Space Flight Dynamics as a Service (SFDaaS)

as a Cloud Computing Web Service

presented at the

Ground System Architectures Workshop 2012 (GSAW 2012)

Session 11E: Cloud Computing for Spacecraft Operations II

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Outline

- Presentation's Objectives
- A Quick Synopsis of Space Flight Dynamics
- *Space Flight Dynamics as a Service (SFDaaS)*
- A Very Simple Use Case
- Live Demo
- Things to Carefully Consider
- Links to Presentation Materials
- Questions, Comments & Suggestions

Presentation's Objectives

- To consider the possibility of a *Space Flight Dynamics as a Service* for analysis and operations

- To initiate an open discussion on the topic and receive feedback from the community

- Perhaps plant the seed for an *Open Space Flight Dynamics Interface (OSFDI)*

A Quick synopsis of Space Flight Dynamics

6 DoF Guidance, Navigation & Control (GN&C) of the trajectory and attitude of a spacecraft in order to efficiently meet mission targets, constraints and objectives

- Model and measure external and internal forces and torques on spacecraft
- Collect range, range rate, azimuth & elevation, etc. observations on spacecraft
- Perform orbit and attitude determinations on spacecraft
- Perform conjunction and collision assessments relative to other objects
- Utilize spacecraft telemetry and ground based data in order to effectively and efficiently use on-board actuators
- Provide actuator parameters to spacecraft control center in order to command spacecraft
- Update estimates of actuator efficiencies based on empirical data
- Store and retrieve historical data
- Estimate end of mission

Space Flight Dynamics as a Service (SFDaaS)

Space Flight Dynamics as a Service

A Cloud based <u>web service</u> for
Space Flight Dynamics capabilities

- On-demand Service
- Resource pooled
- Rapidly elastic
- Measured service
- Load balanced
- Multi-tenancy
- Access Control Lists
- Messaging & queuing
- Distributed computing
- Firewalled
- Virtual Private Networked (VPN)
- Encrypted file systems
- Encrypted Virtual Machines
- Encrypted traffic
- Discoverable Services
- Publish/subscribe

Space Flight Dynamics as a Service

Leverage Open Source, GOTS & COTS for selection(s) of Space Flight Dynamics "Engines" (SFDE)

- General Mission Analysis Tool (GMAT)
- Goddard Trajectory Determination System (GTDS)*
- Java Astrodynamics Toolkit (JAT)
- OreKit

Licensing is simpler & open collaboration and development

- FDC (Intelsat)
- focusSuite (GMV)
- FreeFlyer (ai-solutions)
- Quartz++ (Astrium)
- STK (AGI)

Licensing is complex and closed development

*** Closed Source GOTS**

Space Flight Dynamics as a Service (

Space Flight Dynamics "Engines" (SFDE), CCSDS, XTCe, etc. ....

- Discoverable SFDE's
- User selectable SFDE
- Granular security modeling
- Granular auditability of all services and objects within service
- Mission Mode
- Analysis Mode

- Use CCSDS Standards
  - Attitude Data Messages
  - Mission Operations Services Concept
  - Orbit Data Messages
  - Tracking Data Message
  - XTCe

Space Flight Dynamics as a Service

<u>Abstract</u> Space Flight Dynamics functionalities into Services

- Forces
  - Solar system bodies
  - Drag
  - Solar Radiation Pressure
  - Gravity potential
  - Maneuvers
- Propagation
  - Attitude and Orbit
- Time & Frames
- Differential Corrections
  - Attitude & Orbit Determinations
- Actuator modelling
  - Propulsion system(s)
  - Thrusters
  - Wheels
  - etc.

Space Flight Dynamics as a Service

User Interface (UI) and User Experience (UX)

- Django as a web framework
- Web browser based Dashboard using HTML5 & Web 2.0+ features
- Javascript
- Web-based Graphics Library (WebGL)
- Accessed via desktops, laptops, mobile phones, tablets, & thin clients
- Clients' UI & UX is independent of clients' operating systems

Space Flight Dynamics as a Service

The Back-end of SFDaaS

- OpenStack: An Open Source Cloud Computing Frameworks
- Leverage IaaS
- Develop PaaS and SaaS
- Memcached
  - Distributed memory caching for rapid retrieval of often requested/created data
- GMSEC, XMPP
- Programming Languages
  - Python, Jython
  - Java
  - Ruby
  - Javascript
  - PHP
  - Matlab syntax

Space Flight Dynamics as a Service

Possible Services

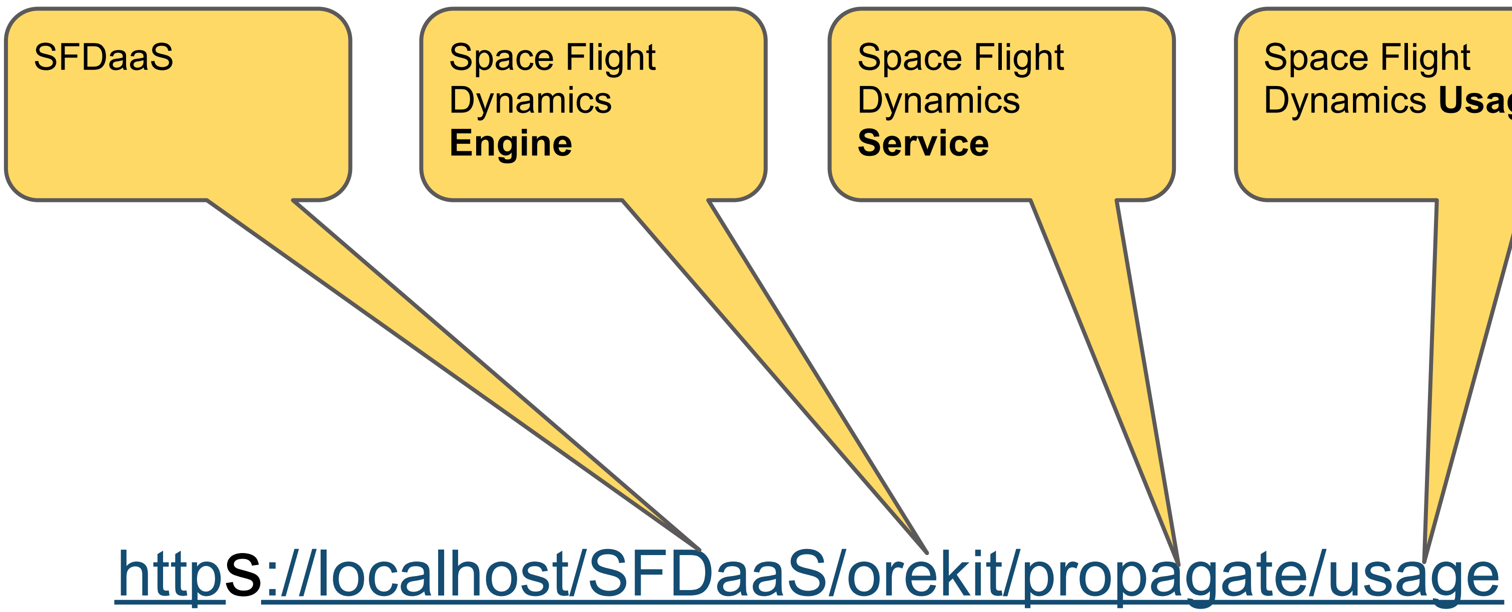
- Space Flight Dynamics Services
- Telemetry Services
- Planning Services
- Scheduling Services
- Data Distribution Services
- Visualization Services
- Notification Services
- Security Services
- Directory Services
- Memory Storage Services
- Object Disk Storage Services

A Simple Use Case

A Simple Use Case

- Uses OreKit
  - http://orekit.org/- "*A free low level space dynamics library*"
  - Written in Java
- SFDaaS
  - Linux
  - Links to OreKit
  - Written in Java
  - Eclipse as the IDE
  - Apache Tomcat 7.0.22
  - Uses Memcached
  - Abstracts orbit state propagation into a service

A Simple Use Case



A Simple Use Case (Usage)

http://localhost/SFDaaS/orekit/propagate/usage

```
Space Flight Dynamics as a Service (SFDaaS)

Usage:
 http://localhost/SFDaaS/orekit/propagate& \
  &cf=0                    [default: ignore caching and proceed]
    &cf=1                  [Check if in cache, if in cache use.
                            if not put in cache after propagation]
      &ca=127.0.0.1:11211 [Caching address and port]
      &ct=60               [Default: 60 seconds to store in cache ]
      &ck={KEY}            [User supplied caching key, otherwise use built-in one]
  &sf=1                    [default = null, 1 means use URI provided values ]
  &st=300                  [default = 1800 seconds]
  &t0=yyyymmddThhMMss.sss [only UTC Timezone]
  &tf=yyyymmddThhMMss.sss [only UTC Timezone]
  &r0=[x0,y0,z0]           [only in meters ]
  &v0=[vx0,vy0,vz0]        [only in meters/second ]

 Usage examples:
  1) Usage
  2) Propagation
  3) Propagation with Memcaching using default values (should return 'HTTP Status 500'
error because memcaching server and port are undefined)
  4) Propagation with Memcaching using default values with 3 memcaching servers defined.
  5) Propagation with Memcaching using ct=15, i.e. cache for 15 seconds only
  6) Propagation with Memcaching using ct=15 and providing my own key, ck=MYKEY
  7) Propagation with Memcaching using ct=15 and changing the session expiry time
```

A Simple Use Case (output)

```
http://localhost/SFDaaS/orekit/propagate? \
     t0=2010-05-28T12:00:00.000& \
     tf=2011-05-28T12:00:00.000& \
     r0=[3198022.67,2901879.73,5142928.95]& \
     v0=[-6129.640631,4489.647187,1284.511245]

     Space Flight Dynamics as a Service (SFDaaS)
     A priori state:
      t0 = 2010-05-28T12:00:00.000
      r0 = [3198022.67,2901879.73,5142928.95]
      v0 = [-6129.640631,4489.647187,1284.511245]

     A posteriori state:
      tf = 2011-05-28T12:00:00.000
      rf = [-586503.061381,-4304942.727318,-5125160.805404946]
      vf = [7111.218410,-2612.237696,1387.7771371784445]

     Assumptions:
      1) The epochs, t0 and tf, are assumed to be in UTC.
      2) The radius and velocity vectors are in meters and meters/second, respectively.
      3) The frame is assumed to be the J2000 Earth-centered one.
```

Live Demo

Things to Carefully Consider

- Regional laws and regulations
- Security
  - Confidentiality, Integrity, Availability
- Privacy
- Ownership, Copyright & Licensing
- Intellectual property
- Business model(s)
- Reliability
- Feasibility
- Standardisations
- *Many more*

Links to Presentation Materials

- Proposal of SFDaaS can be found here:
  - https://ido.org/SFDaaS-proposal
- This presentation can be found here:
  - https://ido.org/SFDaaS-GSAW-2012

Thank you.

Questions?

Suggestions?

Comments?

Contact Information

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Acronyms

DoF	Degrees of Freedom
GMAT	General Mission Analysis Tool
GMSEC	Goddard Mission Services Evolution Center
GTDS	Goddard Trajectory Determination System
OSFDI	Open Space Flight Dynamics Interface
REST	Representational State Transfer
SFDaaS	Space Flight Dynamics Interface
SFDE	Space Flight Dynamics "Engine"
URI	Uniform Resource Identifier
VM	Virtual Machine
WebGL	Web-based Graphics Library
XTCE	XML Telemetric and Command Exchange

References

References (1/2)

Software & IT References:

- **Django** https://www.djangoproject.com/
- Fielding, Roy Thomas, 2000, **Architectural Styles and the Design of Network-based Software Architectures**, http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm
- Fielding, Roy Thomas, 2000, **Representational state transfer (REST)** http://www.ics.uci.edu/~fielding/pubs/dissertation/rest_arch_style.htm
- **General Mission Analysis Tool (GMAT)**, http://gmat.gsfc.nasa.gov/
- **Goddard Mission Services Evolution Center (GMSEC),** http://gmsec.gsfc.nasa.gov/missionServices.php
- **Java Astrodynamics Toolkit** http://jat.sourceforge.net/
- **Memcached,** http://en.wikipedia.org/wiki/Memcached
- **Octave**, Similar to Matlab so that most programs are easily portable. http://octave.org/
- **OpenStack, An Open Source Scalable Cloud Framework**. http://openstack.org
- **OreKit , A free low level space dynamics library,** http://orekit.org/
- **Representational State Transfer (REST)** http://en.wikipedia.org/wiki/Representational_state_transfer

References (2/2)

Definitions & CCSDS Standards:

- **Attitude Data Messages** . Blue Book. Issue 1. May 2008. CCSDS 504.0-B-1, http://public.ccsds.org/publications/archive/504x0b1.pdf
- **Mission Operations Services Concept** . Green Book. Issue 3. December 2010. CCSDS 520.0-G-3, http://public.ccsds.org/publications/archive/520x0g3.pdf
- **Navigation Data—Definitions and Conventions** . Green Book. Issue 3. May 2010. CCSDS 500.0-G-3, http://public.ccsds.org/publications/archive/500x0g3.pdf
- **The NIST Definition of Cloud Computing** http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf
- **Orbit Data Messages** . Blue Book. Issue 2. November 2009. CCSDS 502.0-B-2, http://public.ccsds.org/publications/archive/502x0b2.pdf
- **Tracking Data Message** . Blue Book. Issue 1. November 2007. CCSDS 503.0-B-1, http://public.ccsds.org/publications/archive/503x0b1c1.pdf

Keywords

CCSDS, Consultative Committee for Space Data Systems, cloud computing, cloud services, GMAT, GMSEC, Goddard Mission Services Evolution Center, Ground System Architectures Workshop, GSAW, GSAW 2012, GSAW2012, GSFC, hadoop, HTML5, IaaS, Matlab, memcached, Mission Operations Services, MOS, NASA, octave, openstack, orekit, PaaS, SaaS, Service Oriented Architecture, SFDaaS, SOA, space flight dynamics, space flight dynamics as a service, space flightdynamics, spaceflight dynamics, spaceflightdynamics, Web Services, WebGL, XMPP

Backup Slides

Definition of Cloud Computing*

- **On-demand self-service**
  - *According to this presenter, this is the more important capability*
- **Broad network access**
- **Resource pooling**
- **Rapid elasticity**
- **Measured service**

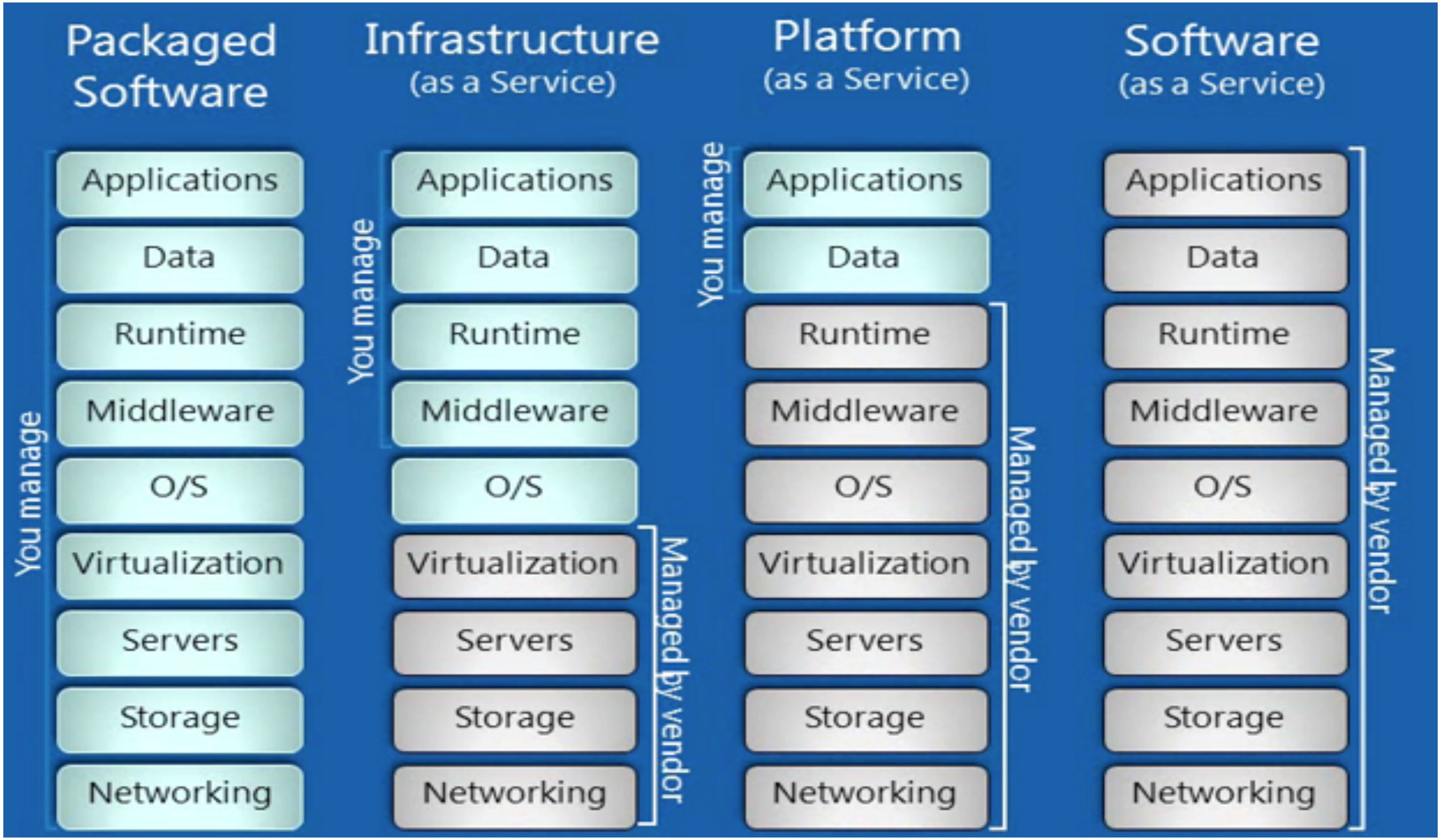
*: NIST's definition

Cloud Service Modes & Deployment Models

- **Cloud Service Modes**
  - Infrastructure as a Service (IaaS)
  - Software as a Service (Saas)
  - Platform as a Service (PaaS)
  - ...
  - *Data as a Service (DaaS)*
  - Many more are being contemplated : *SFDaaS*

- **Cloud Deployment Models**
  - Private cloud
  - Community cloud
  - Public cloud
  - Hybrid cloud

IaaS, PaaS & SaaS

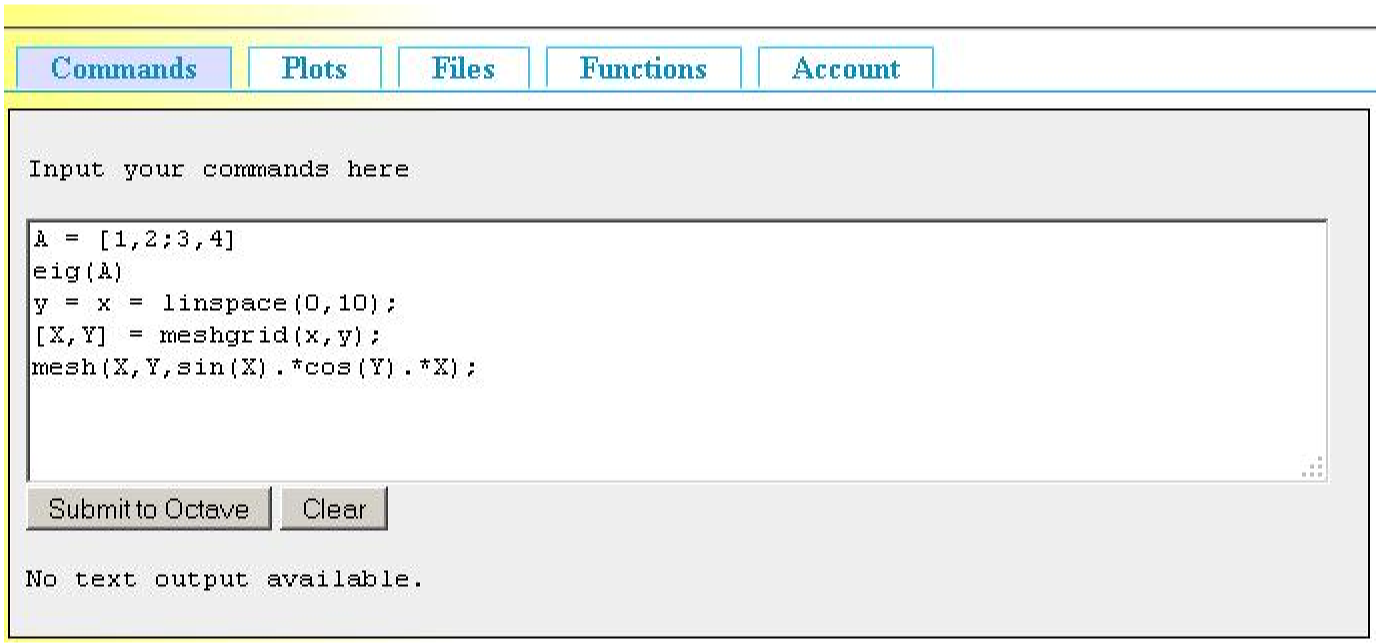


source: http://goo.gl/fJWmh

RESTful Web Services

- REST: Representational State Transfer
- RESTful: Client-server, Stateless, Cacheable, Layered system, Uniform interface
- A web based service implemented using `HTTP` and the principles of REST. It is a collection of resources, with defined aspects:
  - Base URI for the web service, such as http://example.com/resources/
  - Set of operations supported by the web service using `HTTP` methods (e.g., `GET, PUT, POST, or DELETE`).
  - The API must be hypertext driven
- Can `GET` & `PUT` `CSV`, `JSON`, `XML`, etc. content type
- **Example:** `http://books.google.com/books?id=R0ZHAQAAIAAJ`

Octave/Matlab as a ~PaaS



source: http://weboctave.mimuw.edu.pl/weboctave/web/

Session 11E: Cloud Computing for Spacecraft Operations II

http://csse.usc.edu/gsaw/gsaw2012/agenda12.html#session11

Session 11E: **Cloud Computing for Spacecraft Operations II**

Chairs: Ramesh Rangachar, Intelsat; Mark Walker, Kratos Integral Systems International

This working group will be a combination of presentations and group discussion on the topic of cloud computing for space operations. Presenters will include spacecraft operators with interests and accomplishments with virtualization, providers of ground system and cloud computing products and services, and experts in the subject of cloud computing from other domains.

A main objective of the working group is to continue development and improvement of a roadmap for developing and migrating to cloud environment and to identify the tools/vendors to consider at each step of the roadmap