy features
  - Lean memory footprint by leveraging NanoLambda Cloud/Edge for bytecode generation
  - Object-oriented VM implementation & first class embedding support
- IoTPy provides a C/C++ interface for native extensions / functions
  - Built in libraries include: math, json, device, and interaction with NanoLambda Cloud/Edge's Lambda service
- Security
  - Python VM provides memory protection and container-like isolation

# NanoLambda Cloud/Edge

- Service provides two REST API servers offering
  - Persistent object storage compatible with S3
  - A FaaS service that deploys functions written for AWS Lambda
- Built with CSPOT -- a low level framework providing FaaS primitives
  - S3 is implemented as a layer on top CSPOT's append only object storage
  - Lambda is implemented with event handlers triggered by invocation log updates
  - Handlers are run in Linux containers allowing for concurrent but isolated execution
- Provides a registry of function definitions stored in S3 service
- Binary API for fetching compiled function bytecode

# NanoLambda On Device

- Runs python handlers on non-Linux IoT devices
- Much like NanoLambda Cloud/Edge, invocations triggered by log events
  - Events can originate from sensors on device
  - Data can also be delivered remotely over CSPOT’s network
- Each append runs a C-language handler function invoking IoTPy
  - On cold start function bytecode is requested from NanoLambda Cloud/Edge
  - IoTPy caches bytecode & interpreter state to accelerate future runs

# Execution Offloading

NanoLambda On Device is code compatible with NanoLambda Cloud/Edge

- On Device supports devices as small as ESP8266 and the CC3220SF
- NanoLambda Cloud/Edge runs on Linux at the edge and in the cloud

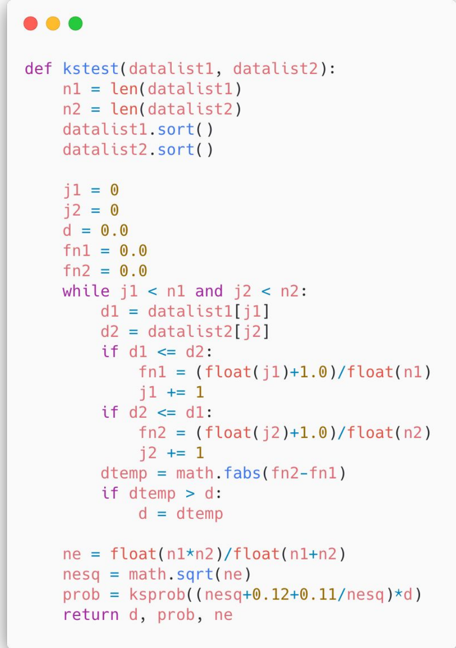
Portability: The choice to use NanoLambda allows for On Device, at the Edge, in the private Cloud, or directly on AWS Lambda

# Predictive Maintenance Application

- Predictive Maintenance is a technique using sensors to detect part failure
- We examine failure detection in motors using accelerometers
- Setup:
    - Accelerometer attached to a motor reads vibration magnitude 5 times a second
    - Data is appended to a WooF for persistence, a history of 32 records is kept.
    - Each append triggers failure detection handler to run
- Handler is benchmarked running on NanoLambda On Device and NanoLambda Cloud/Edge for various problem sizes and configurations

# Predictive Maintenance Application

```python
def new_accel_sample(payload, ctx):
    global fan_mdl
    transformed = []
    for record in payload:
        transformed.append(magnitude(record))
    payload = None
    prob = kstest(transformed, reference)
    return str(prob)
```



```python
def kstest(datalist1, datalist2):
    n1 = len(datalist1)
    n2 = len(datalist2)
    datalist1.sort()
    datalist2.sort()

    j1 = 0
    j2 = 0
    d = 0.0
    fn1 = 0.0
    fn2 = 0.0
    while j1 < n1 and j2 < n2:
        d1 = datalist1[j1]
        d2 = datalist2[j2]
        if d1 <= d2:
            fn1 = (float(j1)+1.0)/float(n1)
            j1 += 1
        if d2 <= d1:
            fn2 = (float(j2)+1.0)/float(n2)
            j2 += 1
        dtemp = math.fabs(fn2-fn1)
        if dtemp > d:
            d = dtemp

    ne = float(n1*n2)/float(n1+n2)
    nesq = math.sqrt(ne)
    prob = ksprob((nesq+0.12+0.11/nesq)*d)
    return d, prob, ne
```

```python
def ksprob(alam):
    fac = 2.0
    sum = 0.0
    termbf = 0.0

    a2 = -2.0*alam*alam
    for j in range(1, 11):
        term = fac*math.exp(a2*j*j)
        sum += term
        if math.fabs(term) <= 0.001*termbf or math.fabs(term) <= 1.0e-8*sum:
            return sum
        fac = -fac
        termbf = math.fabs(term)

    return 1.0
```

# Plotting Power & Invocation Latency

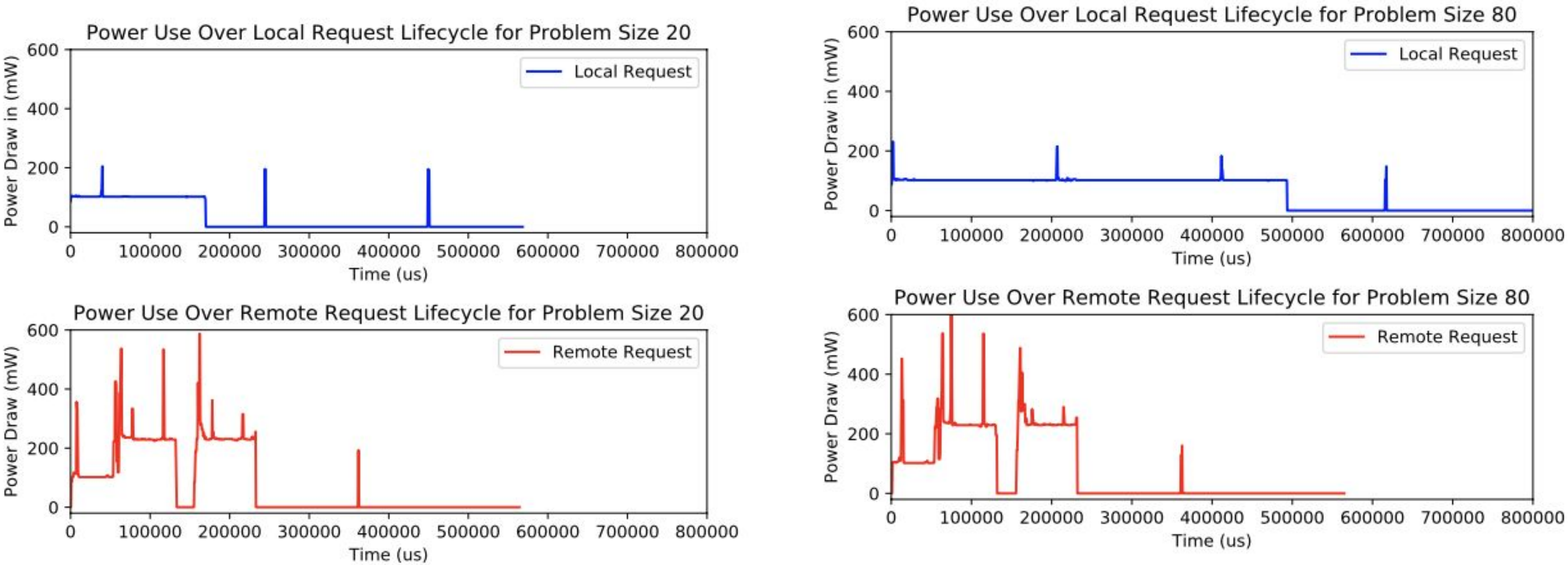


Fig. 5. Comparison of power draw over request lifecycle for various KS problem sizes using both remote and local strategies.

# Naive Offloading Scheduler

Naive algorithm:

- Pick the lowest latency (time to result) execution strategy based on history
  - Local (On Device) or Remote (Cloud)
- Every 16 invocations reset the history to allow model to recover from network spikes

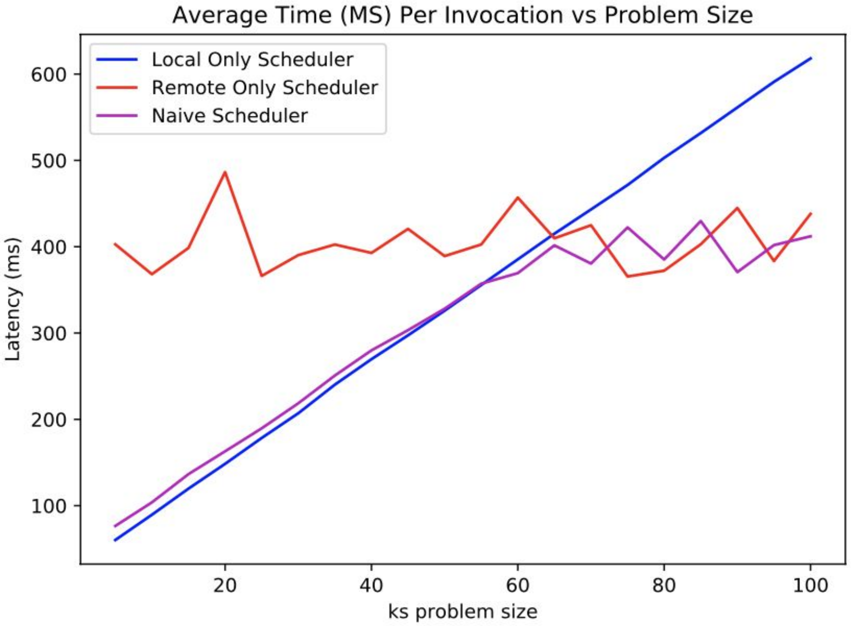
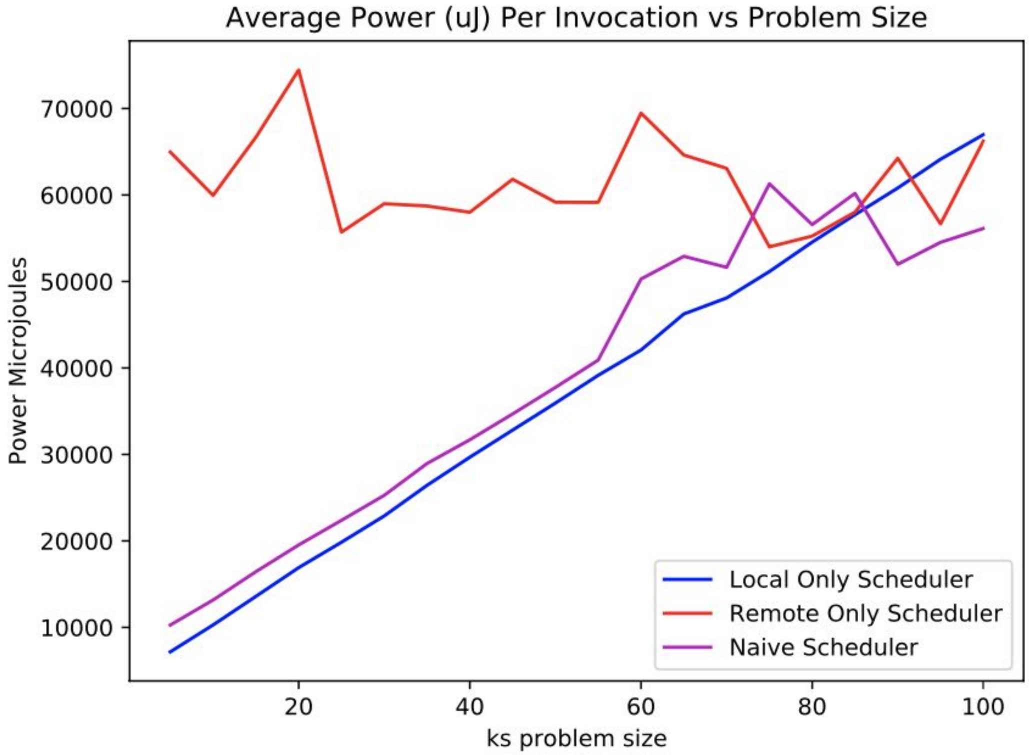


Fig. 6. Comparison of average invocation latency for local invocation strategy, remote invocation strategy, and offloading scheduler invocation strategy.

# Naive Offloading Scheduler Power



# Concluding Remarks

NanoLambda Contributions:

- Power & Latency Savings
- Ease of development
- Reprogrammability
- Portability
- Security

# Thank you!

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