Software Engineering

Cloud-Based Software:

Virtualization and containers,

Everything as a service, Software as a service

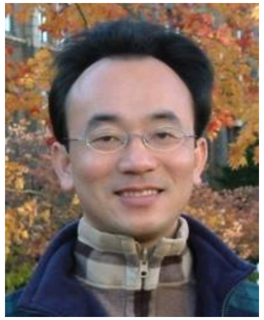
1132SE06
MBA, IM, NTPU (M5010) (Spring 2025)
Wed 2, 3, 4 (9:10-12:00) (B3F17)

aws educate | Cloud Ambassador
2020 Cohort

aws academy Accredited Educator

aws certified Cloud Practitioner

aws certified Solutions Architect Associate



Min-Yuh Day, Ph.D,
Professor

Institute of Information Management, National Taipei University

https://web.ntpu.edu.tw/~myday

https://meet.google.com/ish-gzmy-pmo

2025-04-16

Syllabus

Week	Date	Subject/Topics
1	2025/02/19	Introduction to Software Engineering
2	2025/02/26	Software Products and Project Management: Software product management and prototyping with Generative AI
3	2025/03/05	Agile Software Engineering: Agile methods, Scrum, and Extreme Programming
4	2025/03/12	Case Study on Software Engineering I
5	2025/03/19	Features, Scenarios, and Stories
6	2025/03/26	Software Architecture: Architectural design, System decomposition, and Distribution architecture

Syllabus

Week	Date	Subject/Topics
7	2025/04/02	Make-up holiday for NTPU Sports Day (No Classes)
8	2025/04/09	Midterm Project Report
9	2025/04/16	Cloud-Based Software: Virtualization and containers, Everything as a service, Software as a service
10	2025/04/23	Cloud Computing and Cloud Software Architecture
11	2025/04/30	Case Study on Software Engineering II
12	2025/05/07	Microservices Architecture, RESTful services, Service deployment

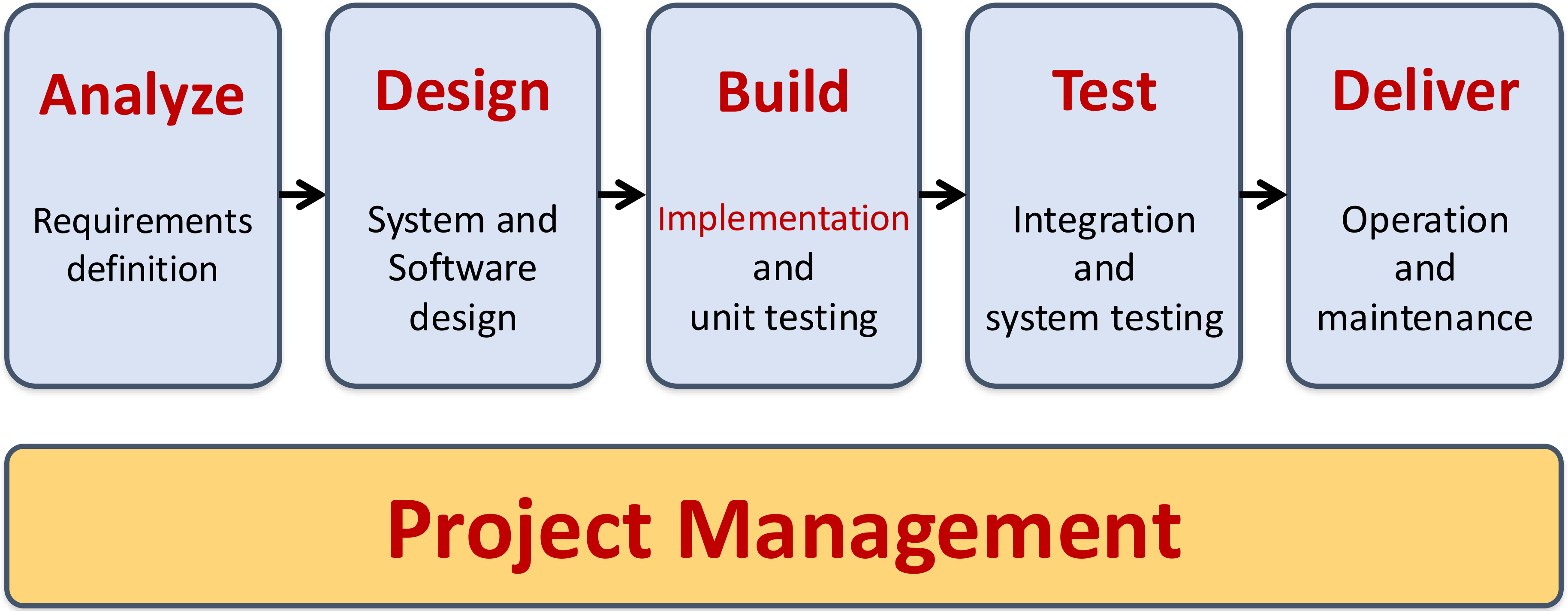
Syllabus

Week	Date	Subject/Topics
13	2025/05/14	Industry Practices of Software Engineering
14	2025/05/21	Security and Privacy; Reliable Programming; Testing: Functional testing, Test automation, Test-driven development, and Code reviews; DevOps and Code Management: Code management and DevOps automation
15	2025/05/28	Final Project Report I
16	2025/06/04	Final Project Report II

Cloud-Based Software:

Virtualization and containers,
Everything as a service,
Software as a service

Software Engineering
and
Project Management



Analyze

Requirements definition

Design

System and Software design

Build

Implementation and unit testing

Test

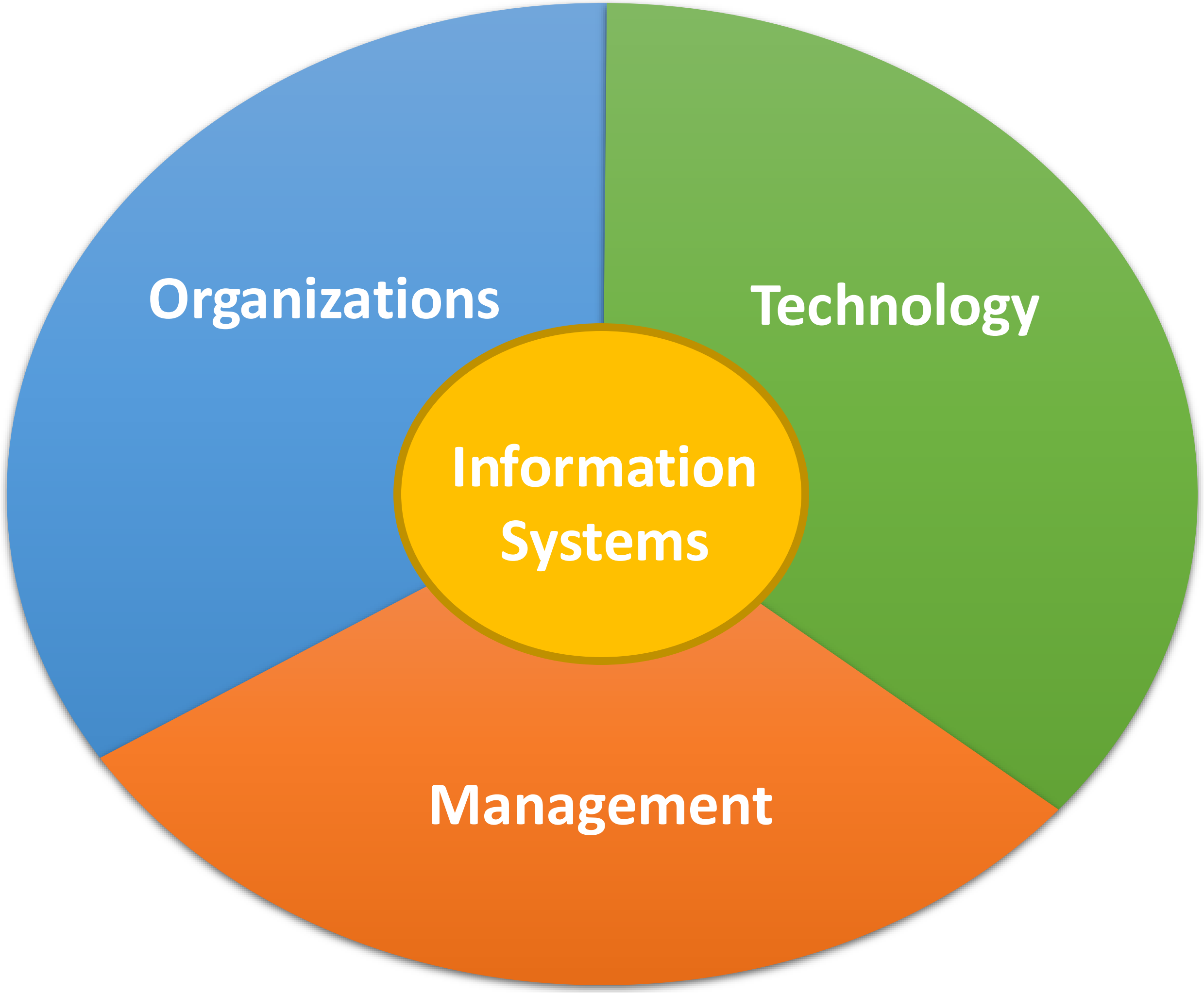
Integration and system testing

Deliver

Operation and maintenance

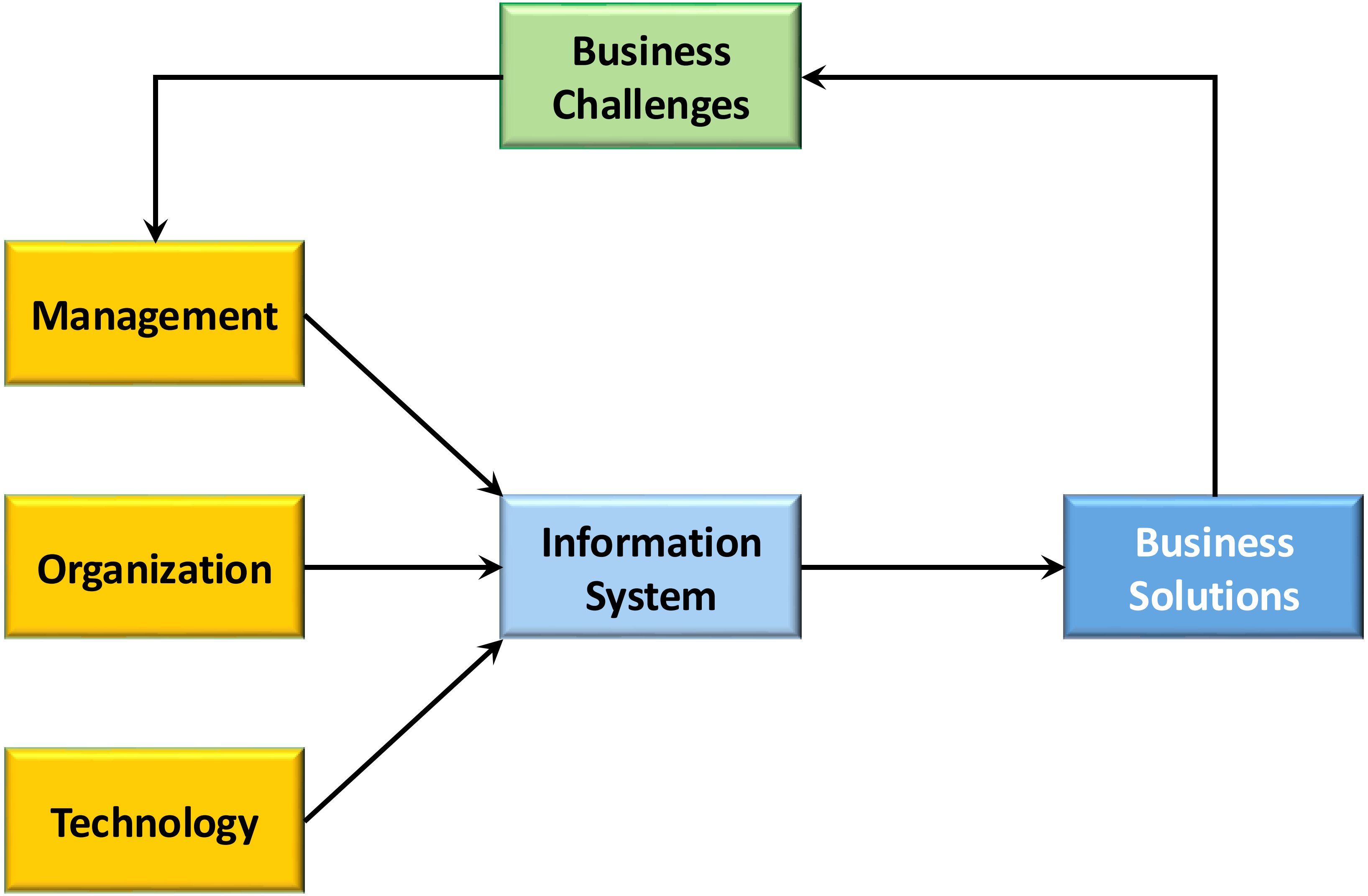
Project Management

Information Management (MIS)
Information Systems



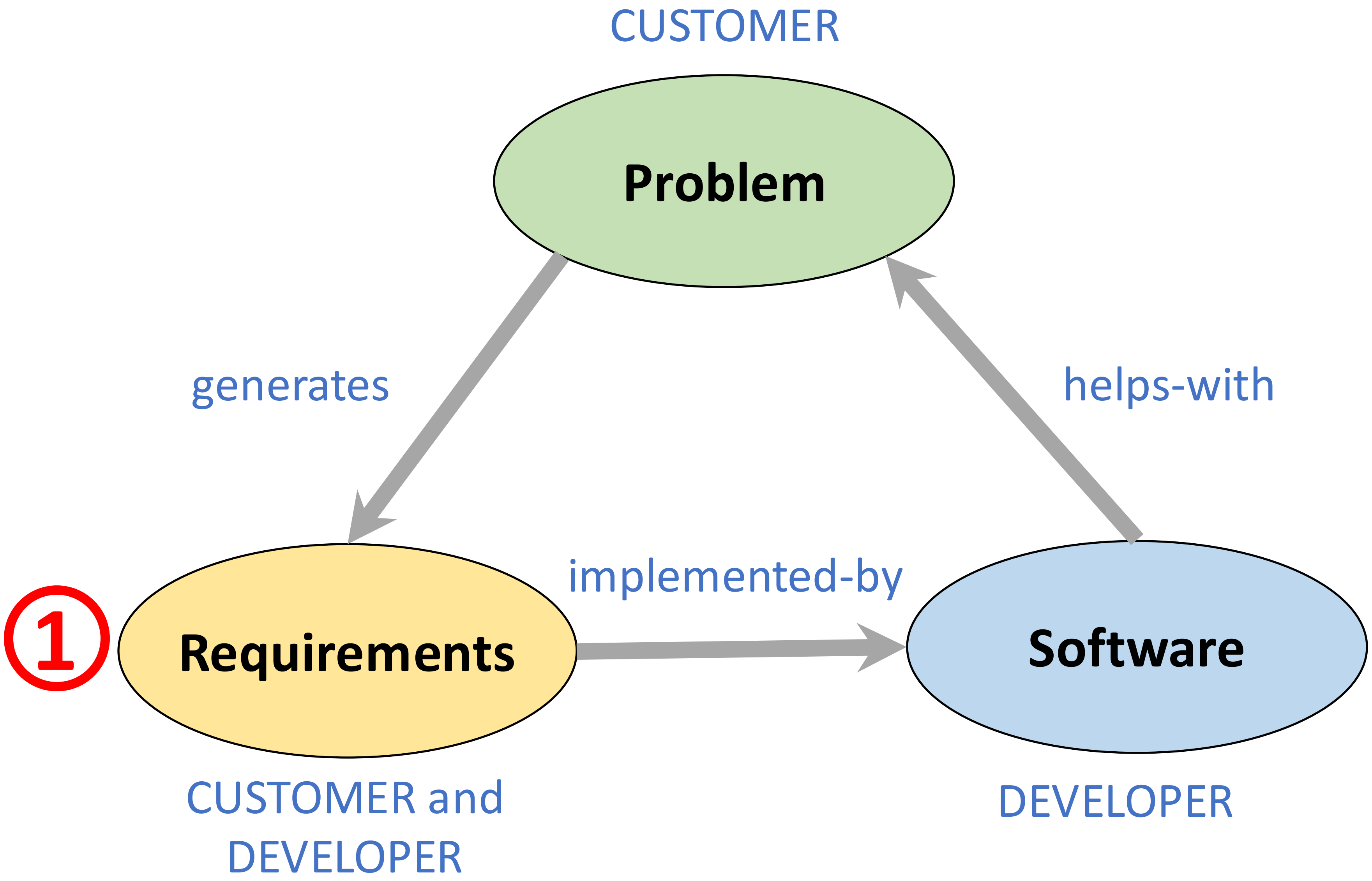
Source: Kenneth C. Laudon & Jane P. Laudon (2014), Management Information Systems: Managing the Digital Firm, Thirteenth Edition, Pearson.

Fundamental MIS Concepts



Source: Kenneth C. Laudon & Jane P. Laudon (2014), Management Information Systems: Managing the Digital Firm, Thirteenth Edition, Pearson.

Project-based software engineering



CUSTOMER

Problem

generates

helps-with

implemented-by

①

Requirements

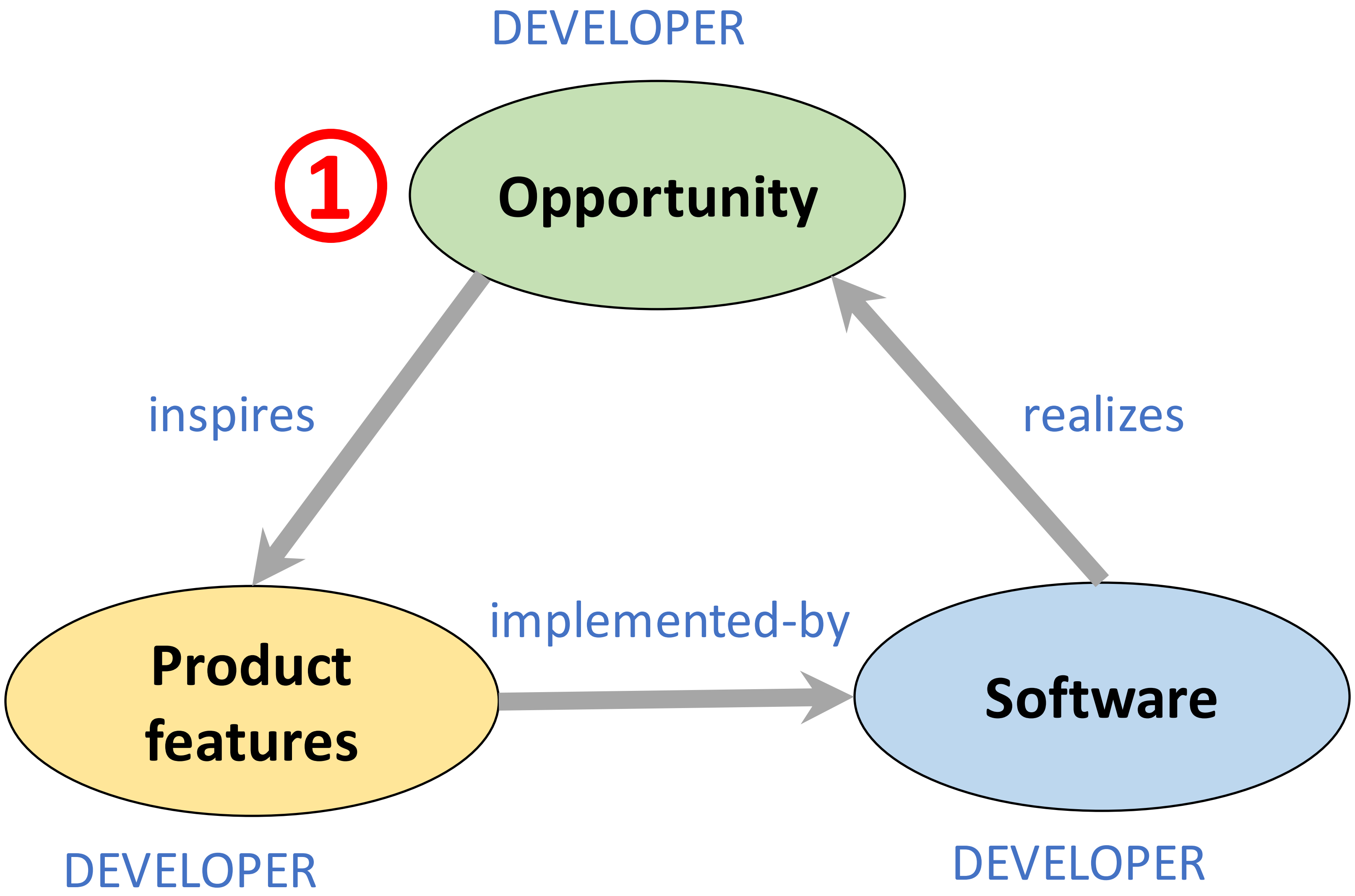
Software

CUSTOMER and DEVELOPER

DEVELOPER

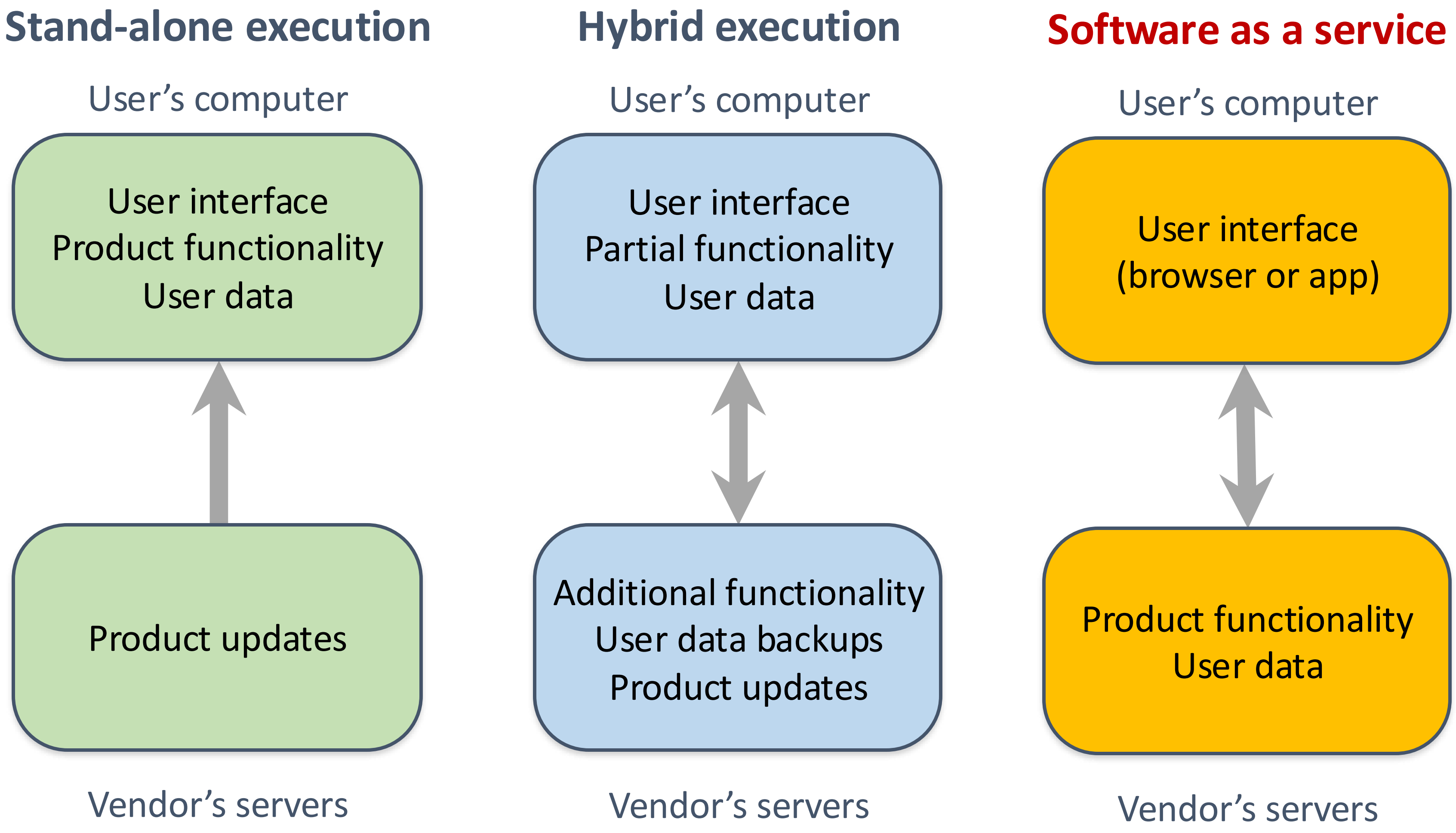
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Product software engineering



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software execution models



Stand-alone execution

User's computer

User interface
Product functionality
User data

Product updates

Vendor's servers

Hybrid execution

User's computer

User interface
Partial functionality
User data

Additional functionality
User data backups
Product updates

Vendor's servers

Software as a service

User's computer

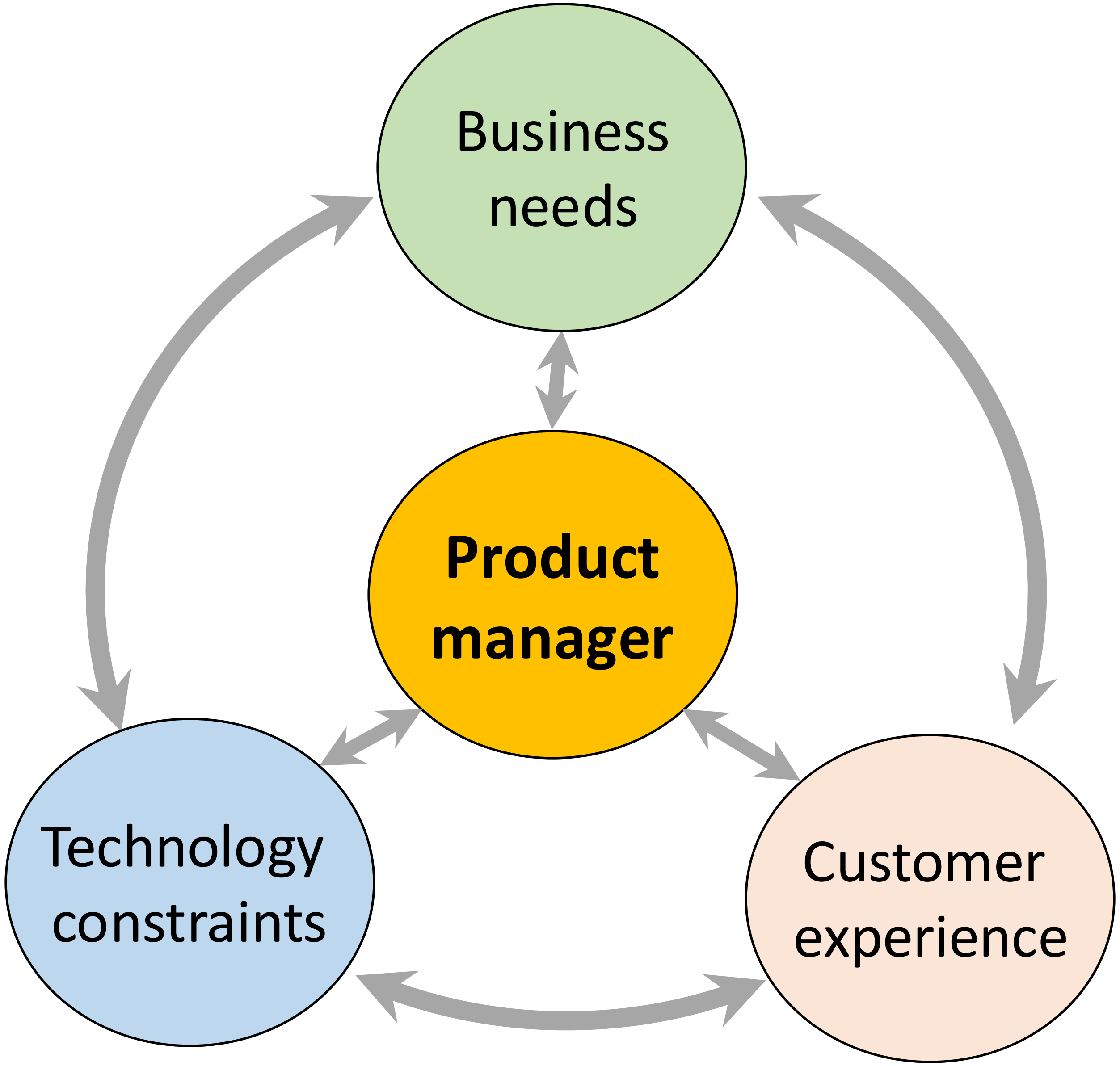
User interface
(browser or app)

Product functionality
User data

Vendor's servers

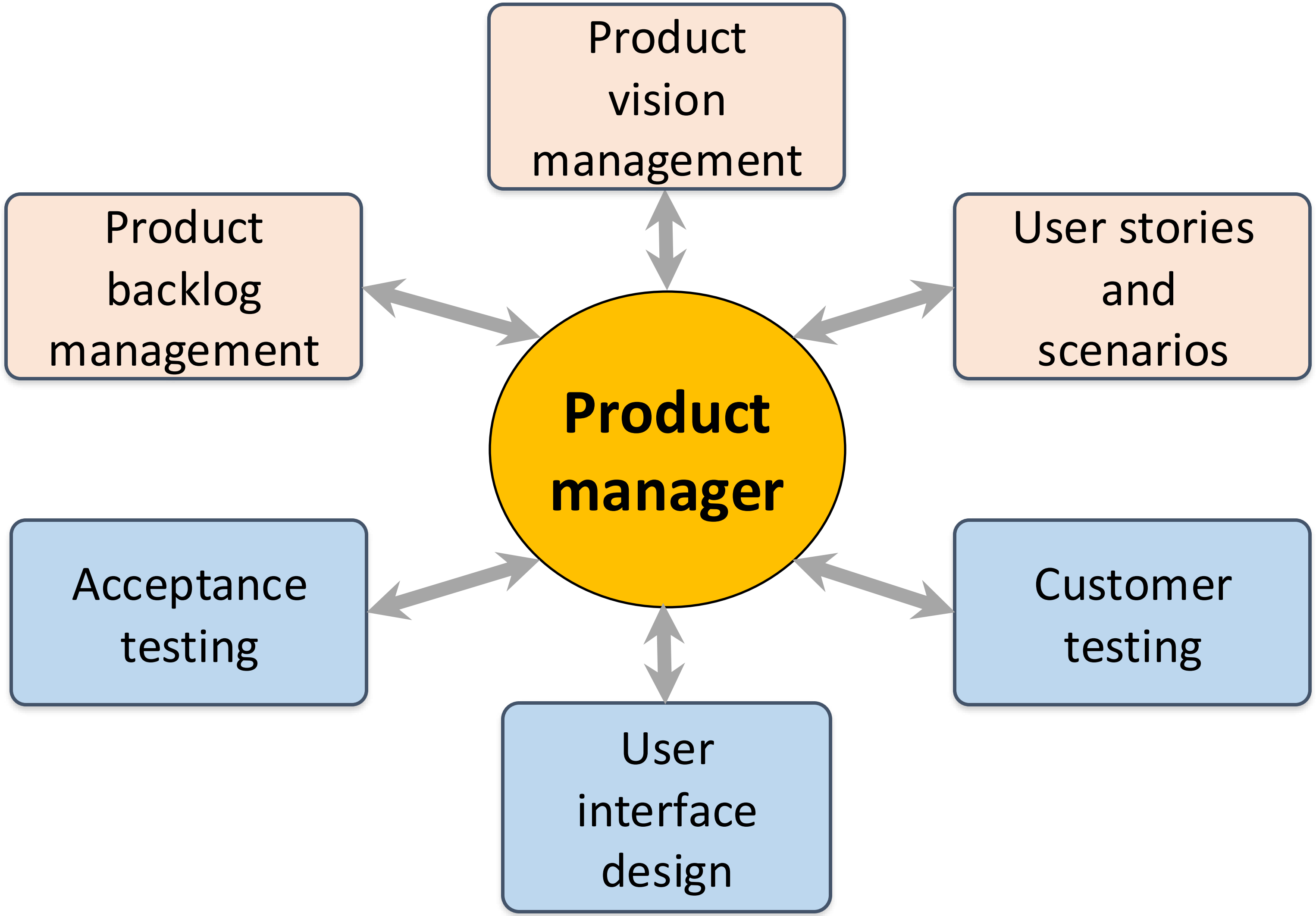
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Product management concerns



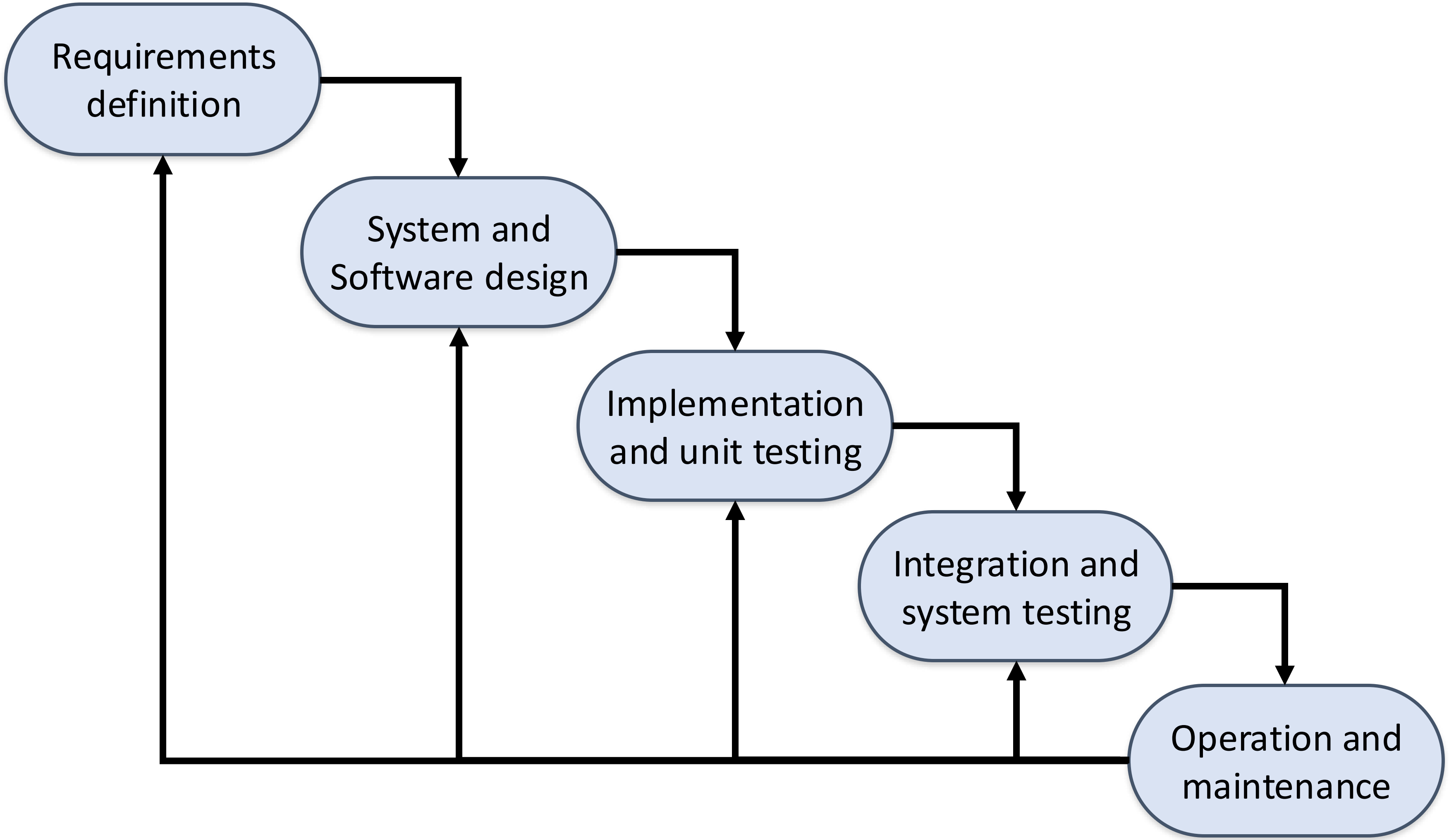
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Technical interactions of product managers


Product vision management
Product backlog management
User stories and scenarios
Product manager
Acceptance testing
Customer testing
User interface design

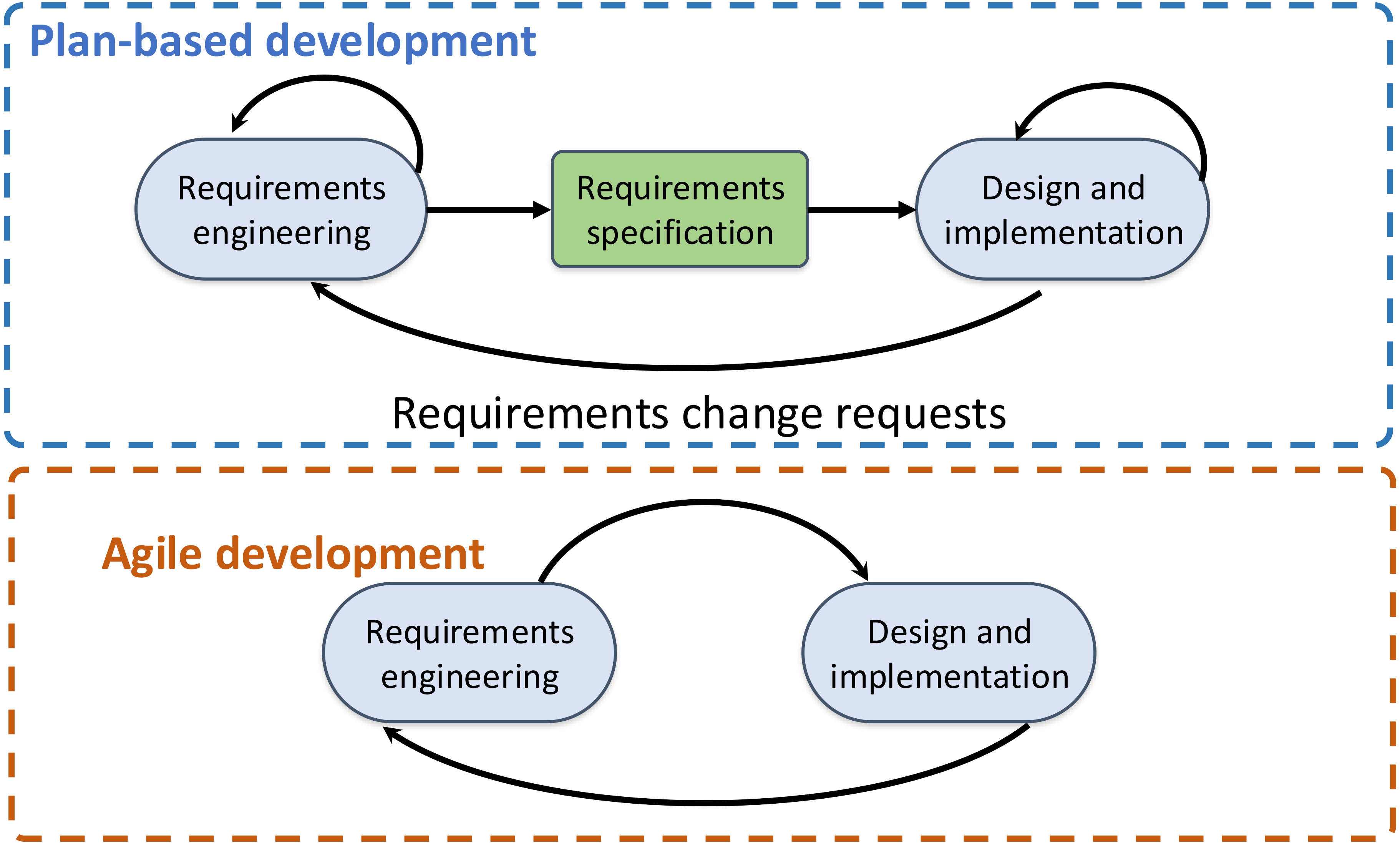
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software Development Life Cycle (SDLC)
The waterfall model


Requirements definition
System and Software design
Implementation and unit testing
Integration and system testing
Operation and maintenance

Source: Ian Sommerville (2015), Software Engineering, 10th Edition, Pearson.

Plan-based and Agile development



Plan-based development

Requirements engineering

Requirements specification

Design and implementation

Requirements change requests

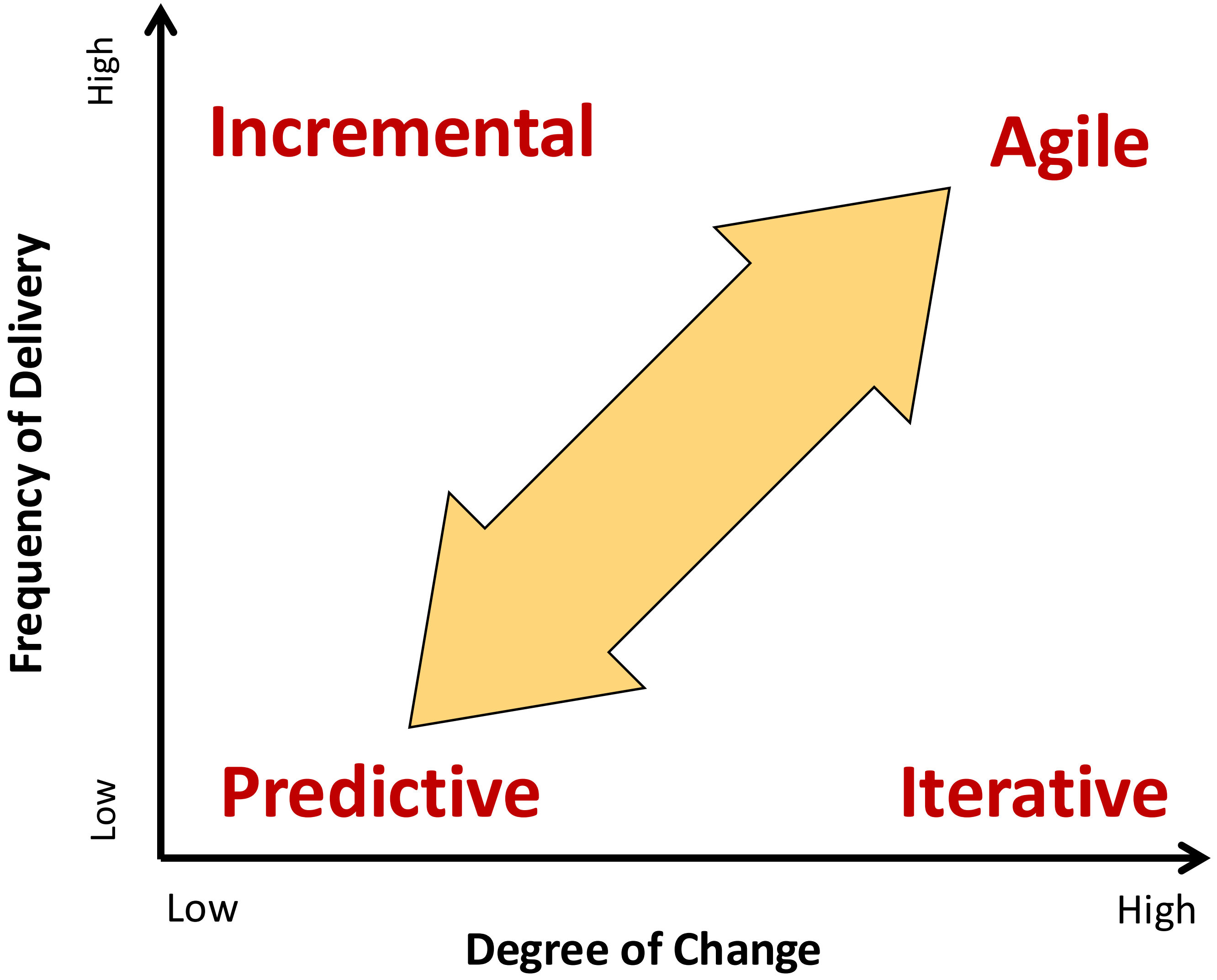
Agile development

Requirements engineering

Design and implementation

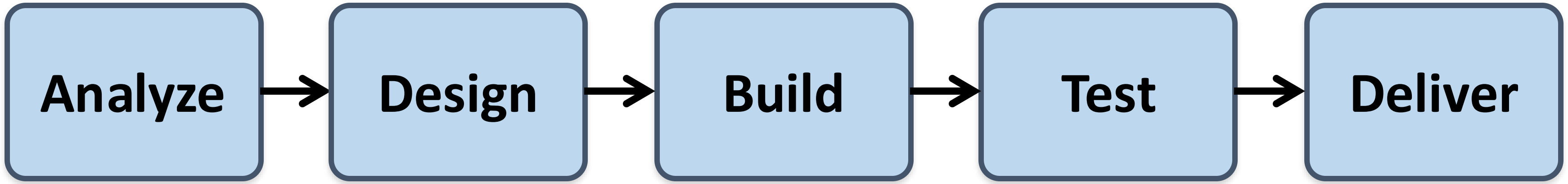
Source: Ian Sommerville (2015), Software Engineering, 10th Edition, Pearson.

The Continuum of Life Cycles



Source: Project Management Institute (2017), Agile Practice Guide, Project Management Institute

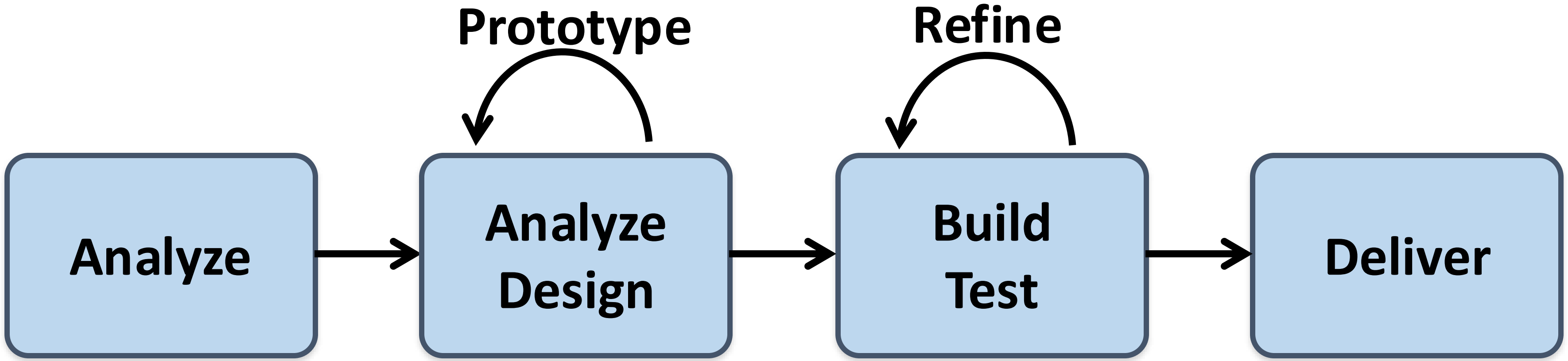
Predictive Life Cycle



Analyze → Design → Build → Test → Deliver

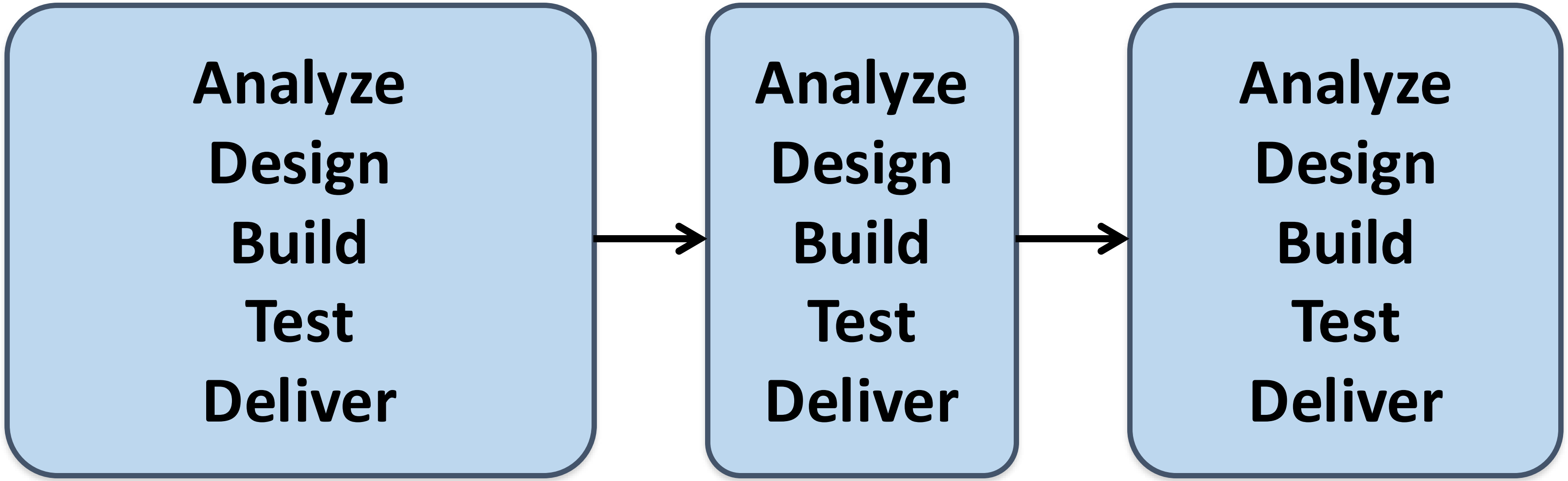
Source: Project Management Institute (2017), Agile Practice Guide, Project Management Institute

Iterative Life Cycle



Source: Project Management Institute (2017), Agile Practice Guide, Project Management Institute

A Life Cycle of Varying-Sized Increments



Analyze
Design
Build
Test
Deliver

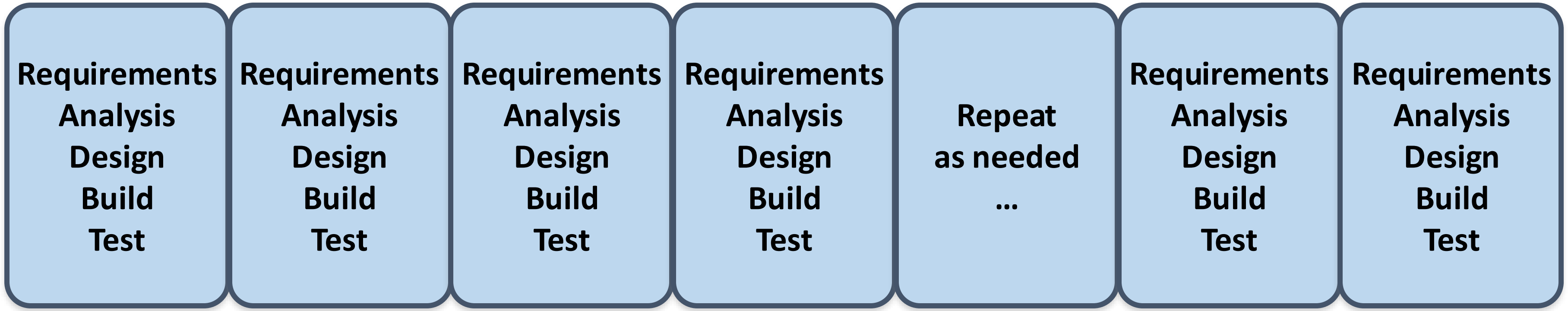
Analyze
Design
Build
Test
Deliver

Analyze
Design
Build
Test
Deliver

Source: Project Management Institute (2017), Agile Practice Guide, Project Management Institute

Iteration-Based and Flow-Based Agile Life Cycles

Iteration-Based Agile



Requirements Analysis Design Build Test

Requirements Analysis Design Build Test

Requirements Analysis Design Build Test

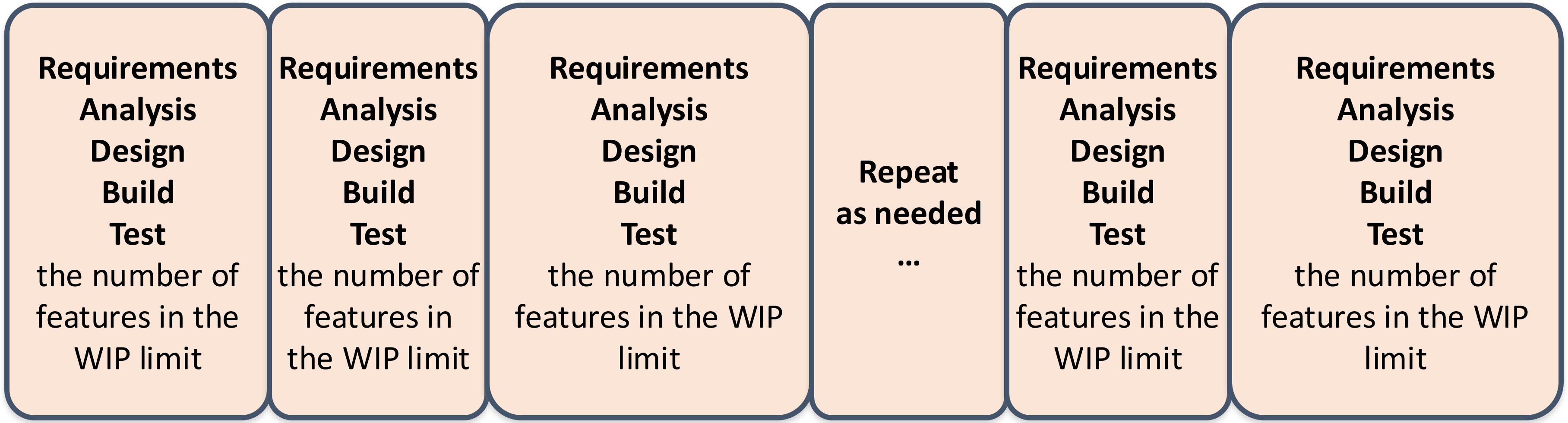
Requirements Analysis Design Build Test

Repeat as needed …

Requirements Analysis Design Build Test

Requirements Analysis Design Build Test

Flow-Based Agile



Requirements Analysis Design Build Test the number of features in the WIP limit

Requirements Analysis Design Build Test the number of features in the WIP limit

Requirements Analysis Design Build Test the number of features in the WIP limit

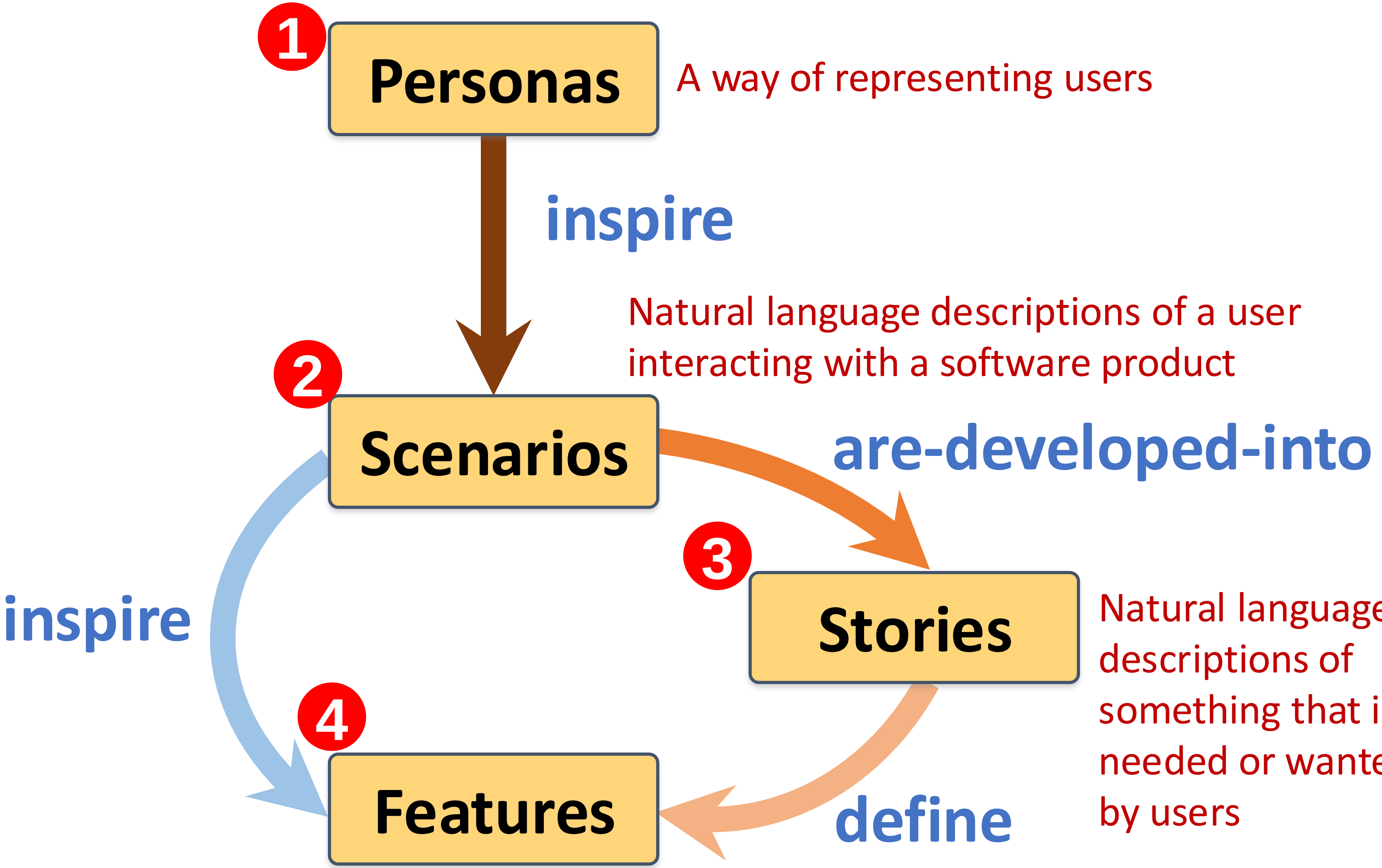
Repeat as needed …

Requirements Analysis Design Build Test the number of features in the WIP limit

Requirements Analysis Design Build Test the number of features in the WIP limit

Source: Project Management Institute (2017), Agile Practice Guide, Project Management Institute

From personas to features



1 Personas

inspire

2 Scenarios

are-developed-into

3 Stories

define

4 Features

inspire

A way of representing users

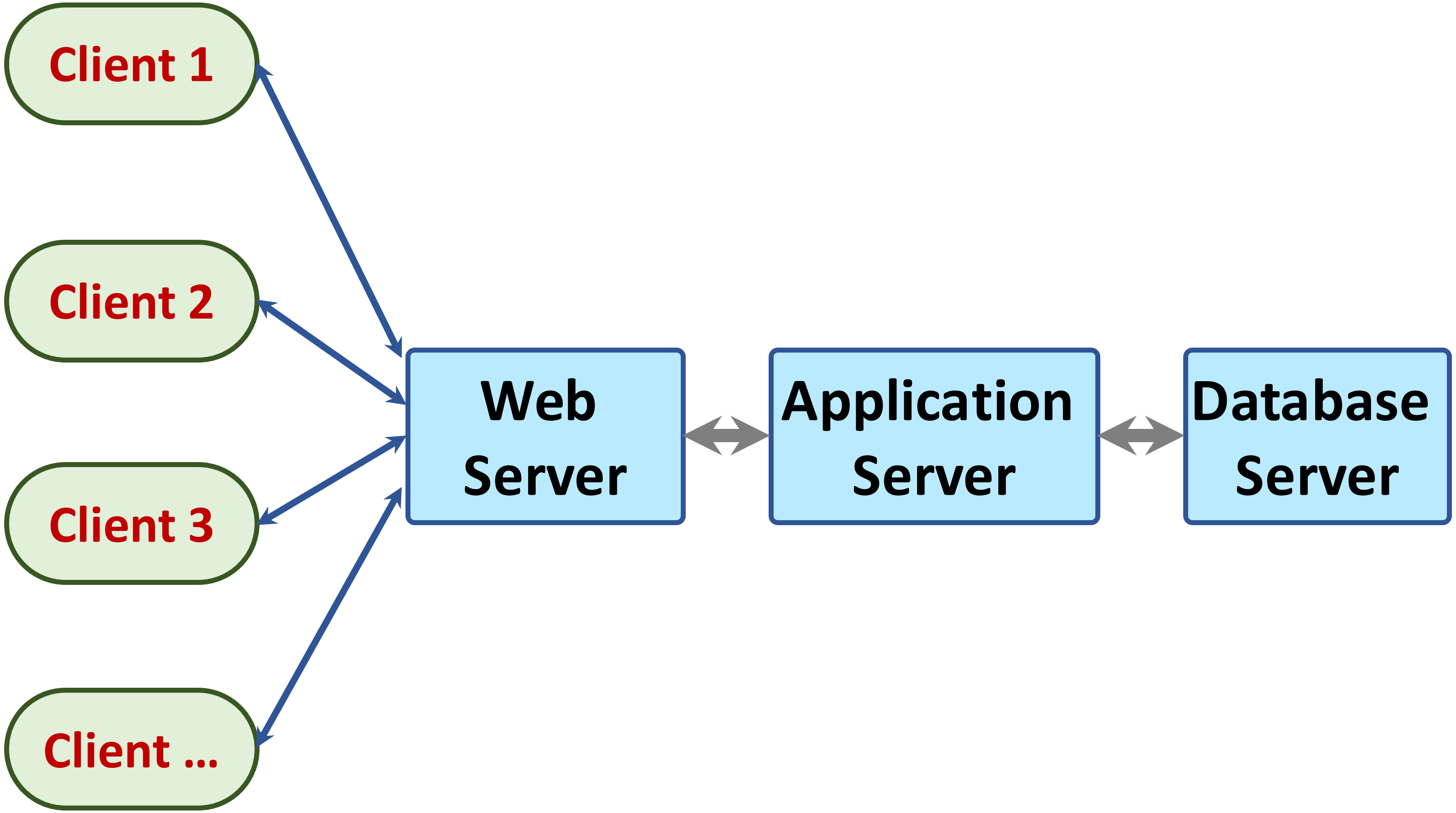
Natural language descriptions of a user interacting with a software product

Natural language descriptions of something that is needed or wanted by users

Fragments of product functionality

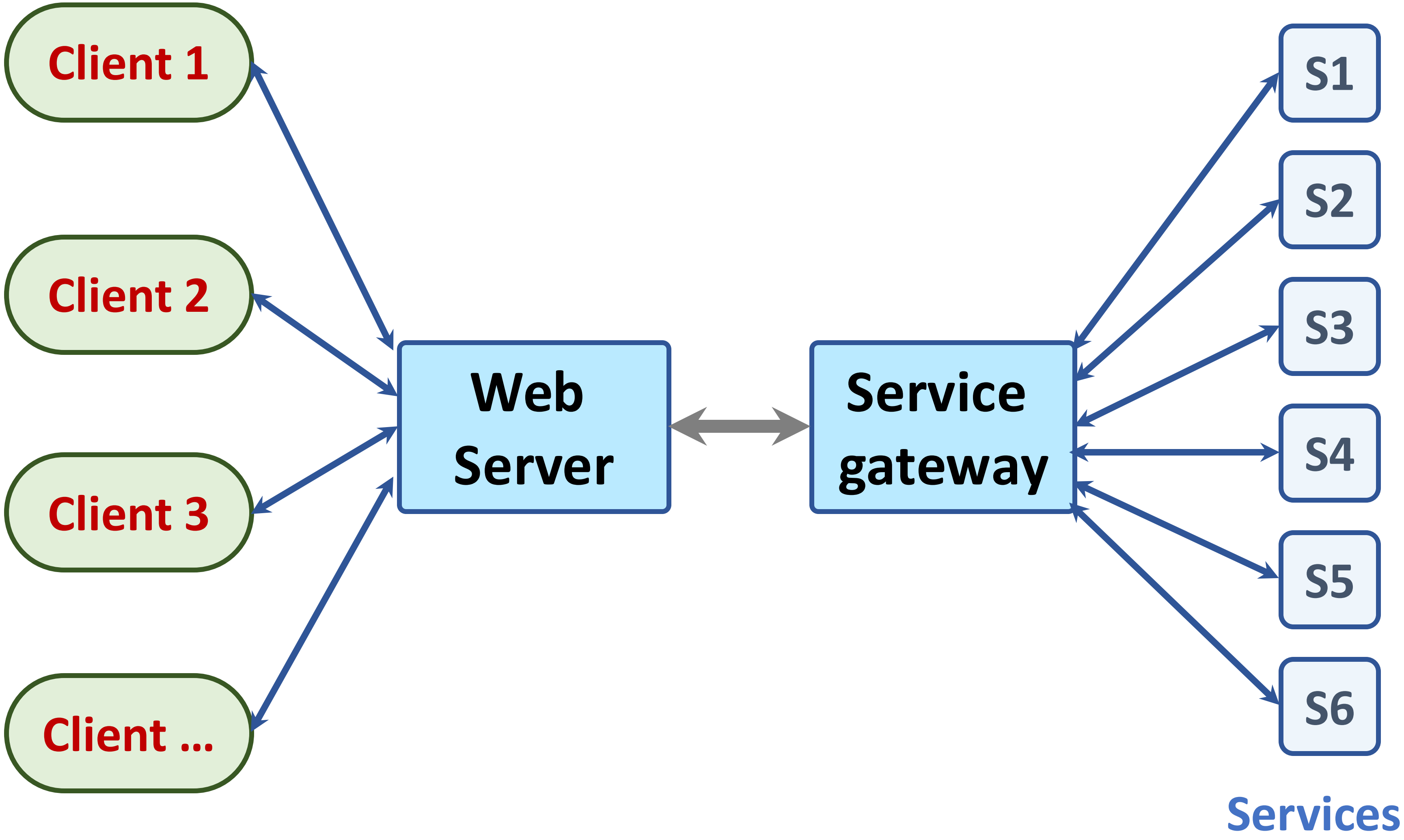
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Multi-tier client-server architecture

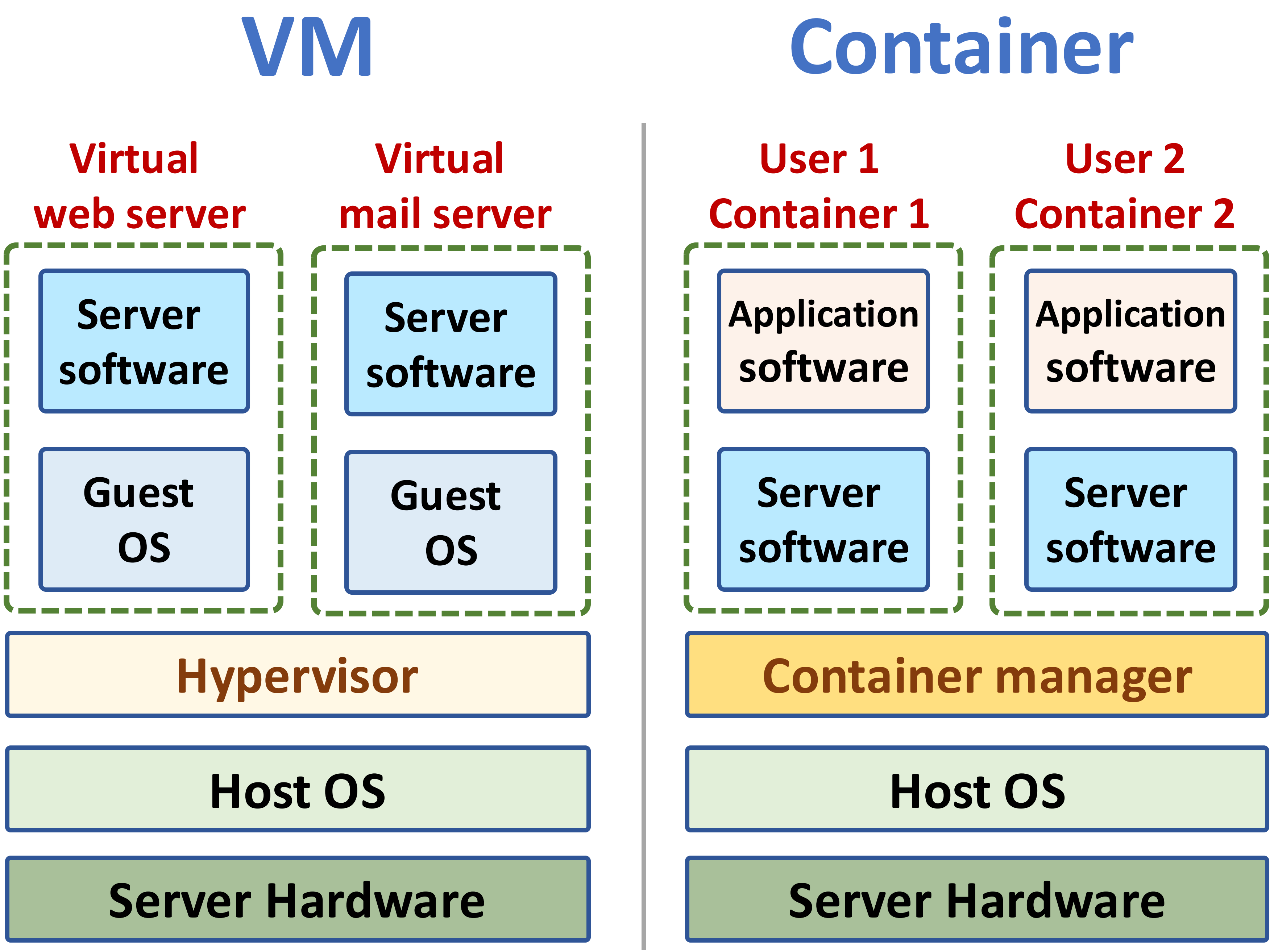


Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Service-oriented Architecture



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.



VM

Virtual web server

Server software

Guest OS

Virtual mail server

Server software

Guest OS

Hypervisor

Host OS

Server Hardware

Container

User 1 Container 1

Application software

Server software

User 2 Container 2

Application software

Server software

Container manager

Host OS

Server Hardware

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Everything as a service

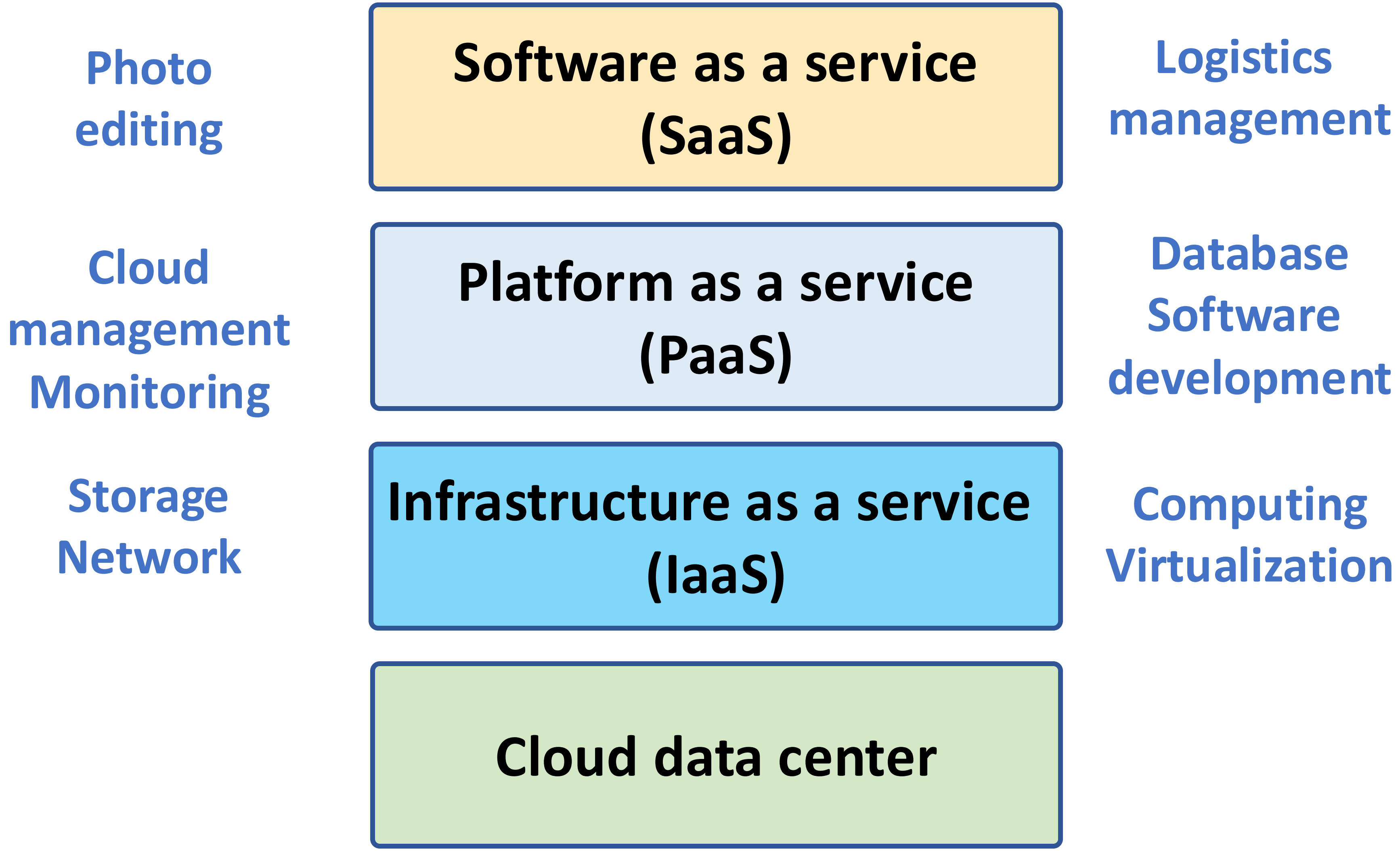


Photo editing

Software as a service (SaaS)

Logistics management

Cloud management Monitoring

Platform as a service (PaaS)

Database Software development

Storage Network

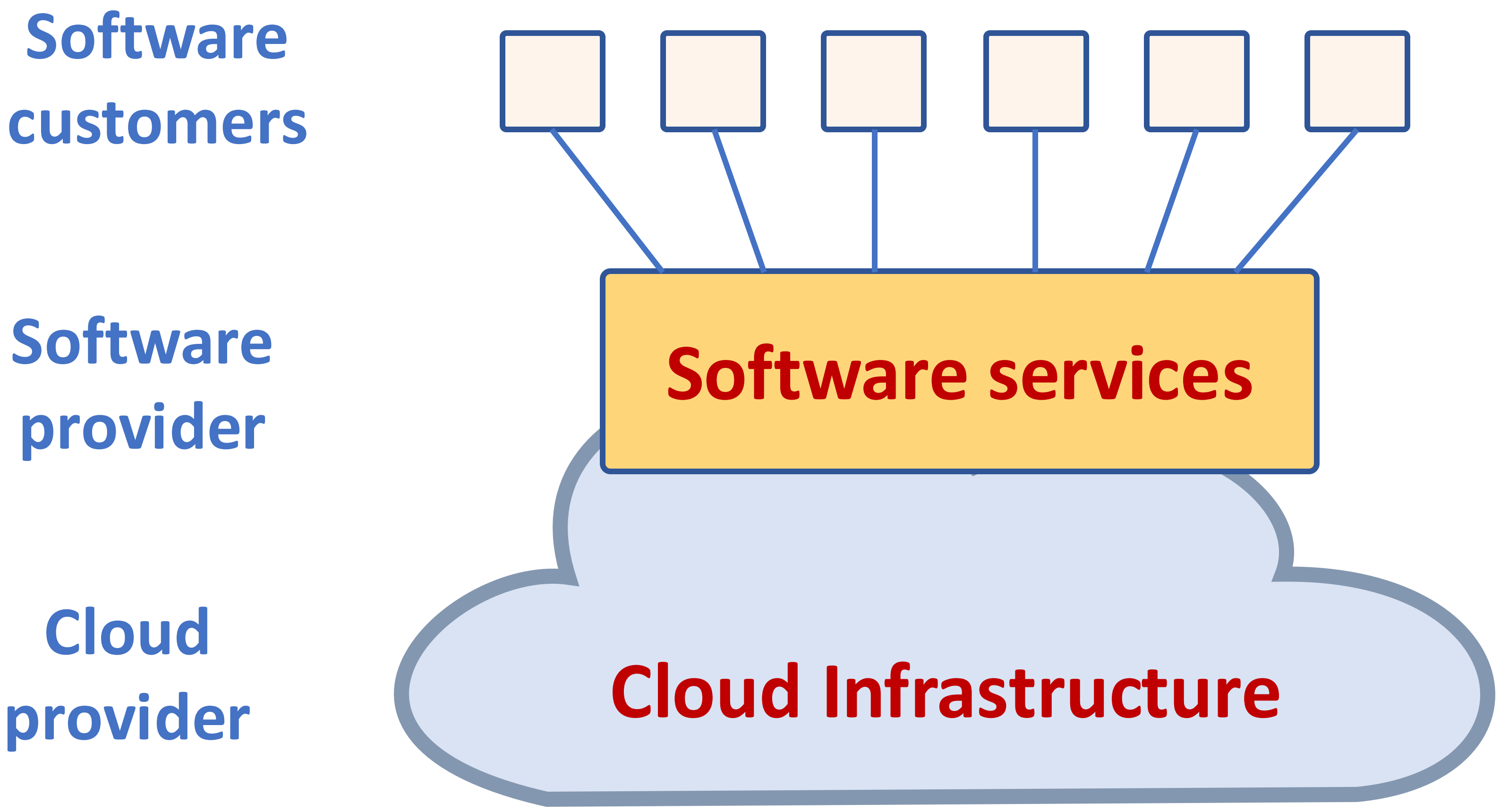
Infrastructure as a service (IaaS)

Computing Virtualization

Cloud data center

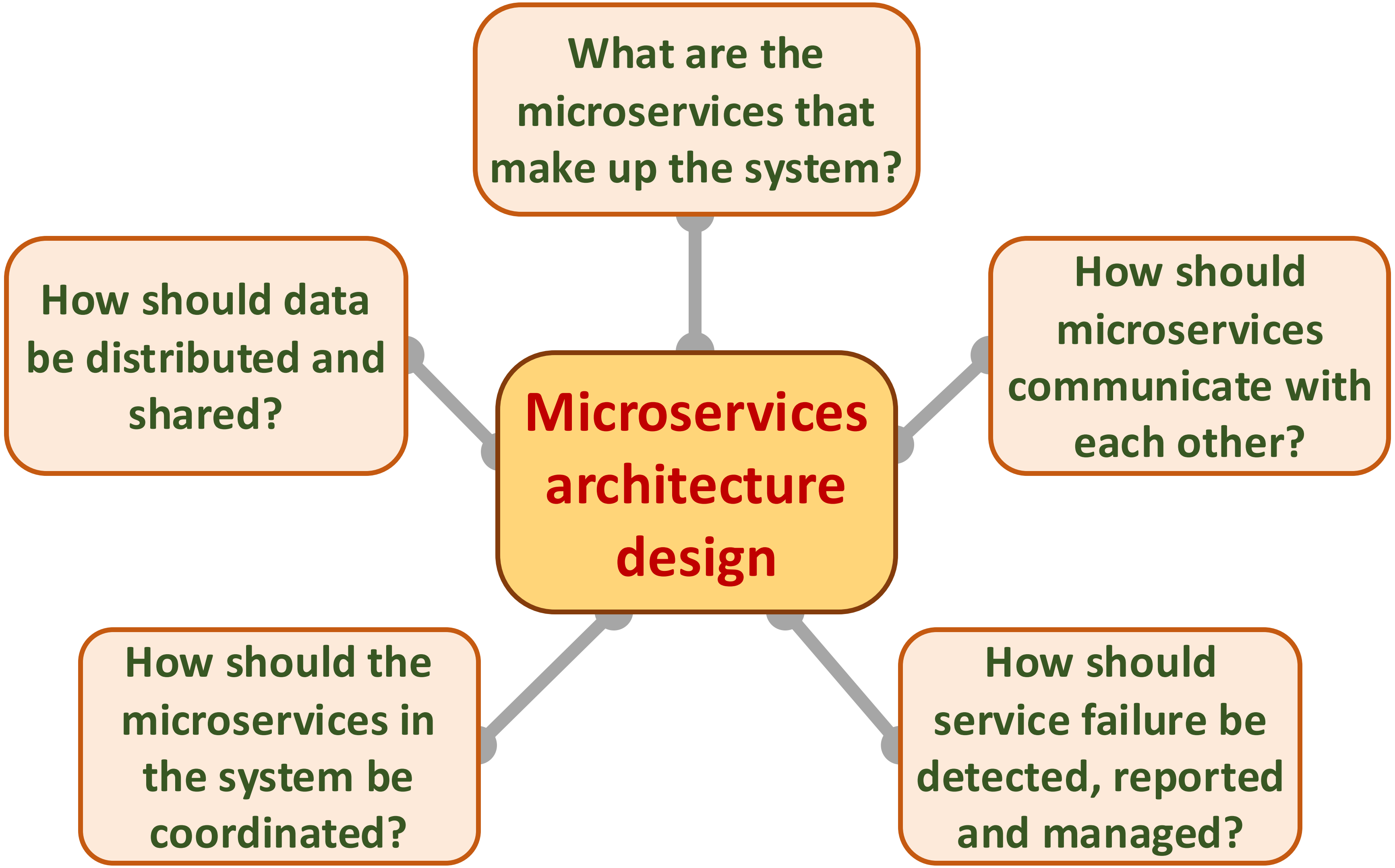
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software as a service



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Microservices architecture – key design questions



Microservices architecture design

What are the microservices that make up the system?

How should microservices communicate with each other?

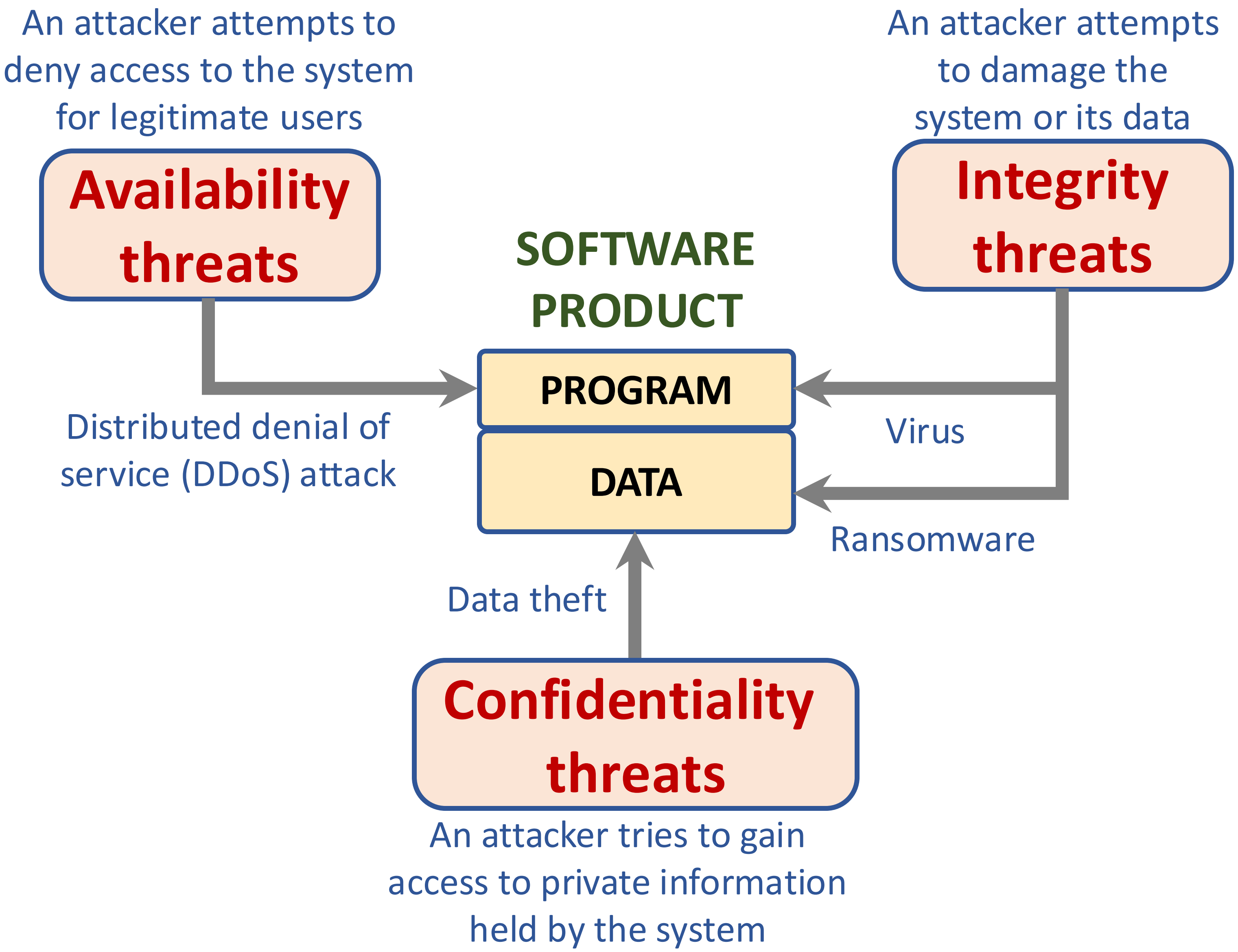
How should service failure be detected, reported and managed?

How should the microservices in the system be coordinated?

How should data be distributed and shared?

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Types of security threat



An attacker attempts to deny access to the system for legitimate users

Availability threats

Distributed denial of service (DDoS) attack

SOFTWARE PRODUCT

PROGRAM

DATA

An attacker attempts to damage the system or its data

Integrity threats

Virus

Ransomware

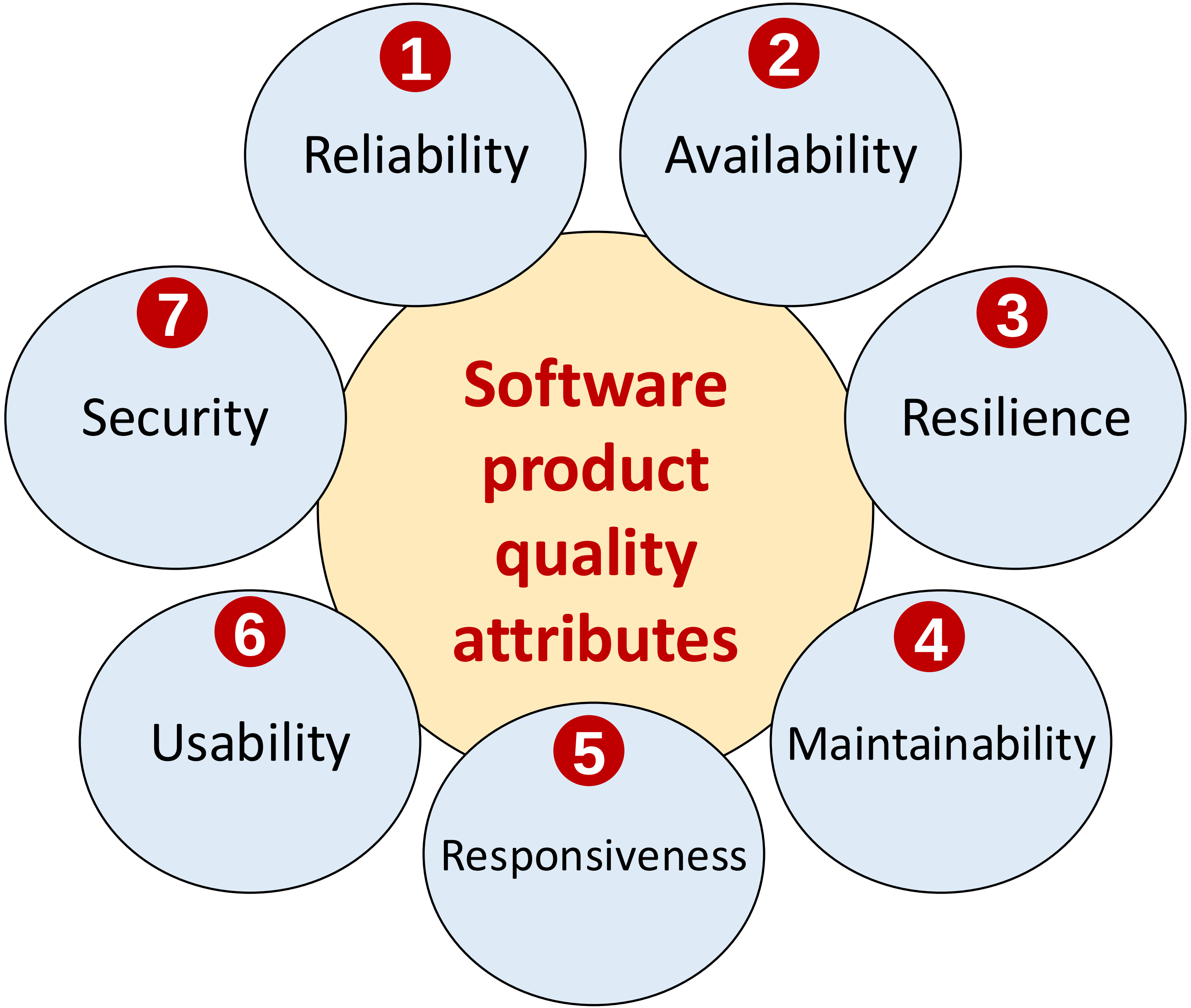
Data theft

Confidentiality threats

An attacker tries to gain access to private information held by the system

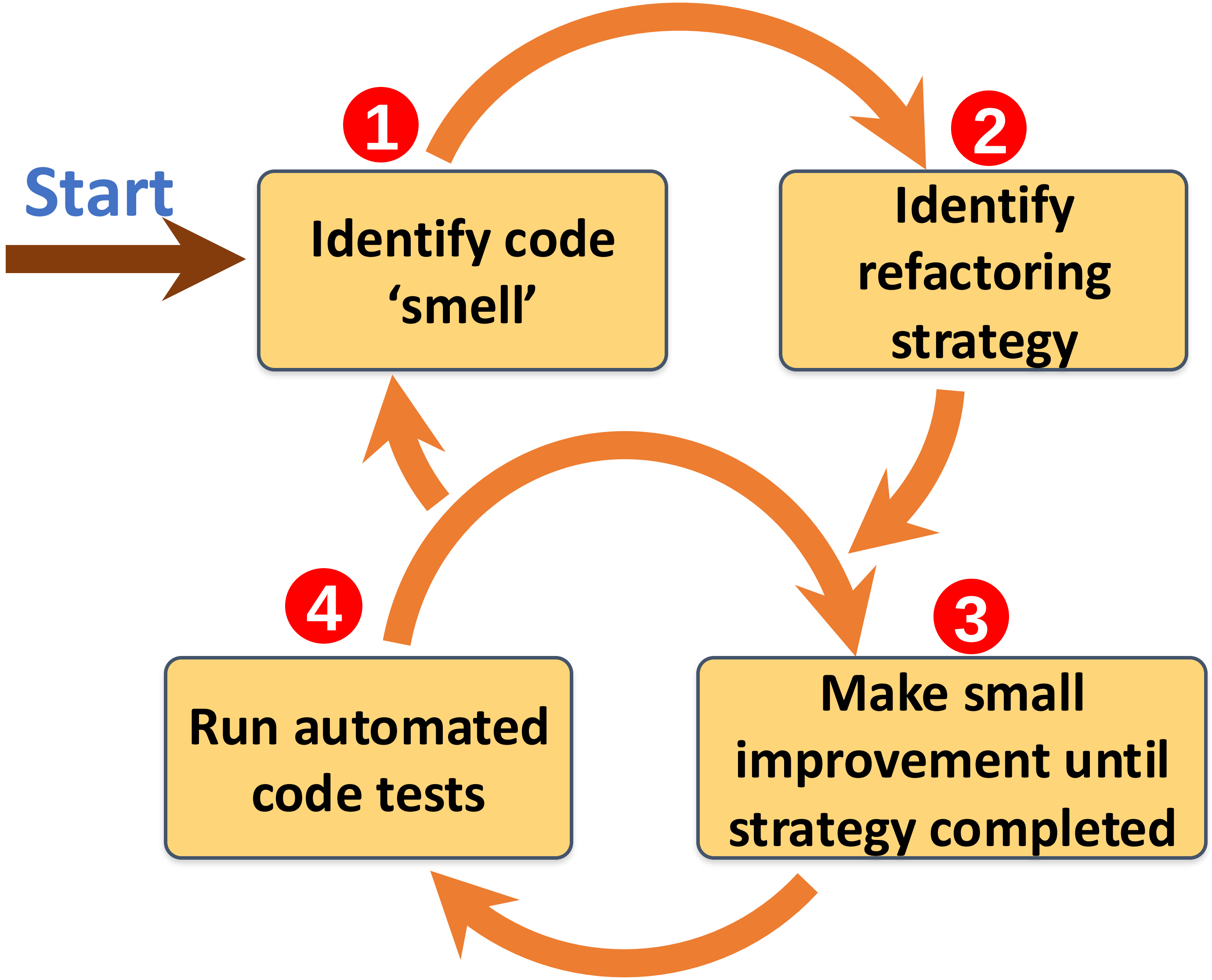
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software product quality attributes



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

A refactoring process



Start

1 Identify code 'smell'

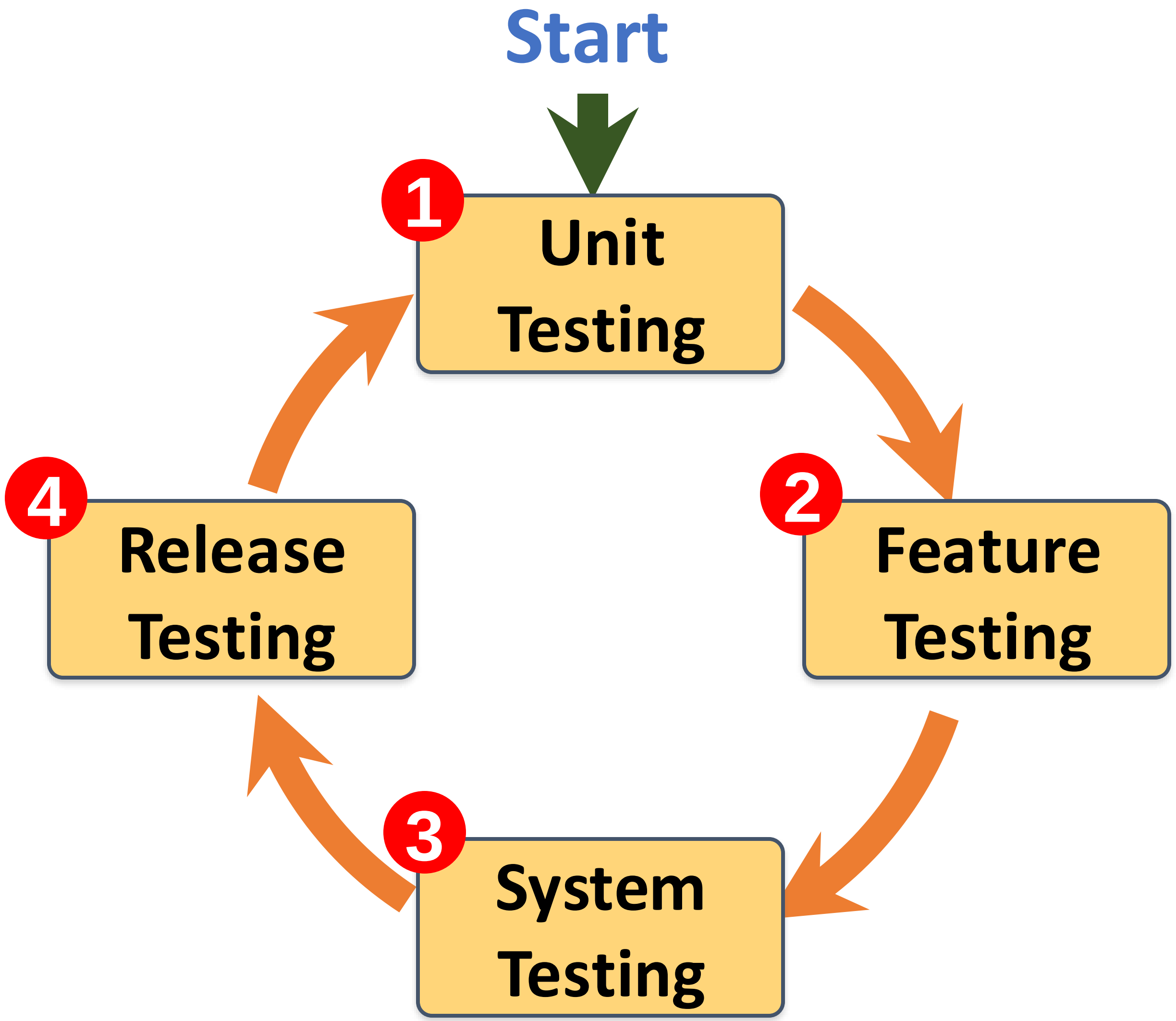
2 Identify refactoring strategy

3 Make small improvement until strategy completed

4 Run automated code tests

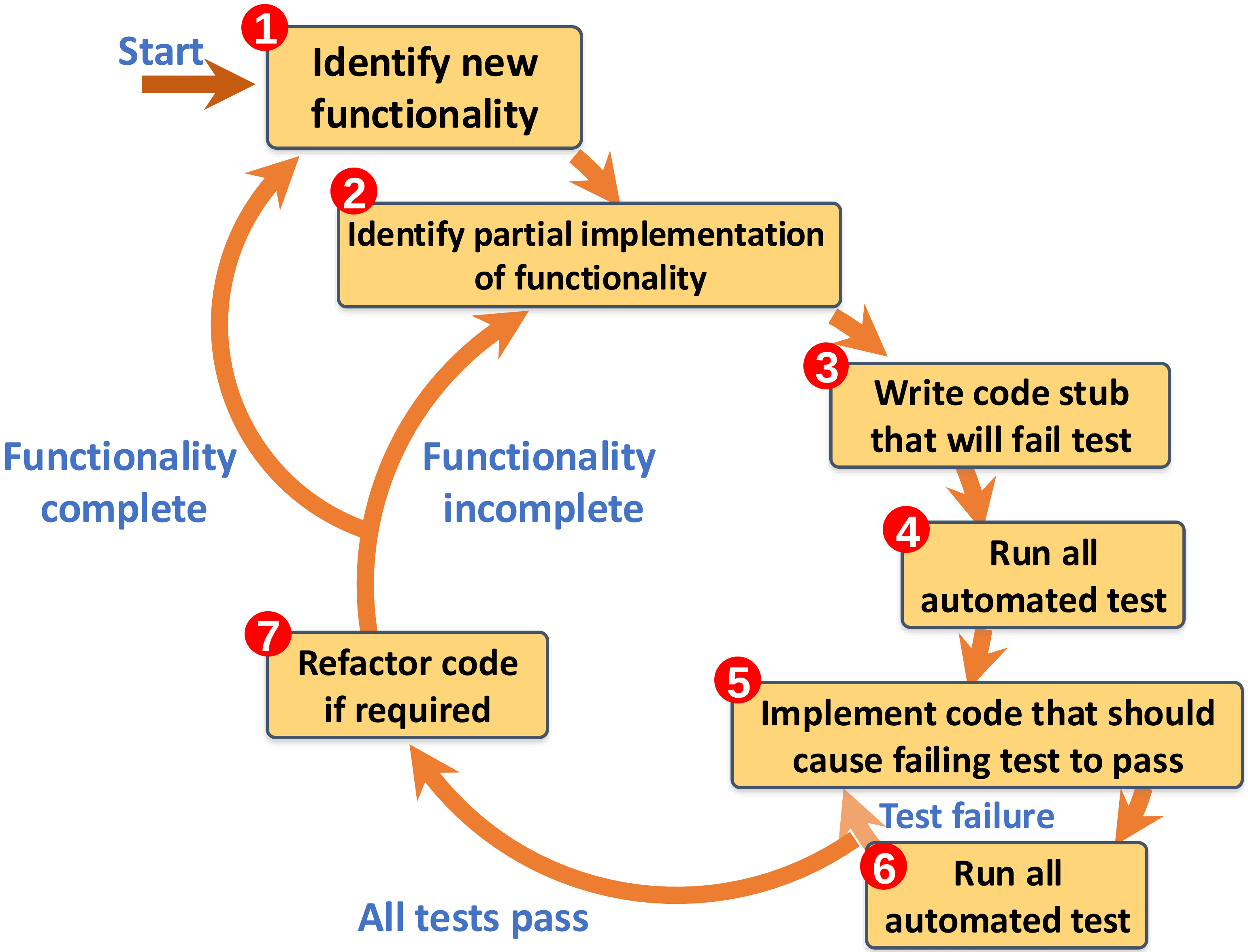
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Functional testing



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Test-driven development (TDD)



Start

1 Identify new functionality

2 Identify partial implementation of functionality

3 Write code stub that will fail test

4 Run all automated test

5 Implement code that should cause failing test to pass

Test failure

6 Run all automated test

All tests pass

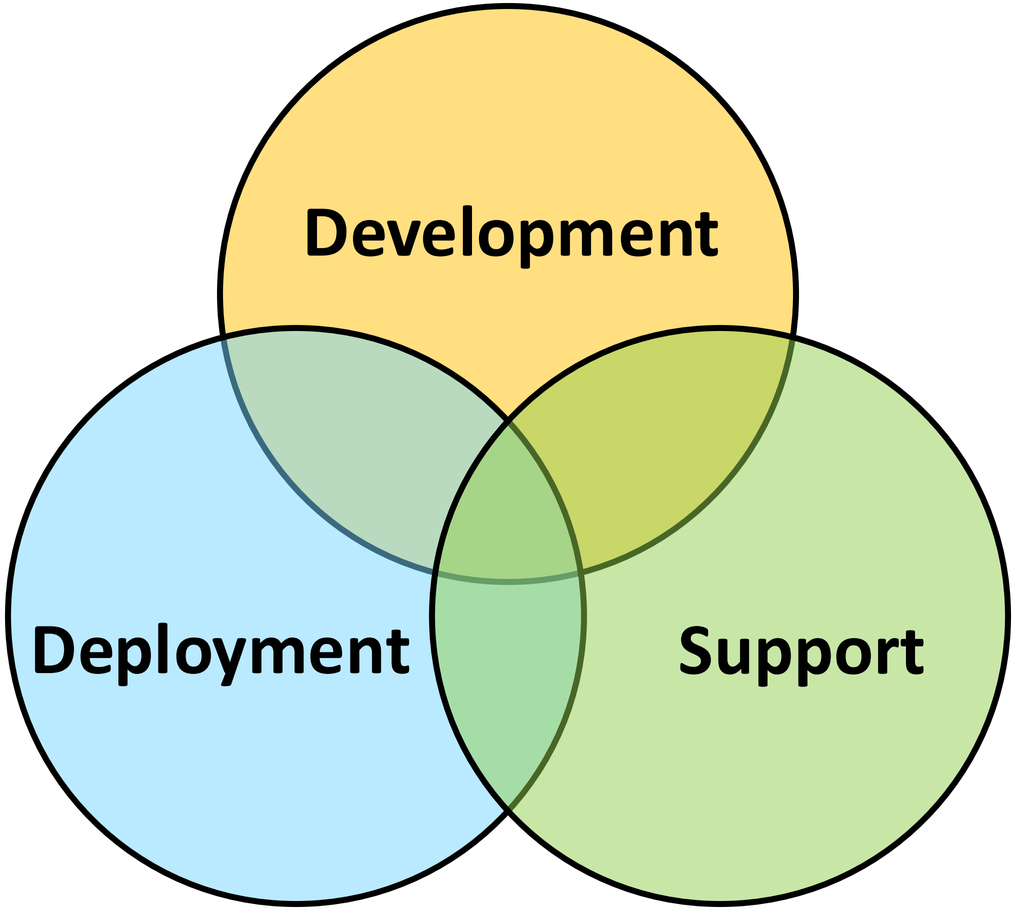
7 Refactor code if required

Functionality incomplete

Functionality complete

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

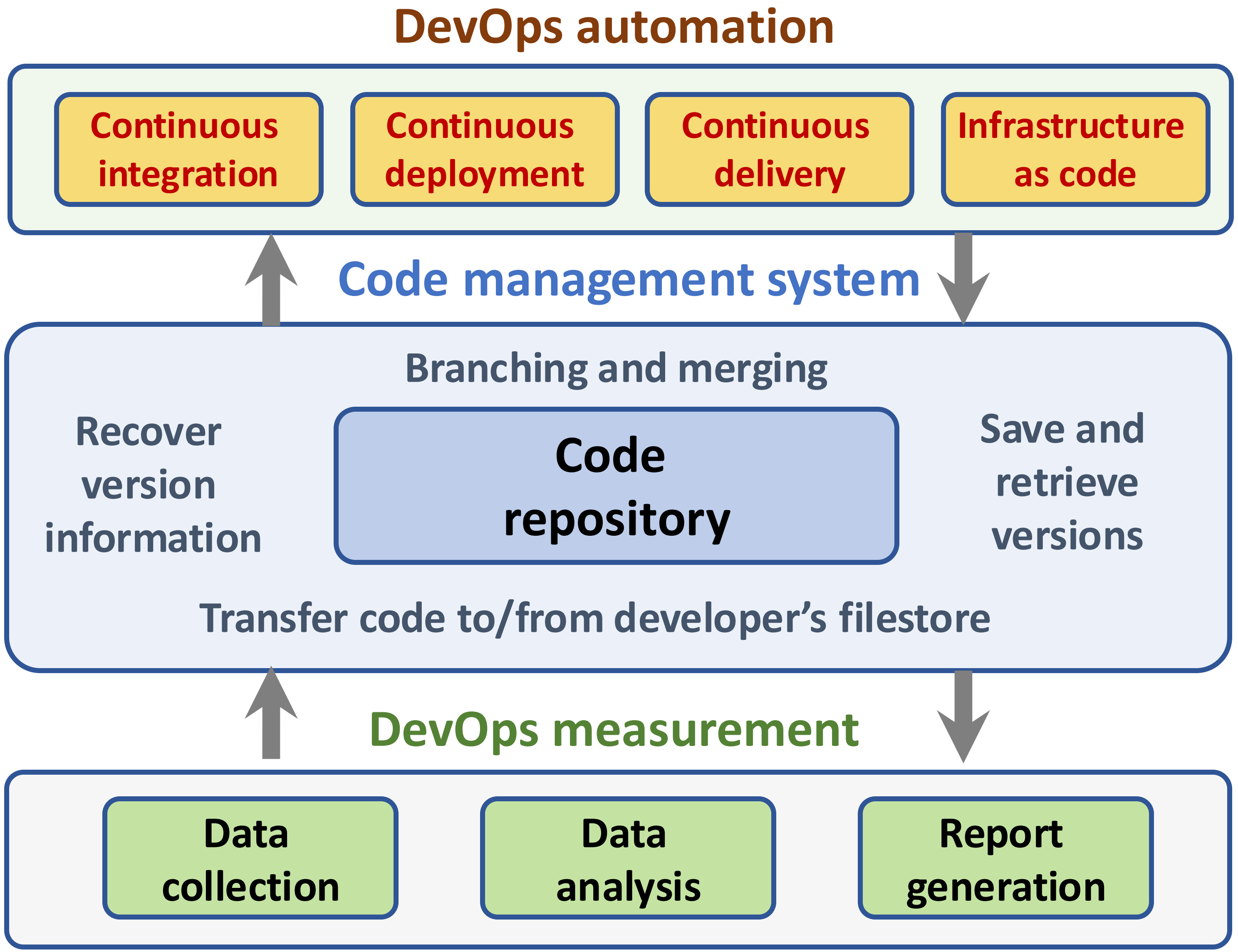
DevOps



Multi-skilled DevOps team

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Code management and DevOps



DevOps automation

Continuous integration

Continuous deployment

Continuous delivery

Infrastructure as code

Code management system

Branching and merging

Recover version information

Code repository

Save and retrieve versions

Transfer code to/from developer's filestore

DevOps measurement

Data collection

Data analysis

Report generation

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

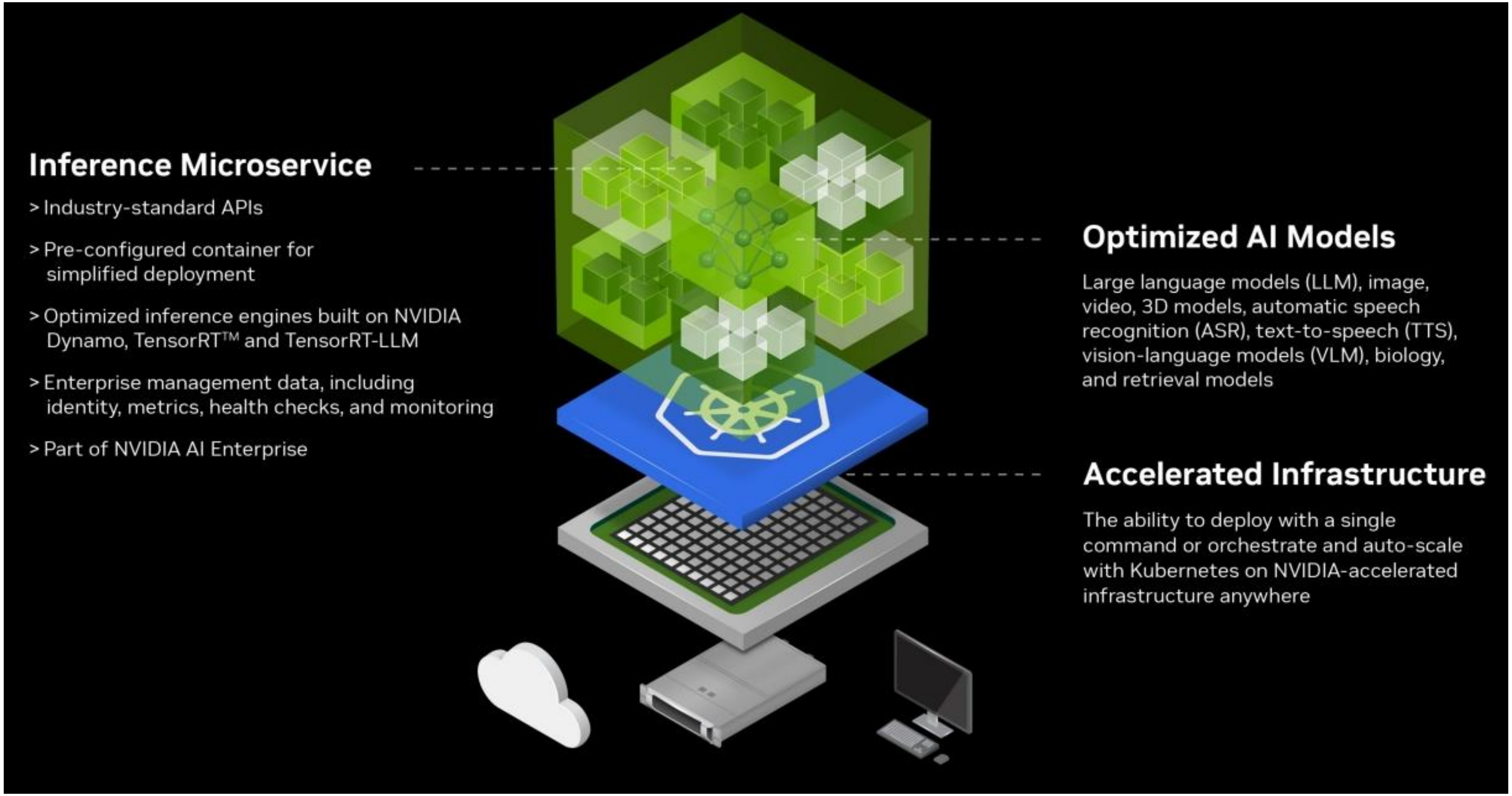
Cloud-Based Software:

Virtualization and containers, Everything as a service, Software as a service

Nvidia Inference Microservices (NIM)

Designed for rapid, reliable deployment of accelerated generative AI inference anywhere

NVIDIA NIM™ provides prebuilt, optimized inference microservices for rapidly deploying the latest AI models on any NVIDIA-accelerated infrastructure—cloud, data center, workstation, and edge.



Inference Microservice

> Industry-standard APIs

> Pre-configured container for simplified deployment

> Optimized inference engines built on NVIDIA Dynamo, TensorRT™ and TensorRT-LLM

> Enterprise management data, including identity, metrics, health checks, and monitoring

> Part of NVIDIA AI Enterprise

Optimized AI Models

Large language models (LLM), image, video, 3D models, automatic speech recognition (ASR), text-to-speech (TTS), vision-language models (VLM), biology, and retrieval models

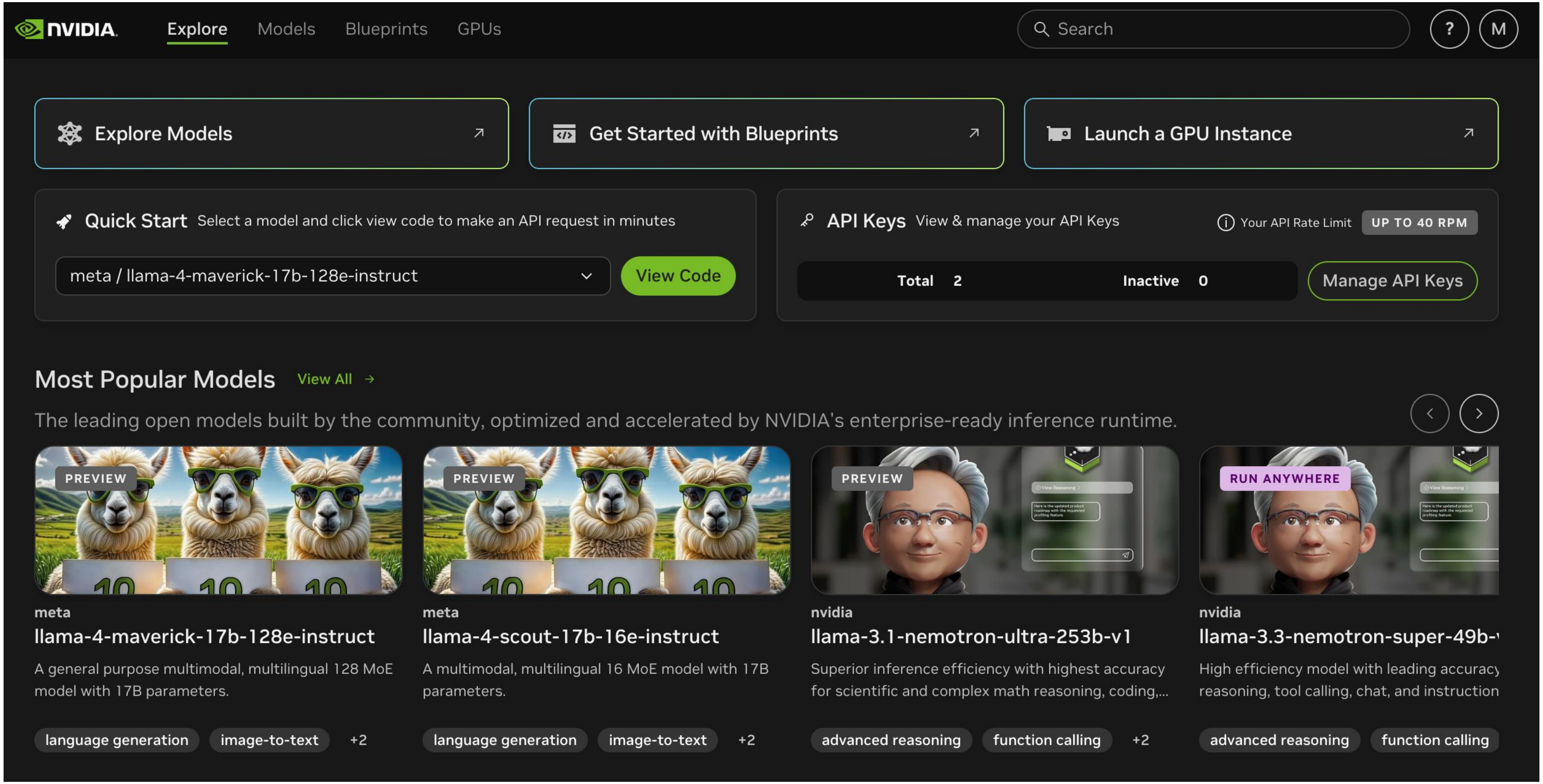
Accelerated Infrastructure

The ability to deploy with a single command or orchestrate and auto-scale with Kubernetes on NVIDIA-accelerated infrastructure anywhere

https://www.nvidia.com/en-us/ai-data-science/products/nim-microservices/

Nvidia Inference Microservices (NIM)

Designed for rapid, reliable deployment of accelerated generative AI inference anywhere



Quick Start Select a model and click view code to make an API request in minutes

meta / llama-4-maverick-17b-128e-instruct

API Keys View & manage your API Keys

Your API Rate Limit UP TO 40 RPM

Total 2 Inactive 0

Most Popular Models View All →

The leading open models built by the community, optimized and accelerated by NVIDIA's enterprise-ready inference runtime.

meta
llama-4-maverick-17b-128e-instruct
A general purpose multimodal, multilingual 128 MoE model with 17B parameters.
language generation | image-to-text | +2

meta
llama-4-scout-17b-16e-instruct
A multimodal, multilingual 16 MoE model with 17B parameters.
language generation | image-to-text | +2

nvidia
llama-3.1-nemotron-ultra-253b-v1
Superior inference efficiency with highest accuracy for scientific and complex math reasoning, coding,...
advanced reasoning | function calling | +2

nvidia
llama-3.3-nemotron-super-49b-v
High efficiency model with leading accuracy reasoning, tool calling, chat, and instruction
advanced reasoning | function calling

https://build.nvidia.com/

The cloud

- The cloud is made up of very large number of remote servers that are offered for rent by companies that own these servers.
  - Cloud-based servers are ‘virtual servers’, which means that they are implemented in software rather than hardware.

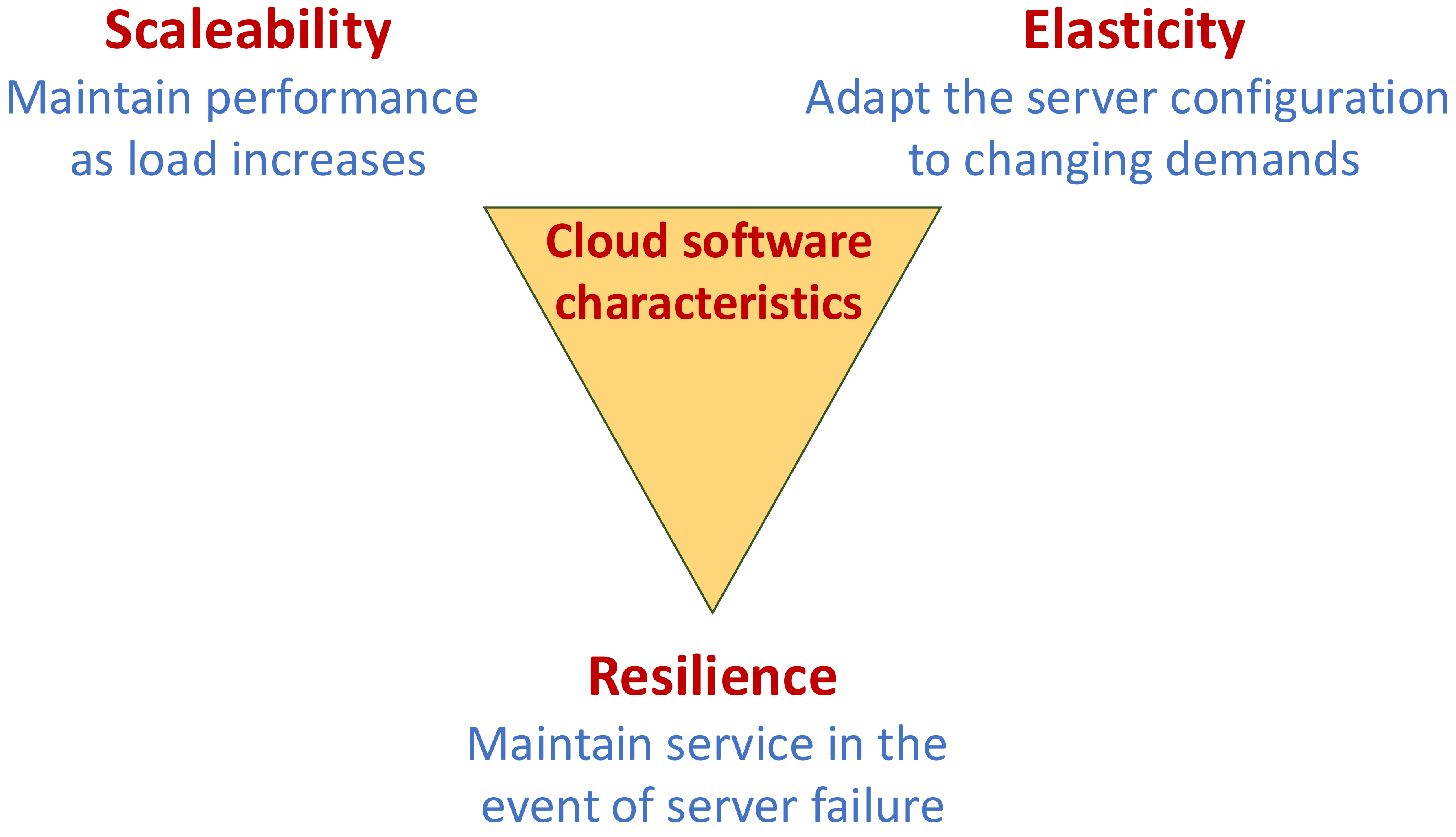
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

The cloud

- You can rent as many servers as you need, run your software on these servers and make them available to your customers.
    - Cloud servers can be started up and shut down as demand changes.
- You may rent a server and install your own software, or you may pay for access to software products that are available on the cloud.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Cloud Software: Scaleability, elasticity and resilience



Scaleability

Maintain performance as load increases

Elasticity

Adapt the server configuration to changing demands

Cloud software characteristics

Resilience

Maintain service in the event of server failure

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Scaleability

- Scaleability reflects the ability of your software to cope with increasing numbers of users.
  - As the load on your software increases, your software automatically adapts so that the system performance and response time is maintained.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Elasticity

- **Elasticity is related to scaleability but also allows for scaling-down as well as scaling-up.**
  - **You can monitor the demand on your application and add or remove servers dynamically as the number of users change.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Resilience

- **Resilience means that you can design your software architecture to tolerate server failures.**
  - **You can make several copies of your software concurrently available. If one of these fails, the others continue to provide a service.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Benefits of using the cloud for software development

- **Cost**

  You avoid the initial capital costs of hardware procurement

- **Startup time**

  Using the cloud, you can have servers up and running in a few minutes.

- **Server choice**

  If you find that the servers you are renting are not powerful enough, you can upgrade to more powerful systems. You can add servers for short-term requirements, such as load testing.

- **Distributed development**

  If you have a distributed development team, working from different locations, all team members have the same development environment and can seamlessly share all information.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Virtual cloud servers

- A virtual server runs on an underlying physical computer and is made up of an operating system plus a set of software packages that provide the server functionality required.
- A virtual server is a stand-alone system that can run on any hardware in the cloud.
  - This 'run anywhere' characteristic is possible because the virtual server has no external dependencies.

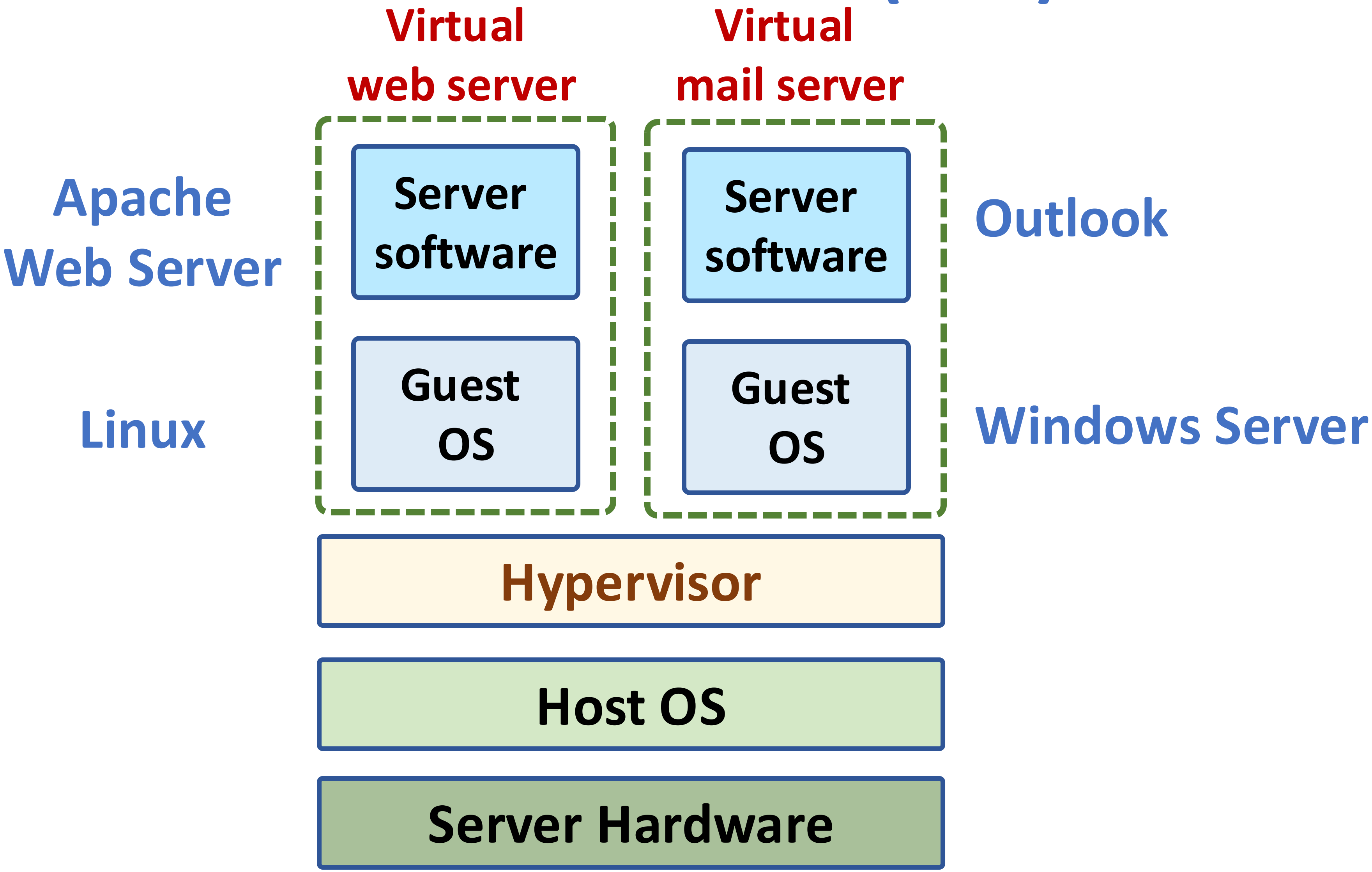
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Virtual cloud servers

- Virtual machines (VMs), running on physical server hardware, can be used to implement virtual servers.
  - A hypervisor provides hardware emulation that simulates the operation of the underlying hardware.
- If you use a virtual machine to implement virtual servers, you have exactly the same hardware platform as a physical server.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Implementing a virtual server as a Virtual Machine (VM)



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Container-based virtualization

- If you are running a cloud-based system with many instances of applications or services, these all use the same operating system, you can use a simpler virtualization technology called ‘containers’.
- Using containers accelerates the process of deploying virtual servers on the cloud.
  - Containers are usually megabytes in size whereas VMs are gigabytes.
  - Containers can be started and shut down in a few seconds rather than the few minutes required for a VM.

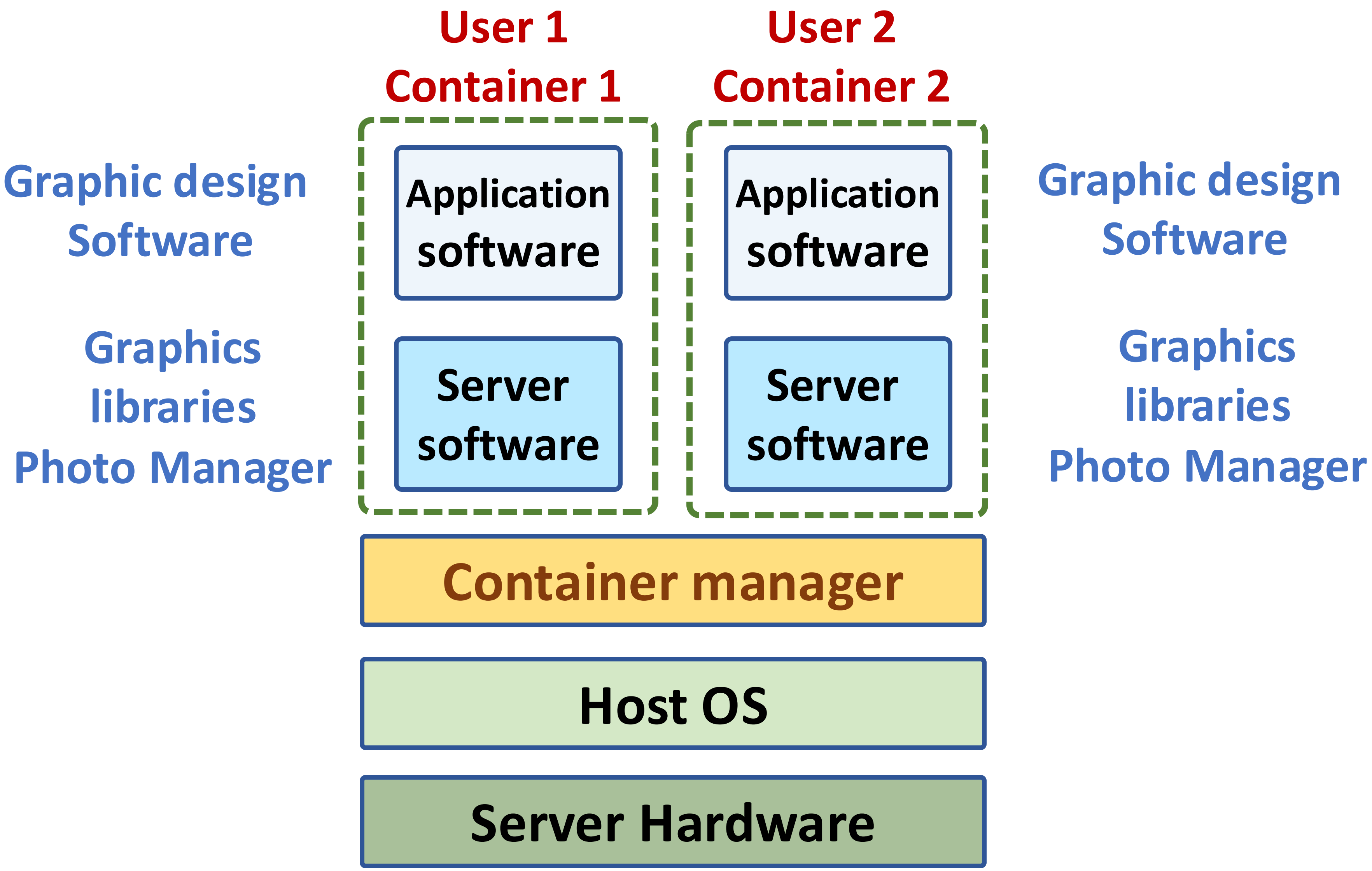
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Container-based virtualization

- Containers are an operating system virtualization technology that allows independent servers to share a single operating system.
  - They are particularly useful for providing isolated application services where each user sees their own version of an application.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Using containers to provide isolated services



User 1

Container 1

User 2

Container 2

Graphic design Software

Graphics libraries

Photo Manager

Application software

Server software

Application software

Server software

Graphic design Software

Graphics libraries

Photo Manager

Container manager

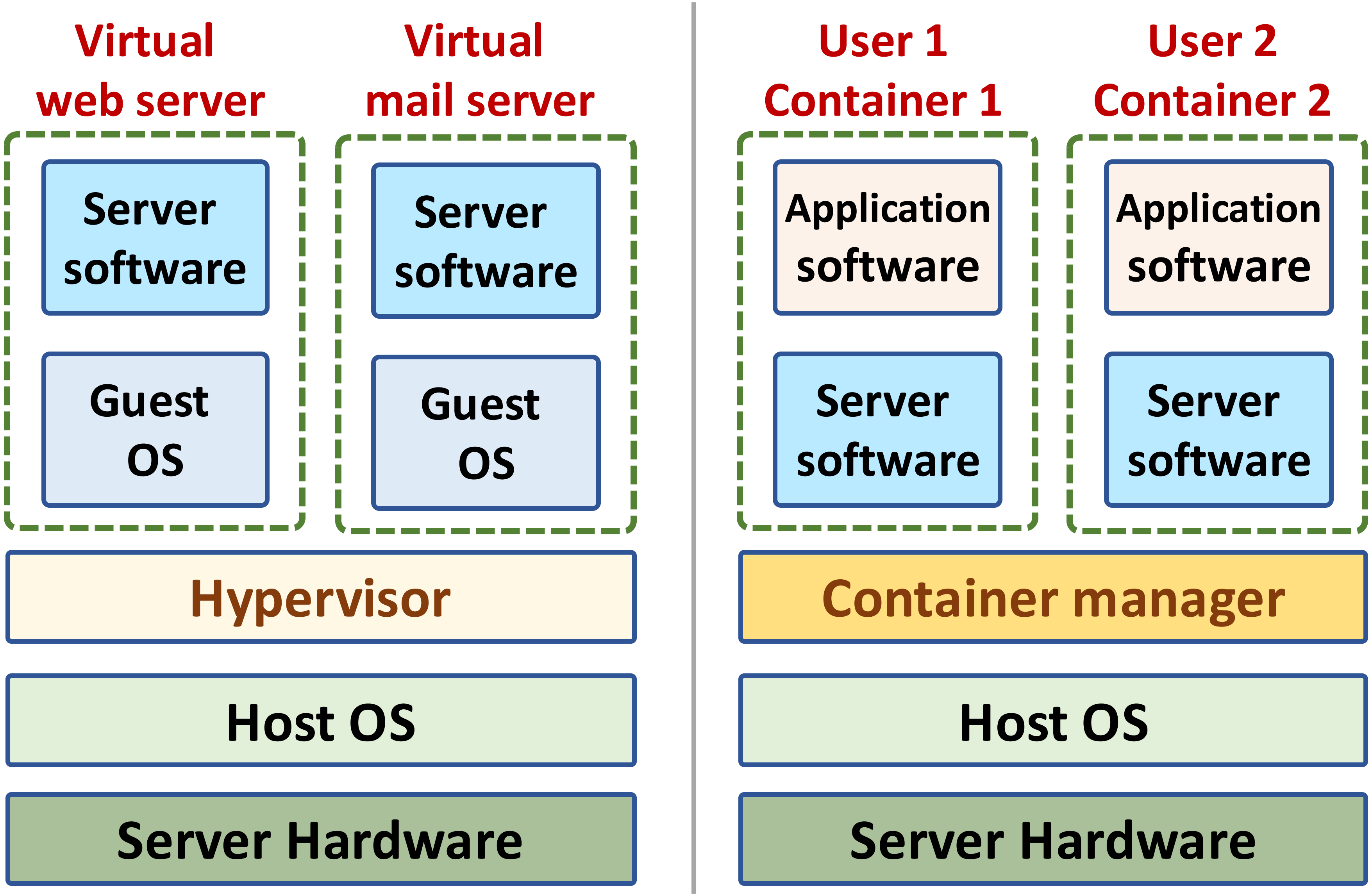
Host OS

Server Hardware

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

VM

Container



Virtual web server

Server software

Guest OS

Virtual mail server

Server software

Guest OS

Hypervisor

Host OS

Server Hardware

User 1 Container 1

Application software

Server software

User 2 Container 2

Application software

Server software

Container manager

Host OS

Server Hardware

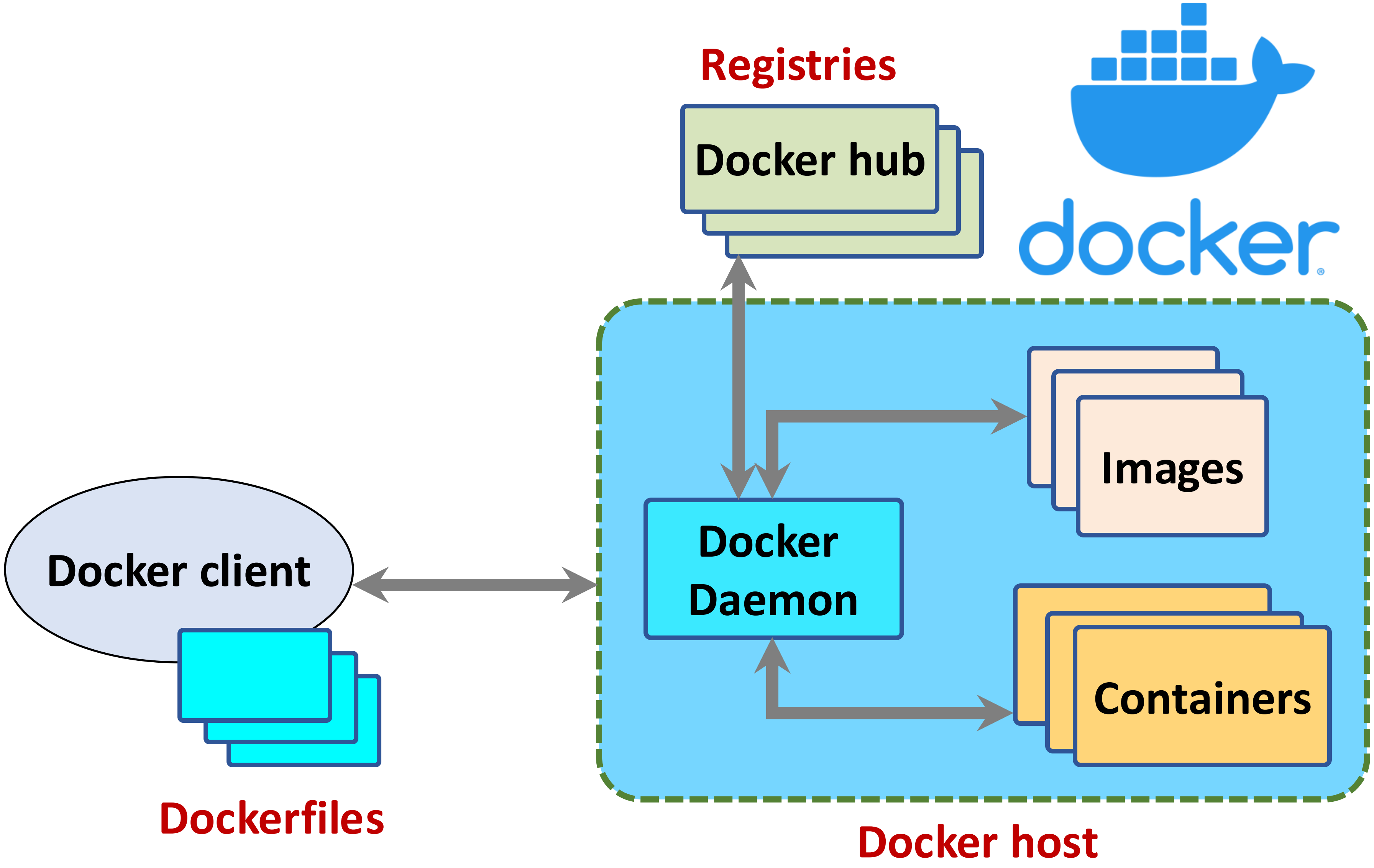
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Docker

- **Containers were developed by Google around 2007 but containers became a mainstream technology around 2015.**
- **An open-source project called Docker provided a standard means of container management that is fast and easy to use.**
- **Docker is a container management system that allows users to define the software to be included in a container as a Docker image.**
- **It also includes a run-time system that can create and manage containers using these Docker images.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

The Docker container system



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

The elements of the Docker container system

- **Docker daemon**
  This is a process that runs on a host server and is used to setup, start, stop, and monitor containers, as well as building and managing local images.
- **Docker client**
  This software is used by developers and system managers to define and control containers

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

The elements of the Docker container system

- **Dockerfiles**

  Dockerfiles define runnable applications (images) as a series of setup commands that specify the software to be included in a container. Each container must be defined by an associated Dockerfile.

- **Image**

  A Dockerfile is interpreted to create a Docker image, which is a set of directories with the specified software and data installed in the right places. Images are set up to be runnable Docker applications.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

The elements of the Docker container system

- **Docker hub**

  This is a registry of images that has been created. These may be reused to setup containers or as a starting point for defining new images.

- **Containers**

  Containers are executing images. An image is loaded into a container and the application defined bby the image starts execution. Containers may be moved from server to server without modification and replicated across many servers. You can make changes to a Docker container (e.g. by modifying files) but you then must commit these changes to create a new image and restart the container.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Docker images

- Docker images are directories that can be archived, shared and run on different Docker hosts. Everything that's needed to run a software system - binaries, libraries, system tools, etc. is included in the directory.
- A Docker image is a base layer, usually taken from the Docker registry, with your own software and data added as a layer on top of this.
  - The layered model means that updating Docker applications is fast and efficient. Each update to the filesystem is a layer on top of the existing system.
  - To change an application, all you have to do is to ship the changes that you have made to its image, often just a small number of files.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Benefits of containers

- They solve the problem of software dependencies.
  - You don’t have to worry about the libraries and other software on the application server being different from those on your development server.
  - Instead of shipping your product as stand-alone software, you can ship a container that includes all of the support software that your product needs.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Benefits of containers

- They provide a mechanism for software portability across different clouds.
    - Docker containers can run on any system or cloud provider where the Docker daemon is available
- They provide an efficient mechanism for implementing software services and so support the development of service-oriented architectures.
- They simplify the adoption of DevOps.
    - This is an approach to software support where the same team are responsible for both developing and supporting operational software.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Everything as a service

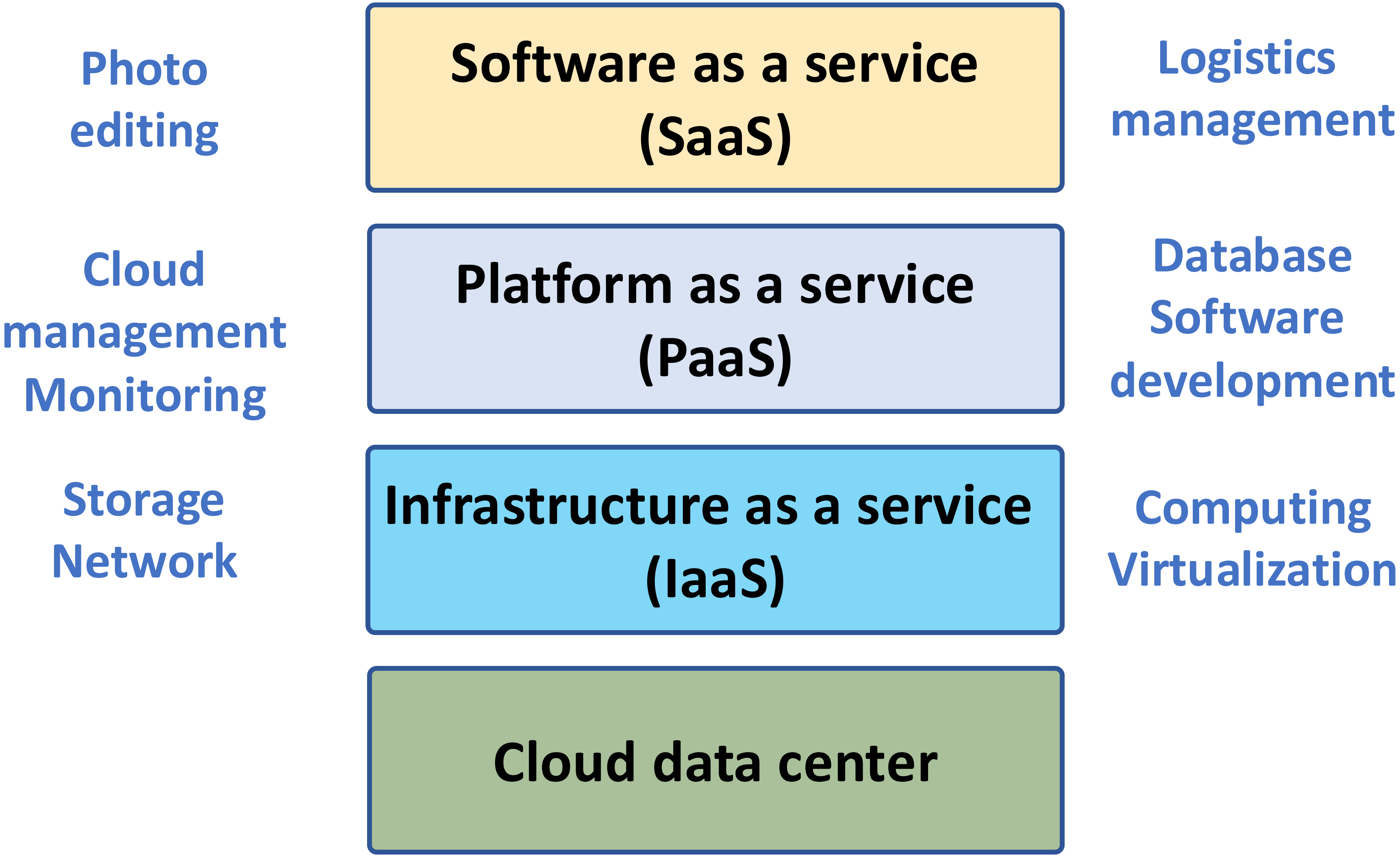


Photo editing

Software as a service (SaaS)

Logistics management

Cloud management Monitoring

Platform as a service (PaaS)

Database Software development

Storage Network

Infrastructure as a service (IaaS)

Computing Virtualization

Cloud data center

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Everything as a service

- The idea of a service that is rented rather than owned is fundamental to cloud computing.
- Infrastructure as a service (IaaS)
- Platform as a service (PaaS)
- Software as a service (SaaS)

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Infrastructure as a service (IaaS)

- **Infrastructure as a service (IaaS)**
  - **Cloud providers offer different kinds of infrastructure service such as a compute service, a network service and a storage service that you can use to implement virtual servers.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Platform as a service (PaaS)

- **Platform as a service (PaaS)**
  - **This is an intermediate level where you use libraries and frameworks provided by the cloud provider to implement your software. These provide access to a range of functions, including SQL and NoSQL databases.**

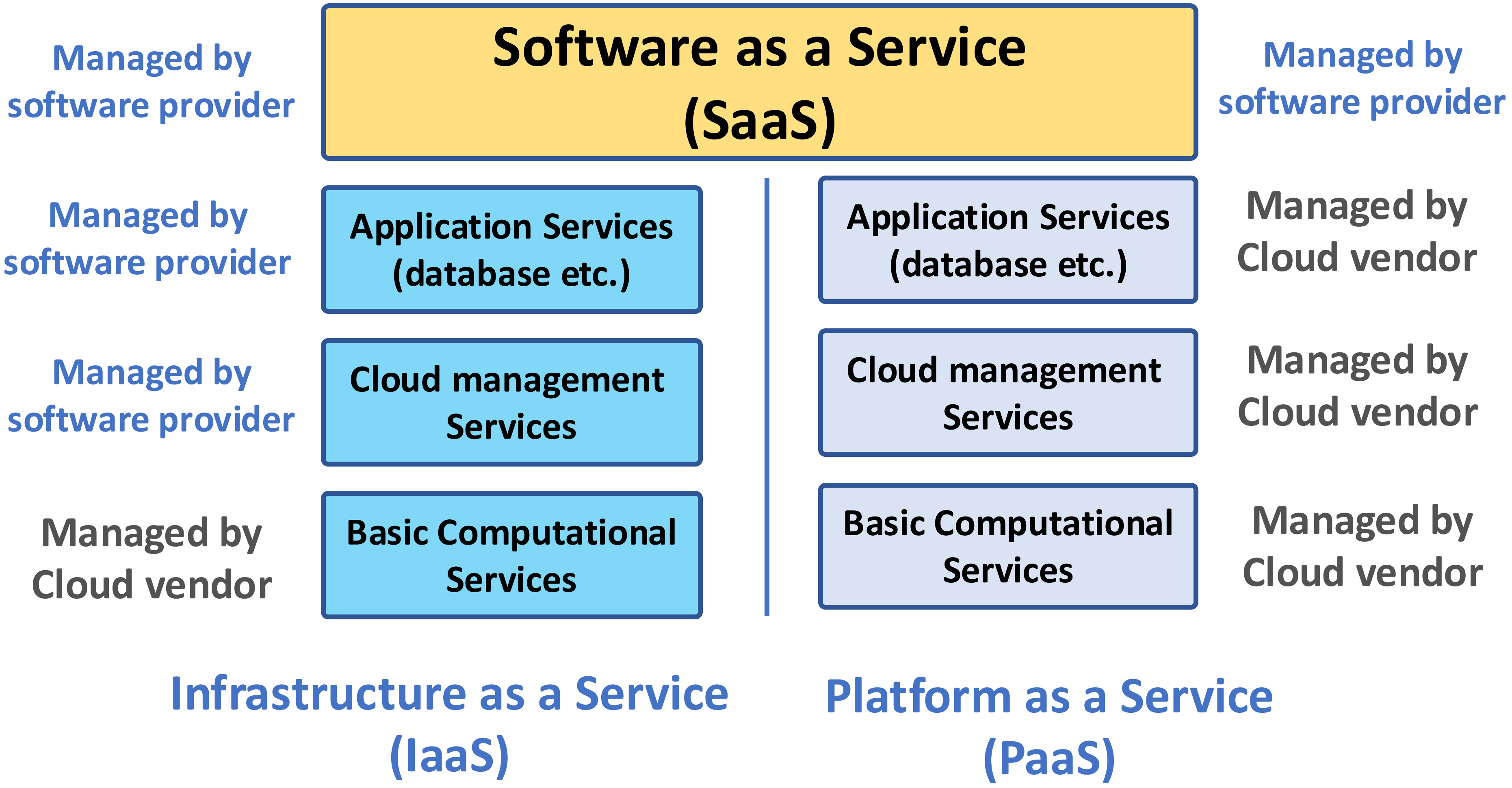
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software as a service (SaaS)

- **Software as a service (SaaS)**
  - **Your software product runs on the cloud and is accessed by users through a web browser or mobile app.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Management responsibilities for IaaS and PaaS



Managed by software provider

Software as a Service (SaaS)

Managed by software provider

Managed by software provider

Application Services (database etc.)

Application Services (database etc.)

Managed by Cloud vendor

Managed by software provider

Cloud management Services

Cloud management Services

Managed by Cloud vendor

Managed by Cloud vendor

Basic Computational Services

Basic Computational Services

Managed by Cloud vendor

Infrastructure as a Service (IaaS)

Platform as a Service (PaaS)

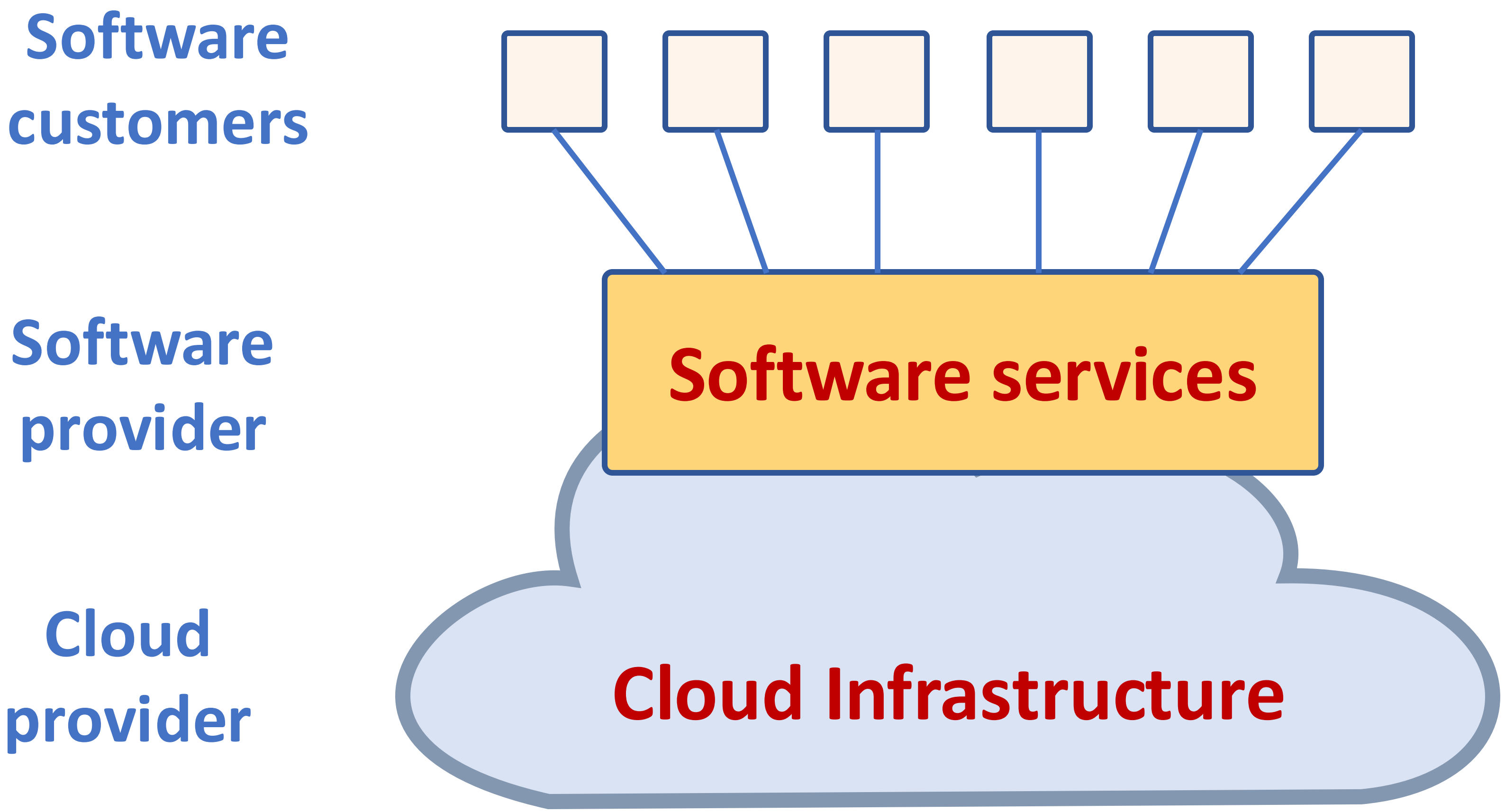
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software as a service

- Increasingly, software products are being delivered as a service, rather than installed on the buyer's computers.
- If you deliver your software product as a service, you run the software on your servers, which you may rent from a cloud provider.
- Customers don't have to install software and they access the remote system through a web browser or dedicated mobile app.
- The payment model for software as a service is usually a subscription model.
  - Users pay a monthly fee to use the software rather than buy it outright.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Software as a service



Software customers

Software provider

Software services

Cloud provider

Cloud Infrastructure

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Benefits of SaaS for software product providers

- **Cash flow**

  Customers either pay a regular subscription or pay as they use the software. This means you have a regular cash flow, with payments throughout the year. You don’t have a situation where you have a large cash injection when products are purchased but very little income between product releases.

- **Update management**

  You are in control of updates to your product and all customers receive the update at the same time. You avoid the issue of several versions being simultaneously used and maintained. This reduces your costs and makes it easier to maintain a consistent software code base.

- **Continuous deployment**

  You can deploy new versions of your software as soon as changes have been made and tested. This means you can fix bugs quickly so that your software reliability can continuously improve.

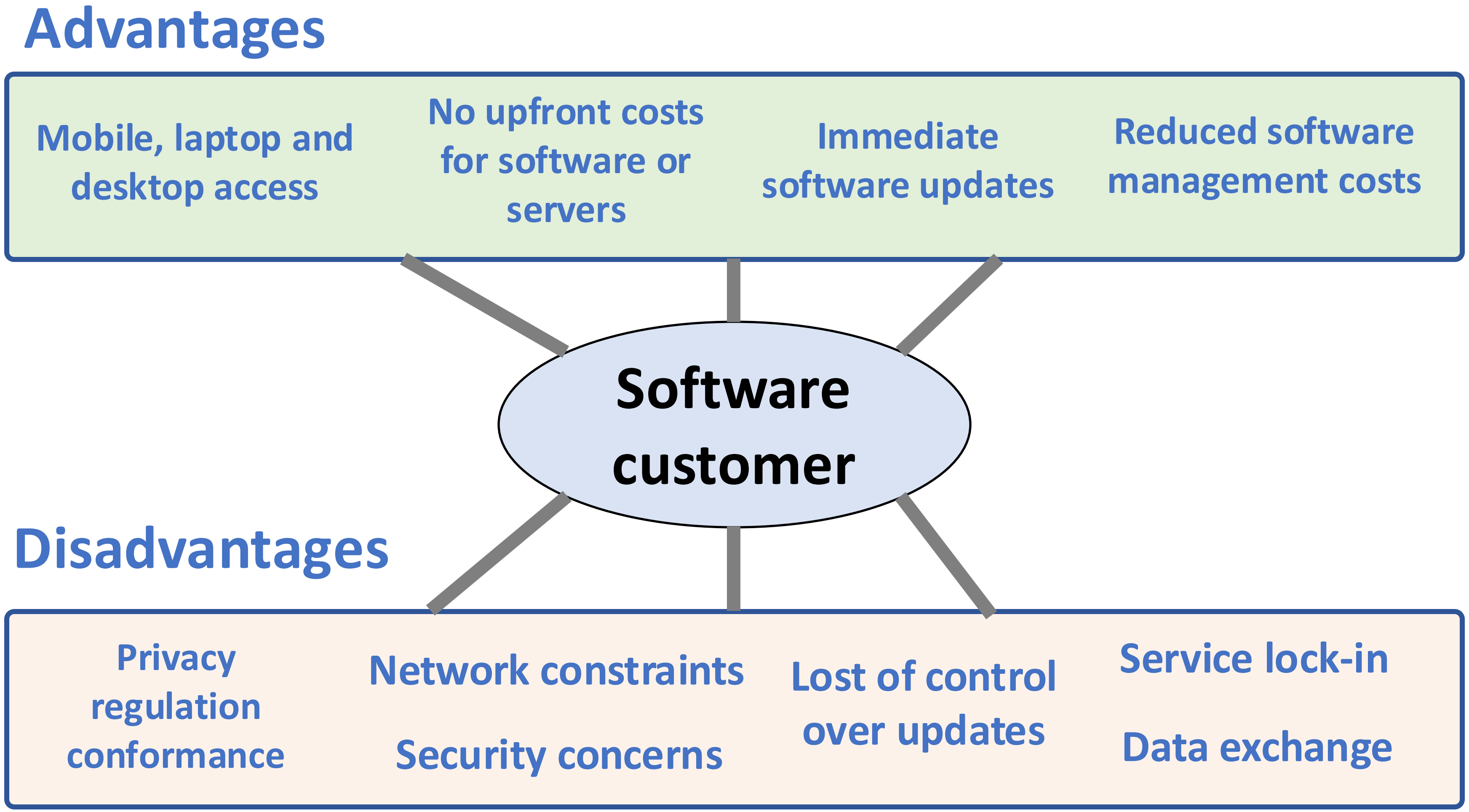
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Benefits of SaaS for software product providers

- **Payment flexibility**
  You can have several different payment options so that you can attract a wider range of customers. Small companies or individuals need not be discouraged by having to pay large upfront software costs.
- **Try before you buy**
  You can make early free or low-cost versions of the software available quickly with the aim of getting customer feedback on bugs and how the product could be approved.
- **Data collection**
  You can easily collect data on how the product is used and so identify areas for improvement. You may also be able to collect customer data that allows you to market other products to these customers.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Advantages and disadvantages of SaaS for customers



Advantages

Mobile, laptop and desktop access

No upfront costs for software or servers

Immediate software updates

Reduced software management costs

Software customer

Disadvantages

Privacy regulation conformance

Network constraints

Security concerns

Lost of control over updates

Service lock-in

Data exchange

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Data storage and management issues for SaaS

- **Regulation**

  Some countries, such as EU countries, have strict laws on the storage of personal information. These may be incompatible with the laws and regulations of the country where the SaaS provider is based. If a SaaS provider cannot guarantee that their storage locations conform to the laws of the customer’s country, businesses may be reluctant to use their product.

- **Data transfer**

  If software use involves a lot of data transfer, the software response time may be limited by the network speed. This is a problem for individuals and smaller companies who can’t afford to pay for very high speed network connections.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Data storage and management issues for SaaS

- **Data security**

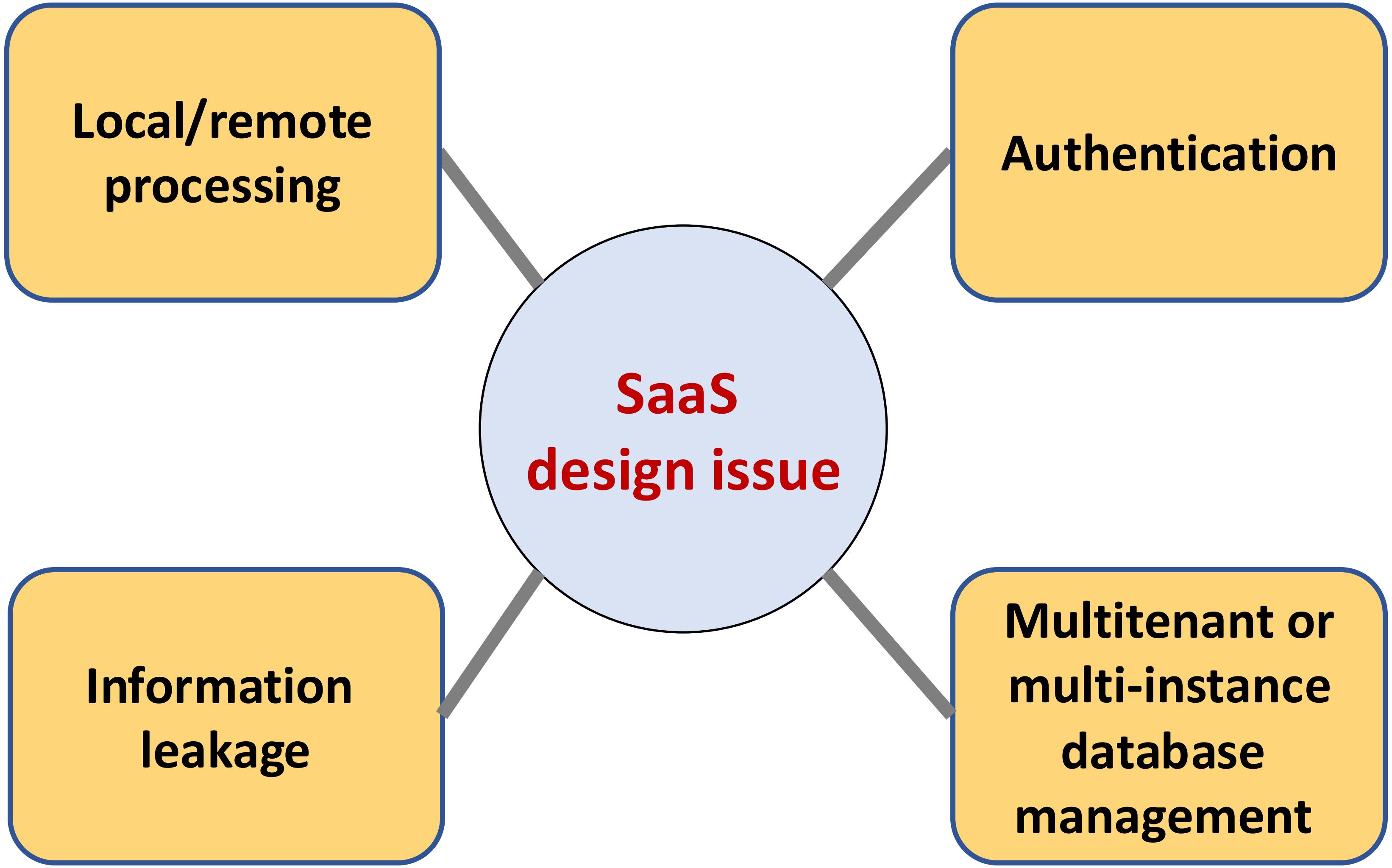
  Companies dealing with sensitive information may be unwilling to hand over the control of their data to an external software provider. As we have seen from a number of high profile cases, even large cloud providers have had security breaches. You can't assume that they always provide better security than the customer's own servers.

- **Data exchange**

  If you need to exchange data between a cloud service and other services or local software applications, this can be difficult unless the cloud service provides an API that is accessible for external use.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Design issues for software delivered as a service



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Multi-tenant systems

- A multi-tenant database is partitioned so that customer companies have their own space and can store and access their own data.
  - There is a single database schema, defined by the SaaS provider, that is shared by all of the system's users.
  - Items in the database are tagged with a tenant identifier, representing a company that has stored data in the system. The database access software uses this tenant identifier to provide 'logical isolation', which means that users seem to be working with their own database.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Possible customisations for SaaS

- **Authentication**
  Businesses may want users to authenticate using their business credentials rather than the account credentials set up by the software provider.
- **Branding**
  Businesses may want a user interface that is branded to reflect their own organisation.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Possible customisations for SaaS

- **Business rules**

  Businesses may want to be able to define their own business rules and workflows that apply to their own data.

- **Data schemas**

  Businesses may want to be able to extend the standard data model used in the system database to meet their own business needs.

- **Access control**

  Businesses may want to be able to define their own access control model that sets out the data that specific users or user groups can access and the allowed operations on that data.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Advantages of multi-tenant databases

- **Resource utilization**

  The SaaS provider has control of all the resources used by the software and can optimize the software to make effective use of these resources.

- **Security**

  Multitenant databases have to be designed for security because the data for all customers is held in the same database. They are, therefore, likely to have fewer security vulnerabilities than standard database products. Security management is simplified as there is only a single copy of the database software to be patched if a security vulnerability is discovered.

- **Update management**

  It is easier to update a single instance of software rather than multiple instances. Updates are delivered to all customers at the same time so all use the latest version of the software.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Disadvantages of multi-tenant databases

- **Inflexibility**

  Customers must all use the same database schema with limited scope for adapting this schema to individual needs. I explain possible database adaptations later in this section.

- **Security**

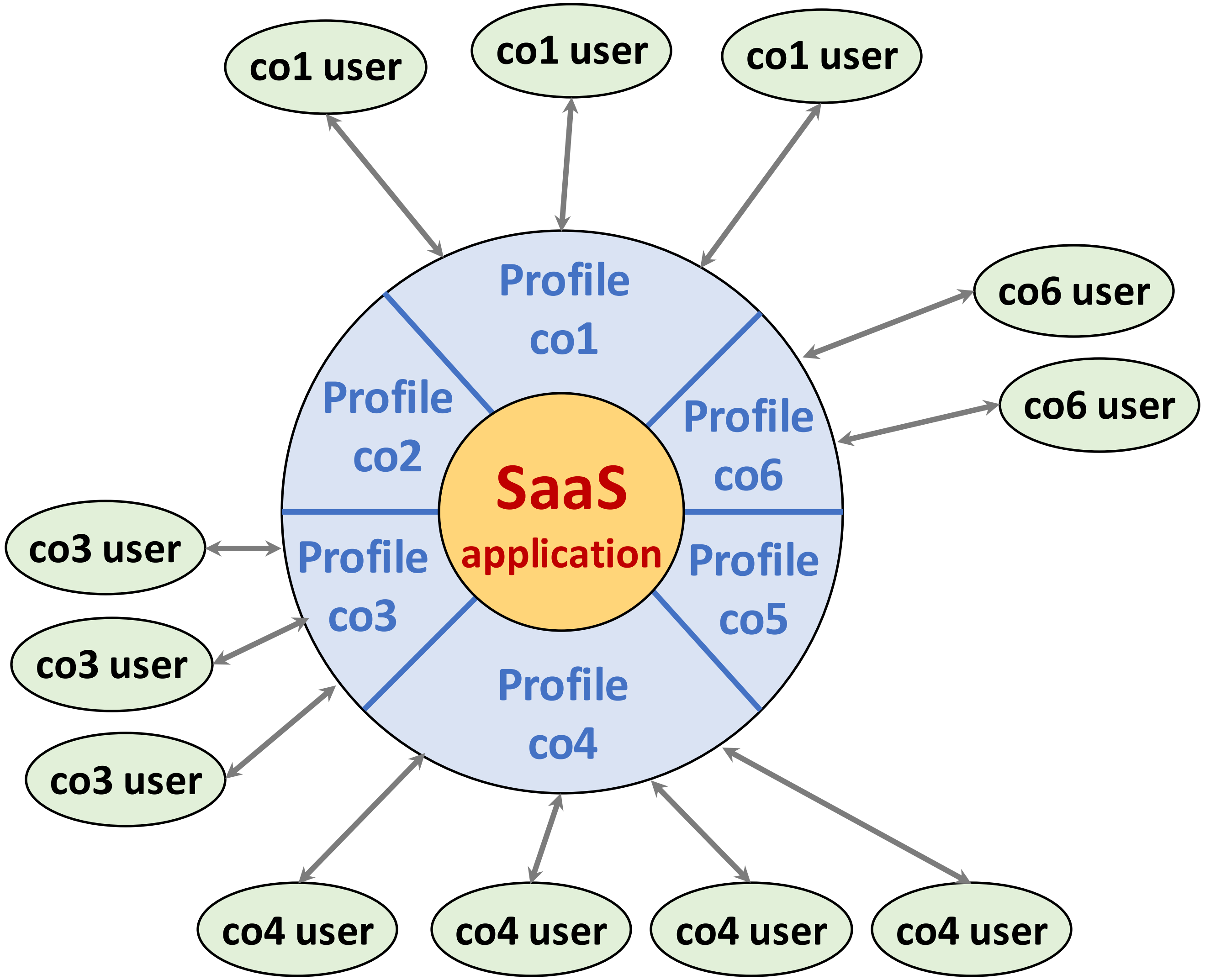
  As data for all customers is maintained in the same database, then there is a theoretical possibility that data will leak from one customer to another. In fact, there are very few instances of this happening. More seriously, perhaps, if there is a database security breach then it affects all customers.

- **Complexity**

  Multitenant systems are usually more complex than multi-instance systems because of the need to manage many users. There is, therefore, an increased likelihood of bugs in the database software.

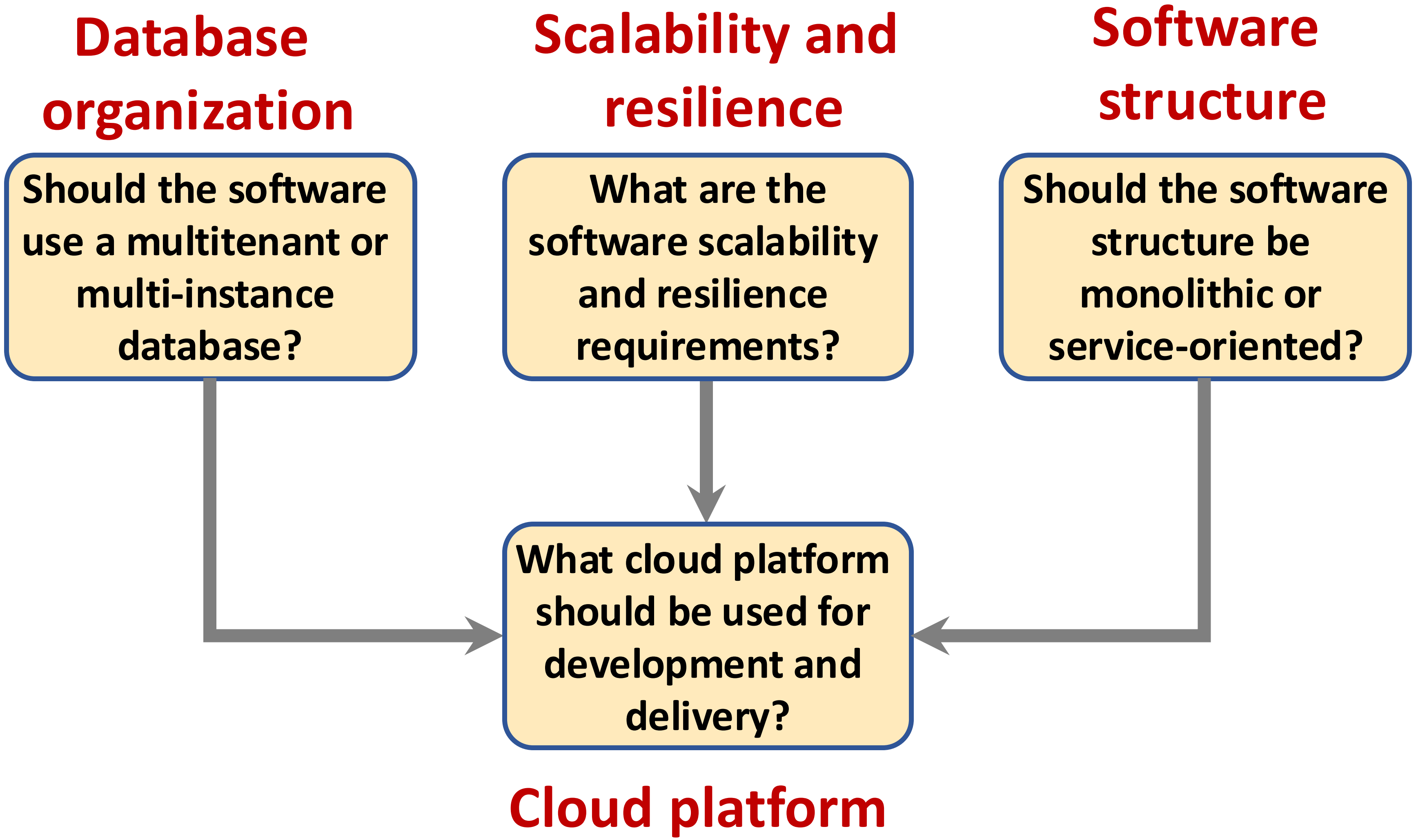
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

User profiles for SaaS access



Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Architectural decisions for cloud software engineering



Database organization

Should the software use a multitenant or multi-instance database?

Scalability and resilience

What are the software scalability and resilience requirements?

Software structure

Should the software structure be monolithic or service-oriented?

What cloud platform should be used for development and delivery?

Cloud platform

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Questions to ask when choosing a database organization

1. **Target customers**
2. **Transaction requirements**
3. **Database size and connectivity**
4. **Database interoperability**
5. **System structure**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Questions to ask when choosing a database organization

- **Target customers**

  Do customers require different database schemas and database personalization? Do customers have security concerns about database sharing? If so, use a multi-instance database.

- **Transaction requirements**

  Is it critical that your products support ACID transactions where the data is guaranteed to be consistent at all times? If so, use a multi-tenant database or a VM-based multi-instance database.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Questions to ask when choosing a database organization

- **Database size and connectivity**

  How large is the typical database used by customers? How many relationships are there between database items? A multi-tenant model is usually best for very large databases as you can focus effort on optimizing performance.

- **Database interoperability**

  Will customers wish to transfer information from existing databases? What are the differences in schemas between these and a possible multitenant database? What software support will they expect to do the data transfer? If customers have many different schemas, a multi-instance database should be used.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Questions to ask when choosing a database organization

- **System structure**
  Are you using a service-oriented architecture for your system? Can customer databases be split into a set of individual service databases? If so, use containerized, multi-instance databases.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Scalability and resilience

- The scalability of a system reflects its ability to adapt automatically to changes in the load on that system.
- The resilience of a system reflects its ability to continue to deliver critical services in the event of system failure or malicious system use.

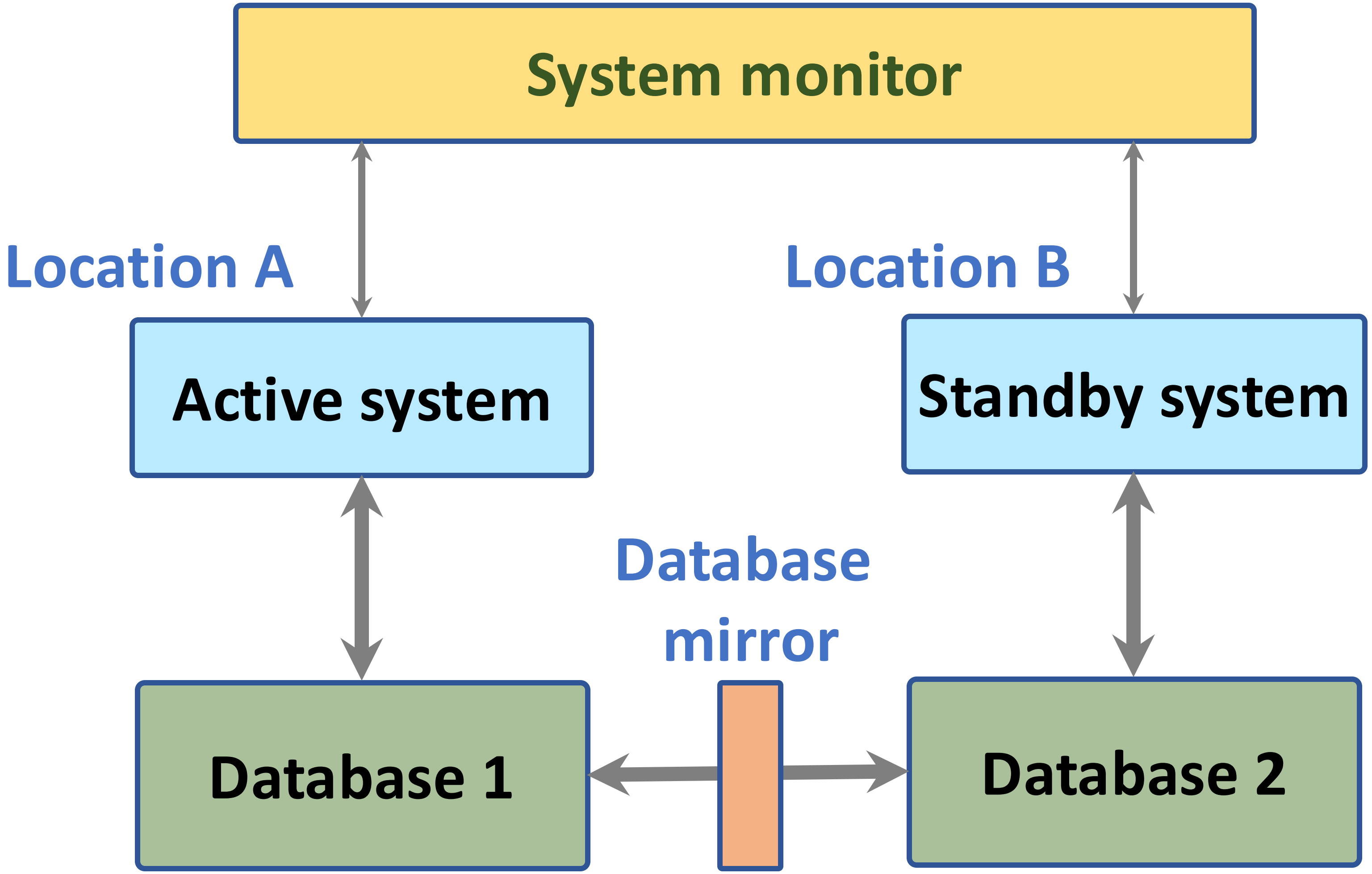
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Scalability and resilience

- You achieve scalability in a system by making it possible to add new virtual servers (scaling-out) or increase the power of a system server (scaling-up) in response to increasing load.
  - In cloud-based systems, scaling-out rather than scaling-up is the normal approach used. Your software has to be organized so that individual software components can be replicated and run in parallel.
- To achieve resilience, you need to be able to restart your software quickly after a hardware or software failure.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Using a standby system to provide resilience



System monitor

Location A

Location B

Active system

Standby system

Database mirror

Database 1

Database 2

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Resilience

- Resilience relies on redundancy:
  - Replicas of the software and data are maintained in different locations.
  - Database updates are mirrored so that the standby database is a working copy of the operational database.
  - A system monitor continually checks the system status. It can switch to the standby system automatically if the operational system fails.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Resilience

- You should use redundant virtual servers that are not hosted on the same physical computer and locate servers in different locations.
  - Ideally, these servers should be located in different data centers.
  - If a physical server fails or if there is a wider data center failure, then operation can be switched automatically to the software copies elsewhere.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

System structure

- An object-oriented approach to software engineering has been that been extensively used for the development of client-server systems built around a shared database.
- The system itself is, logically, a monolithic system with distribution across multiple servers running large software components. The traditional multi-tier client server architecture is based on this distributed system model.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

System structure

- The alternative to a monolithic approach to software organization is a service-oriented approach where the system is decomposed into fine-grain, stateless services.
  - Because it is stateless, each service is independent and can be replicated, distributed and migrated from one server to another.
  - The service-oriented approach is particularly suitable for cloud-based software, with services deployed in containers.

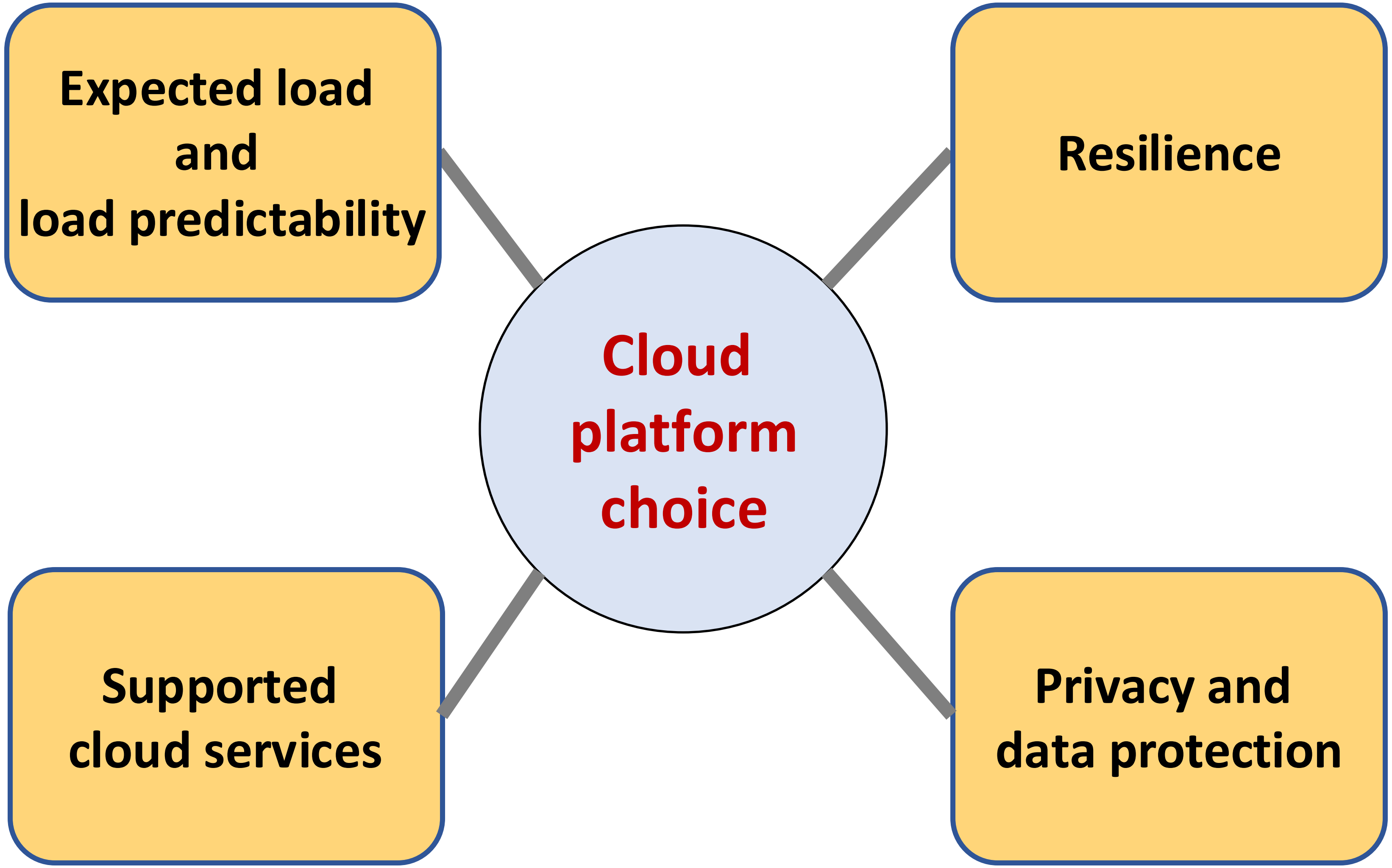
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Cloud platform

- Cloud platforms include general-purpose clouds such as Amazon Web Services or lesser known platforms oriented around a specific application, such as the SAP Cloud Platform. There are also smaller national providers that provide more limited services but who may be more willing to adapt their services to the needs of different customers.
- There is no 'best' platform and you should choose a cloud provider based on your background and experience, the type of product that you are developing and the expectations of your customers.
- You need to consider both technical issues and business issues when choosing a cloud platform for your product.

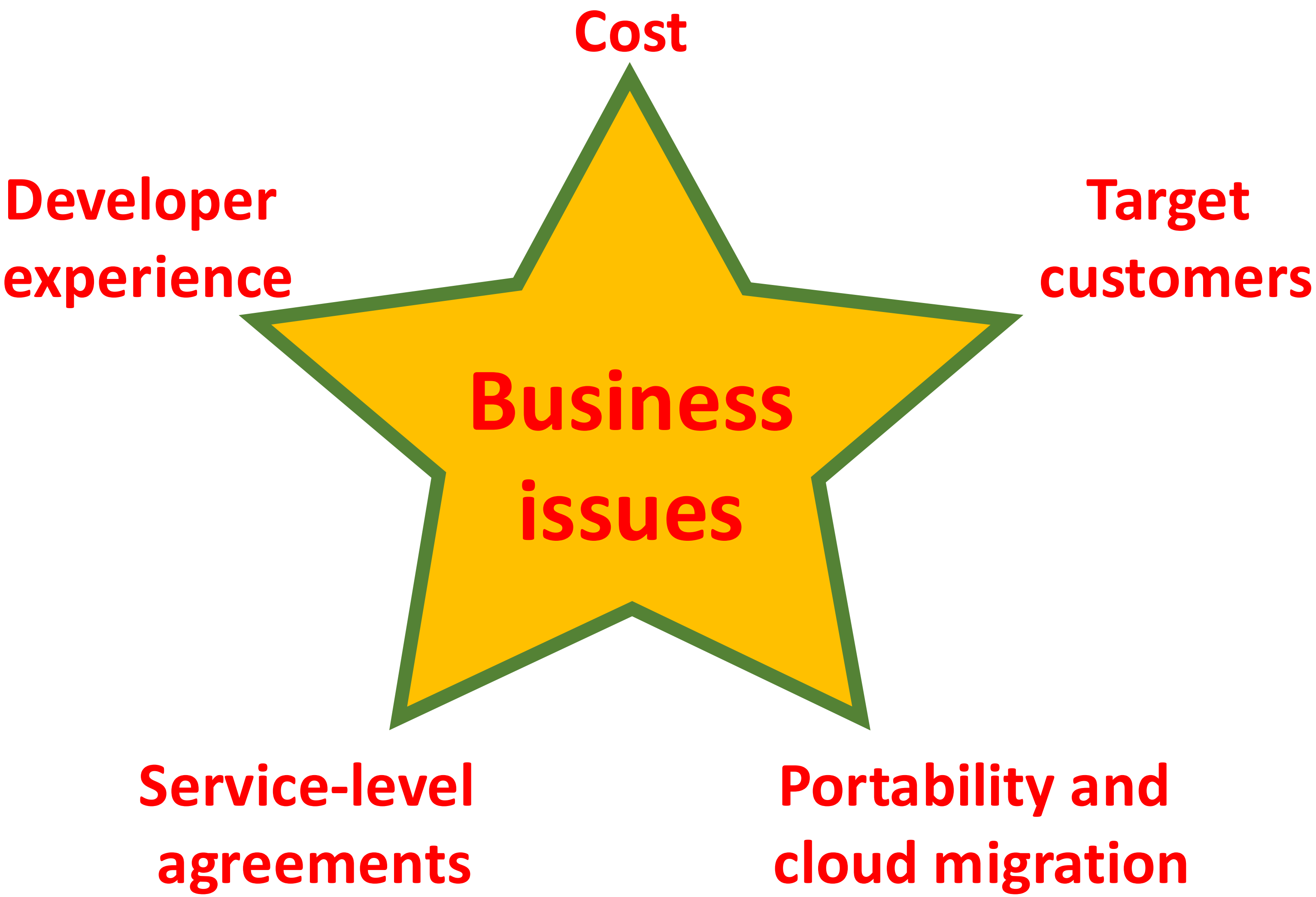
Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Technical issues in cloud platform choice


Expected load and load predictability
Resilience
Cloud platform choice
Supported cloud services
Privacy and data protection

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Business issues in cloud platform choice



Cost

Developer experience

Target customers

Business issues

Service-level agreements

Portability and cloud migration

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Summary

- The cloud is made up of a large number of virtual servers that you can rent for your own use. You and your customers access these servers remotely over the internet and pay for the amount of server time used.
- Virtualization is a technology that allows multiple server instances to be run on the same physical computer. This means that you can create isolated instances of your software for deployment on the cloud.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Summary

- Virtual machines are physical server replicas on which you run your own operating system, technology stack and applications.
- Containers are a lightweight virtualization technology that allow rapid replication and deployment of virtual servers. All containers run the same operating system. Docker is currently the most widely used container technology.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Summary

- A fundamental feature of the cloud is that ‘everything’ can be delivered as a service and accessed over the internet. A service is rented rather than owned and is shared with other users.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Summary

- **Infrastructure as a service (IaaS) means computing, storage and other services are available over the cloud. There is no need to run your own physical servers.**
- **Platform as a service (PaaS) means using services provided by a cloud platform vendor to make it possible to auto-scale your software in response to demand.**
- **Software as a service (SaaS) means that application software is delivered as a service to users. This has important benefits for users, such as lower capital costs, and software vendors, such as simpler deployment of new software releases.**

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

Summary

- **Multitenant systems** are **SaaS** systems where all users share the same database, which may be adapted at run-time to their individual needs. Multi-instance systems are SaaS applications where each user has their own separate database.
- The **key architectural issues** for cloud-based software are the **cloud platform** to be used, whether to use a **multitenant or multi-instance database**, the **scaleability** and **resilience** requirements, and whether to use objects or services as the basic components in the system.

Source: Ian Sommerville (2019), Engineering Software Products: An Introduction to Modern Software Engineering, Pearson.

References

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