

Cloud Migration Patterns: A Multi-Cloud Architectural Perspective

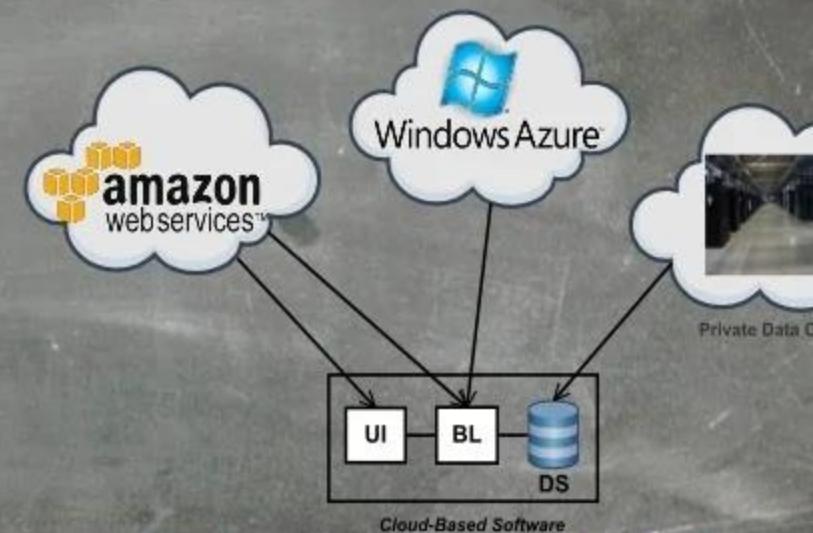
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Five Characteristics of the Cloud – NIST



Motivation

- Plan migration based on architecturally significant, well-defined patterns
- Verifiable migrations
- Decision making based on cost tradeoff

I'VE FINISHED STUDYING OTHER COMPANIES' CLOUD MIGRATION STRATEGIES, 'CLOSE YOUR EYES AND HOPE FOR THE BEST' SEEMS TO BE THE MOST POPULAR...



Objectives

- Identify and exemplify comprehensive set of (multi-)cloud migration patterns from an architectural perspective
- Focus on application components and their migration to the multi-cloud environments
- Define and characterize the patterns with concrete usage scenario
- Migration patterns that avoid vendor lock-in syndrome
- Migration pattern selection, composition and extension

Assumptions

- Migration alternatives, expressed as a set of architecturally significant patterns
- Component-based software architecture
- Component as the migration units
- Simple architectural notations for representing migration patterns
- Some of these migration patterns are inspired by the strategies for *single-cloud migration* presented by *Nabor Mendonça* and *Lawrence Wilkes*

Stairway to Heaven: An Architecture-Level Characterization of Cloud Migration Strategies

What is Multi-Cloud?

N. Grozev and R. Buyya. Inter-cloud architecture: application brokering: taxonomy and survey. *Software Practice and Experience*,

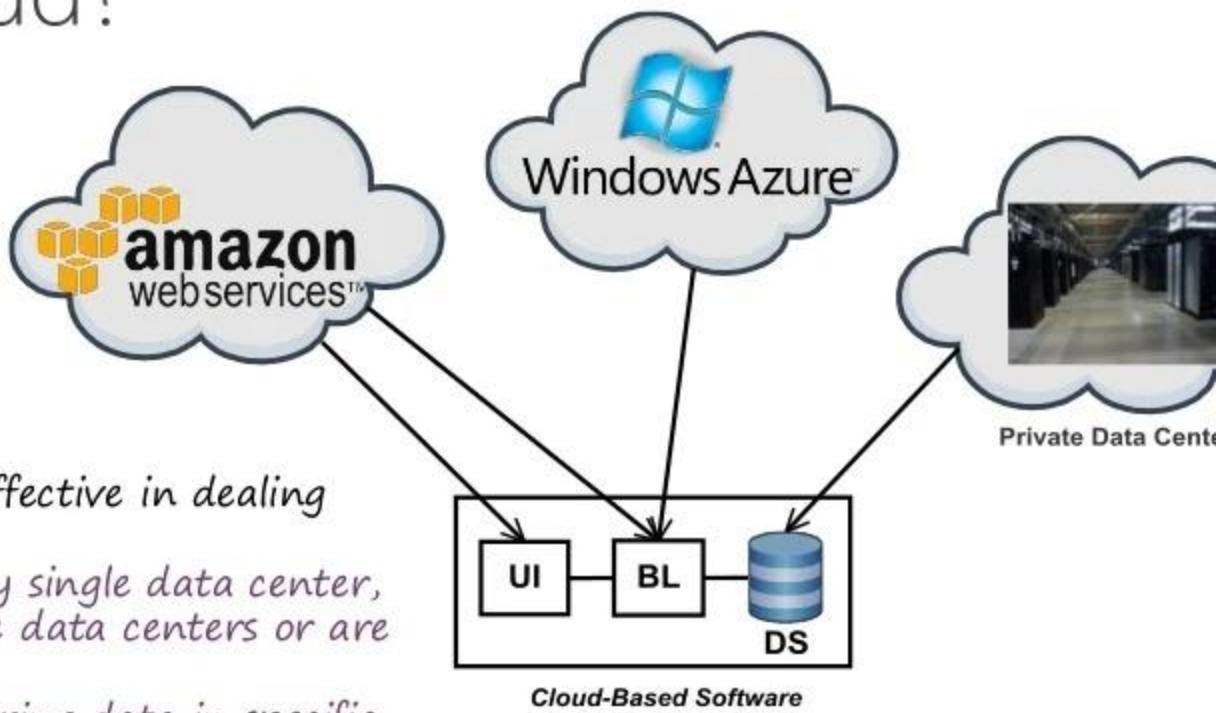
- *Multi-cloud* environment is capable of processing user demands and distributing work to resources deployed across multiple clouds.
- *Multi-cloud* denotes the usage of multiple, independent clouds by a client or a service.
- *Hybrid deployment* when an application is deployed in both on-premise infrastructure as well as cloud platforms.
- A *Federation* is achieved when a set of cloud providers voluntarily interconnect their infrastructures to allow sharing of

Why Multi-Cloud?



The Multi-Cloud Deployment is effective in dealing with the following challenges:

- Users are not clustered near any single data center, but form clusters around multiple data centers or are widely distributed geographically
 - Regulations limit options for storing data in specific data centers
 - Circumstances require that the public cloud be used in concert with on-premises resources
 - Application must be resilient to the loss of a single



Is Multi-Cloud Really Necessary?!

management services

ALERT PREVIEW OPERATION LOGS

SUBSCRIPTION Visual Studio Ultimate wi... ▾ FROM 2014-4-24 12:30 PM ▾ TO 2014-5-01 1:00 PM ▾

STATUS Active ▾ TYPE Azure Incidents ▾ SERVICE NAME ▾

Click the checkmark button to execute the query.

TIME STAMP	OPERATION	STATUS	SERVICE NAME	TYPE	CALL
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	73ed1e0f-5dbc-41e3-b1d3-7...	Azure Incidents	Wind
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	db131c26-55f4-46d1-8b21-c...	Azure Incidents	Wind
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	ed277ca6-7b3d-4308-84a4-5...	Azure Incidents	Wind
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	0a67d81e-35f5-45ad-98af-3c...	Azure Incidents	Wind
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	3e2a567c-4a23-46a0-b2cd-e...	Azure Incidents	Wind
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	4b91c2f7-9105-4e67-b3d0-fa...	Azure Incidents	Wind
5/1/2014 8:54:09 AM	Compute (Service Management) : Partial Service Interruption [West Europe]	Active	d75d8718-f4a0-4823-a514-e...	Azure Incidents	Wind

Cloud Outage Experience

Azure incident that I personally experienced



Incident Details

TIME	TITLE	SUBSCRIPTION ID	DESCRIPTION
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	4c2dabc5-9df6-45b8-a8ea-9a14edb86d70	Starting at 01 May 2014 0939hrs UTC a subset of customers using Storage in West Europe will experience issues accessing services. Engineering teams are actively recovering services. The next update will be provided in 60 minutes.
5/1/2014 11:13:28 AM	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	4c2dabc5-9df6-45b8-a8ea-9a14edb86d70	Starting at 01 May 2014 0939hrs UTC a subset of customers using Storage in West Europe will experience issues accessing services. Engineering teams are actively recovering services. The next update will be provided in 60 minutes.

...And it lasted for 6 odd hours

Cloud Outage Experience

...And it happened again in the evening on the same day!

TIME STAMP	OPERATION	STATUS	SERVICE NAME	TYPE
01/05/2014 21:20:39	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	db131c26-55f4-46d1-8b21-c...	Azure Incidents
01/05/2014 21:20:39	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	73ed8e0f-3dbc-4163-b1d3-7...	Azure Incidents
01/05/2014 21:20:39	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	0a67d81e-35f5-45ad-98af-3c...	Azure Incidents
01/05/2014 19:48:00	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	4b91c2f7-9105-4e67-b3d0-fa...	Azure Incidents
01/05/2014 19:48:00	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	3e2a567c-4a23-46a0-b2cd-e...	Azure Incidents
01/05/2014 11:42:25	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Resolved	ed277ca6-7b3d-4308-84a4-5...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	73ed8e0f-3dbc-4163-b1d3-7...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	db131c26-55f4-46d1-8b21-c...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	ed277ca6-7b3d-4308-84a4-5...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	0a67d81e-35f5-45ad-98af-3c...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	3e2a567c-4a23-46a0-b2cd-e...	Azure Incidents
01/05/2014 11:13:28	SQL Databases, Compute and Storage : Full Service Interruption [West Europe]	Active	4b91c2f7-9105-4e67-b3d0-fa...	Azure Incidents
01/05/2014 09:19:25	Compute (Service Management) : Partial Service Interruption [West Europe]	Resolved	d75d8718-f4a0-4823-a514-e...	Azure Incidents
01/05/2014 09:19:25	Compute (Service Management) : Partial Service Interruption [West Europe]	Resolved	c04fd69-dca5-46f7-bae8-12...	Azure Incidents
01/05/2014 08:54:09	Compute (Service Management) : Partial Service Interruption [West Europe]	Active	d75d8718-f4a0-4823-a514-e...	Azure Incidents

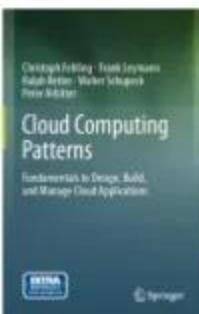
Cloud-Enabled Application Types

1. **Web-based application:** periodic traffic patterns, requires reliable, scalable, secure, and high performance infrastructure
2. **Content delivery network:** requires low latency, high availability, durability, access control, and millions of views
3. **Batch system:** highly variable usage patterns that have usage peaks followed by significant periods of underutilization
4. **Fault tolerant system:** services and infrastructure to build reliable, fault-tolerant, and highly available systems in the cloud
5. **Big data system:** involve huge data sets collected from scientific equipment, measurement devices, or other compute jobs
6. **Advertising system:** internet advertising services need to serve targeted advertising in a small period of time
7. **Disaster recovery application:** duplicating infrastructure to ensure the availability of spare capacity in disaster
8. **File sharing system:** stateless client-server architecture in which web services are viewed as resources and have URLs
9. **Media sharing and social network:** users wants to share their photos and videos on social networking sites
10. **Online game:** peak usage periods, multiple players, and high volumes of write operations
11. **Log file analysis application:** log data can be an important source of knowledge for companies having e-commerce system
12. **Financial system:** on demand provisioning combined with low latency access to on-premise data sources
13. **E-Commerce system:** large product catalogs, global customer base, checkout items securely and product recommendation
14. **Time-series processing system:** data arrive as a succession of regular measurements

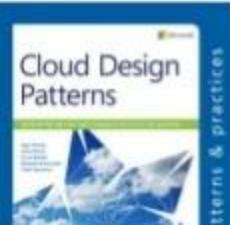
Architectural Elements for Migration Pattern Specification

- Component
- on-premise Platform
- Cloud Platform
- Cloud Service
- Cloud Broker
- Adapter

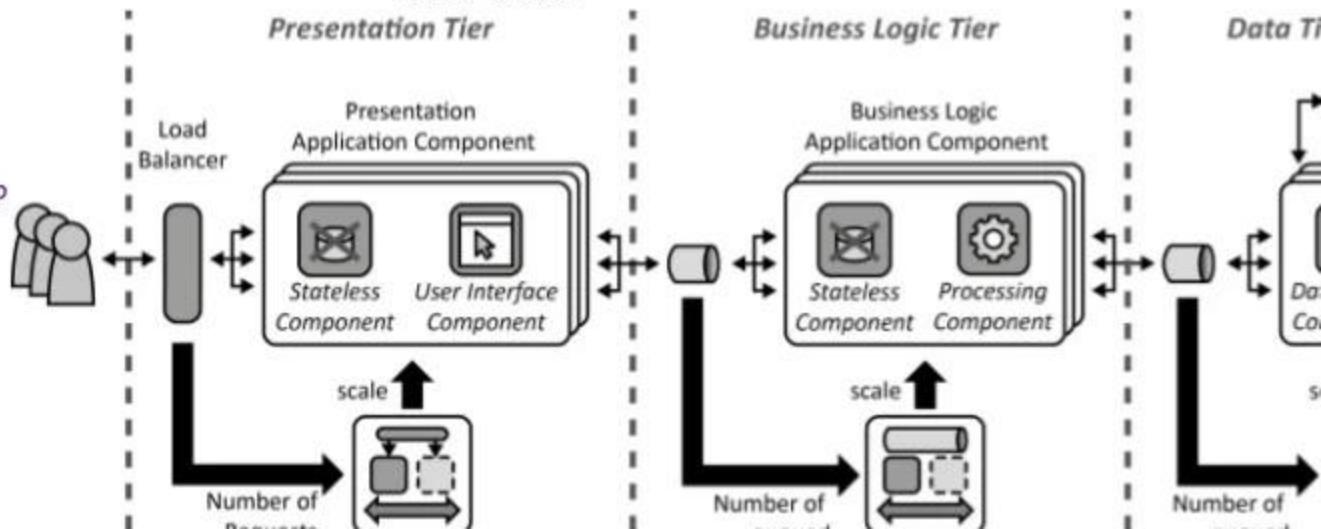
What we don't provide here!



Looking for cloud application architecture?
Read these books



We do not intend to provide cloud application architectural patterns. We rather abstract these architectural layers into general concept of components and connectors. The reason behind this choice is that we have numerous cloud architectures that becomes orthogonal to the migration patterns and just add more ambiguity into that.



Target Audience (Who Cares?!)

- Consultants for SME cloud migration
- Large multi-nationals technology providers
- Systems integrators

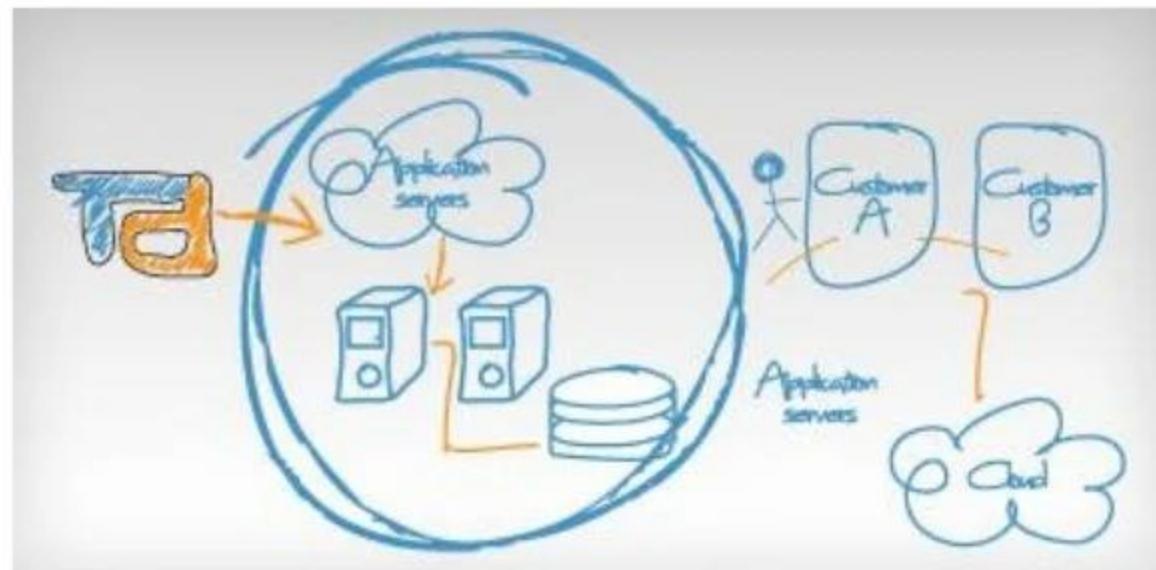
For what concerns such multi-cloud migration patterns may be useful?

- Availability. applications must be architected to guarantee maximum availability.
- Management. runtime information that enable administrators to monitor the system and support on-the-fly changes.
- Scalability. Cloud environments enable applications to scale out to meet bursts in demand, and scale in when demand decreases.
- Resiliency. Cloud environments provide the ability for a system to gracefully handle and recover from failures.

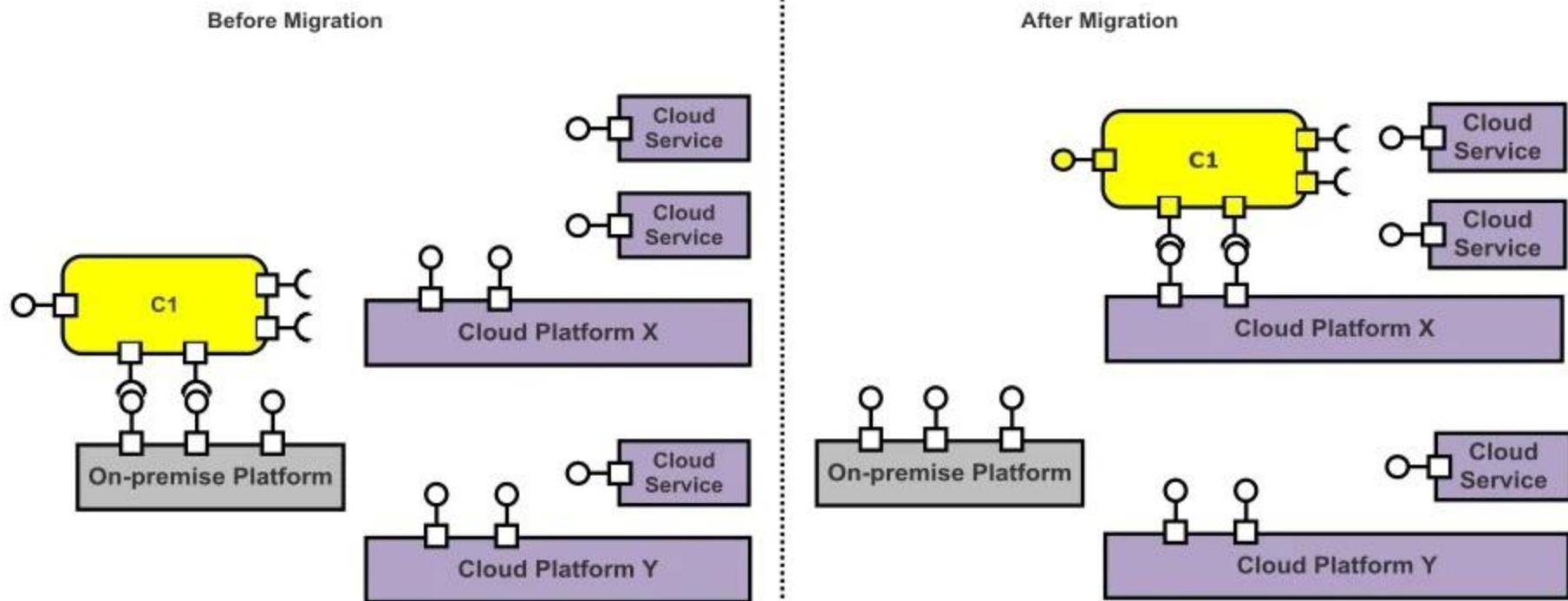
Cloud Migration Patterns!



Facilitating communication with non-technical stakeholders is the key principle for cloud migration planning



MP1: Re-host



MP1: Re-host

Definition: An application (component) is re-hosted as-is on cloud platform(

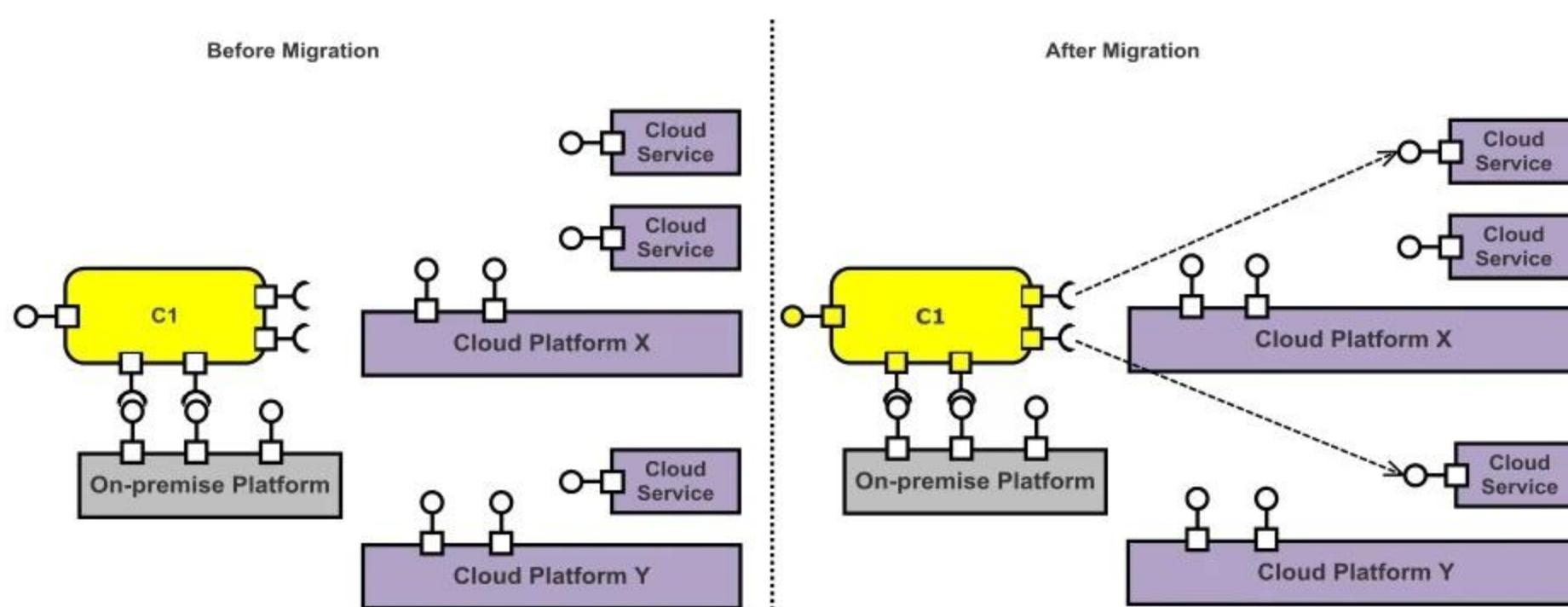
Problem: Resource constraints limit scalability, Need to improve the SLO, Single point of failure, Reduce cost of ownership, Modernization strategies

Solution: Re-host on cloud environments, make use of elastic resources, multiple cloud deployment for failover and scalability.

Benefits: Improved Backup and Failover, Coarse-grained scalability at application level, Simple coarse-grained re-deployment.

Risks: Existing architecture constrains portability, deployment time and cost, scalability, integration may introduce greater complexity.

MP2: Cloudification



MP2: Cloudification

Definition: An application (component) is hosted on-premise as-is but use public cloud services for extending capabilities instead of on-premise components.

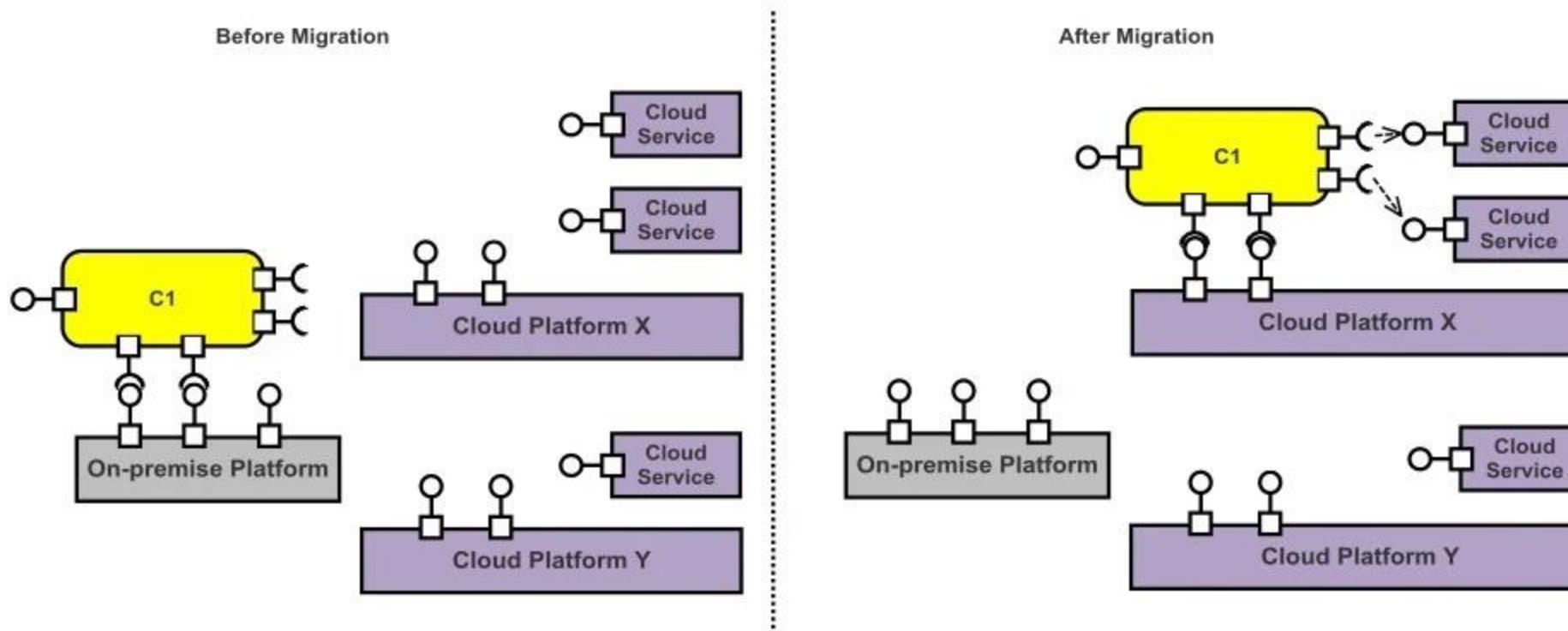
Problem: Need to improve reusability, extensibility, Avoid reinventing the wheel by consuming existing publicly accessible cloud services

Solution: Extend the on-premise application by integrating with existing public cloud services.

Benefits: Improved time to market.

Risks: Integration may introduce greater complexity.

MP3: Relocation and Optimization



MP3: Relocation and Optimization

Definition: A component re-hosted (or relocated) on a cloud platform is optimized but without evolution in the application architecture.

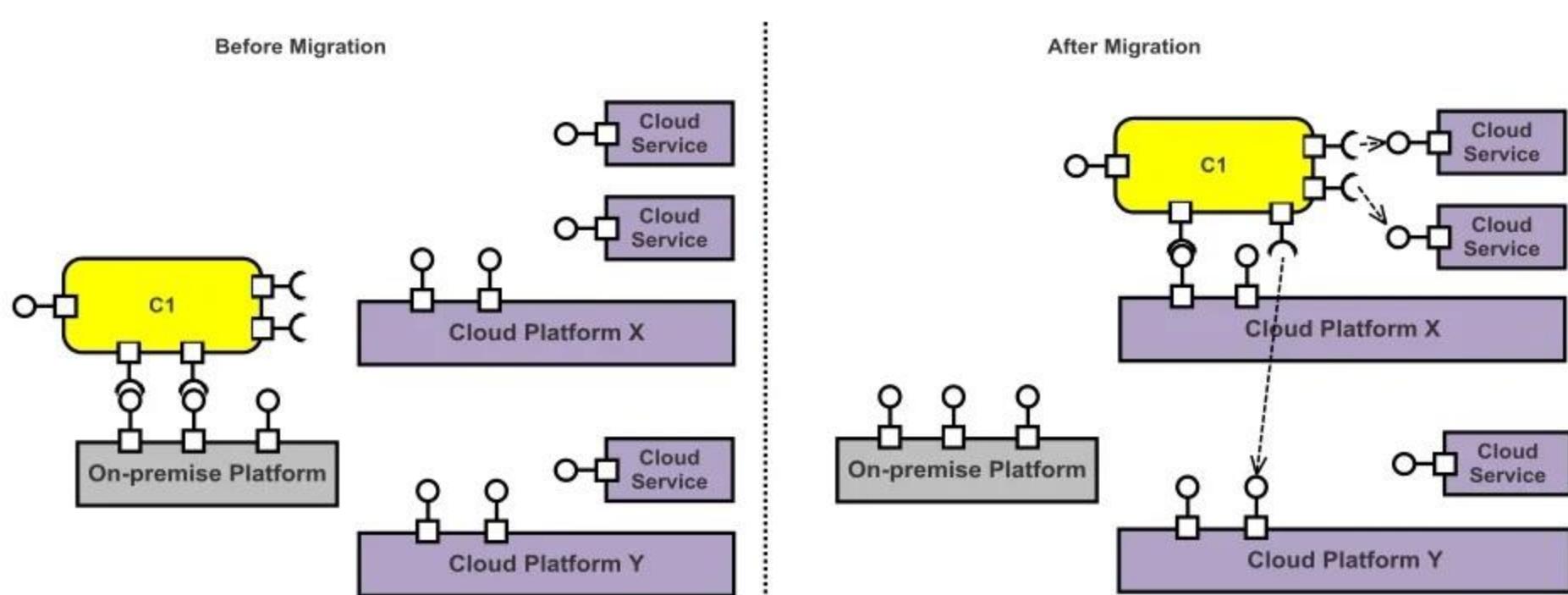
Problem: The performance of an application needs to be enhanced without the significant effort of architecture change, and without incurring capital expenditure for on-premise hardware.

Solution: Leverage cloud platform services (e.g., IaaS, PaaS services) to improve throughput by leveraging Queue, Database partitioning & sharding, NoSQL, Cach

Benefits: As component re-hosting in cloud and optimized performance.

Risks: The type of application requests changes over time for example proportion of read only calls reduces, Cloud provider does not provide the necessary services to wrap the optimizations around the application without re-architecting.

MP4: Multi-Cloud Relocation



MP4: Multi-Cloud Relocation

Definition: A component re-hosted (or relocated) on a cloud platform is enhanced by using the environmental services of the other cloud platforms.

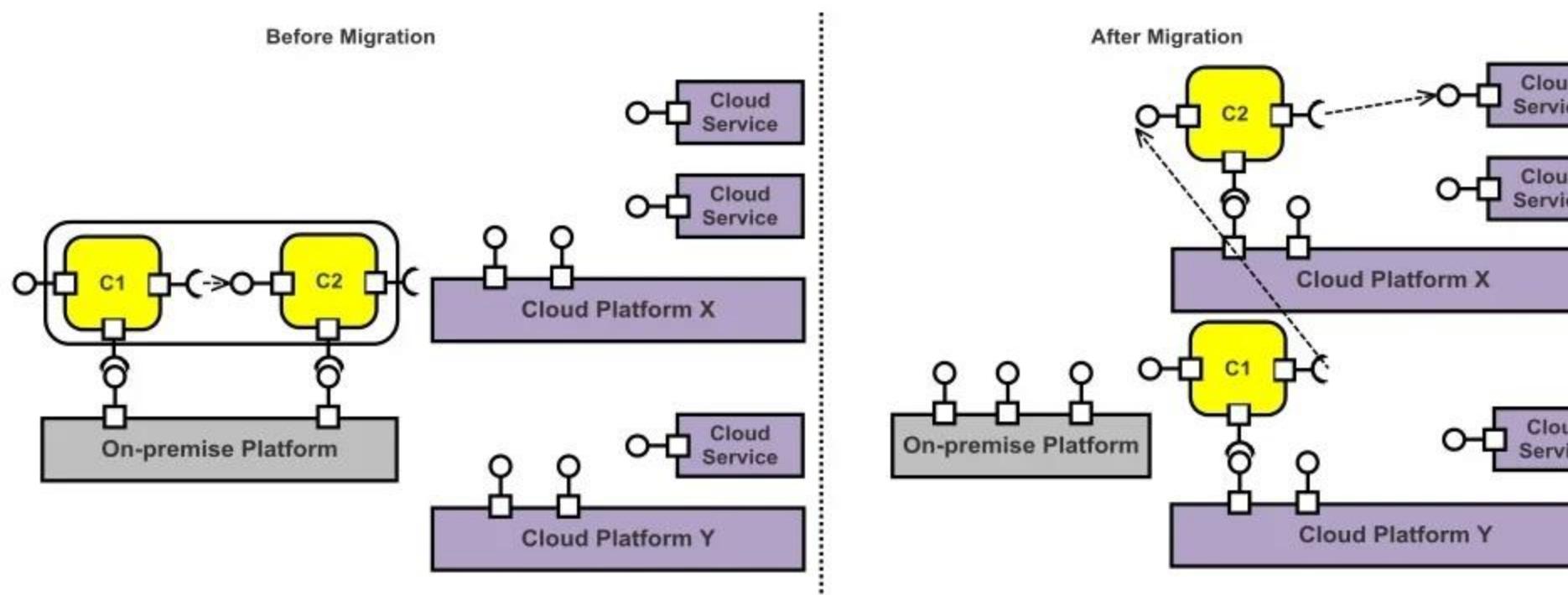
Problem: The availability of an application needs to be enhanced without the significant effort of architecture change, and without incurring capital expenditure for on-premise hardware.

Solution: Leverage cloud platform environment services to improve availability, e.g., live migration from existing platform to the target platform in case of service outage

Benefits: As component re-hosting in multiple cloud platforms and improve availability and avoid vendor lock-in.

Risks: Cloud providers does not provide the necessary services to enable application to run in multiple cloud platforms without re-architecting or rewriting the code.

MP5: Multi-Cloud Refactor



MP5: Multi-Cloud Refactor

Definition: An on-premise application is re-architected for deployment on cloud platform to provide better QoS.

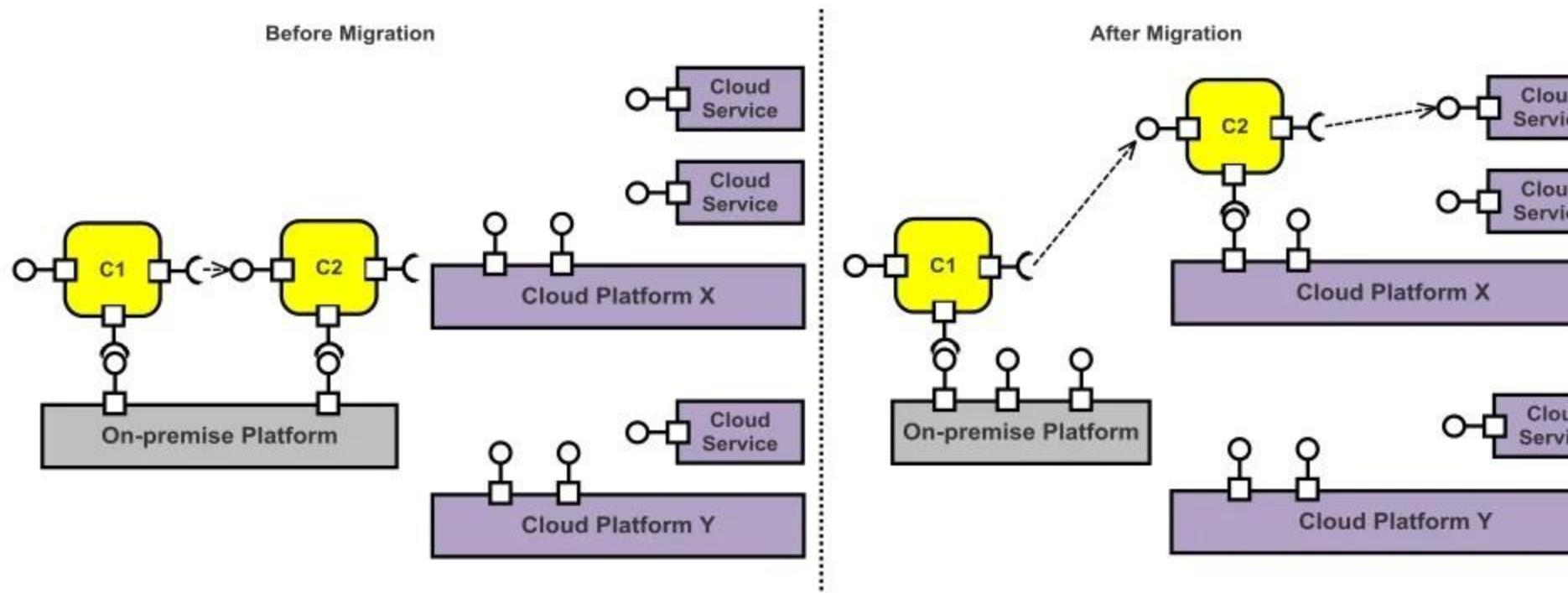
Problem: Coarse-grained applications are not agile enough to respond to requirement changes or variations in workload, and cannot take full advantage of the SLO improvements that can be offered by cloud platforms.

Solution: The application is re-architected as a set of fine-grained components, The deployment of high-usage components can be optimized independently of low-usage ones, Parallel design for better throughput to multiple cloud platforms, Components designed as independent integrity units to reduce dependencies and enable replacement.

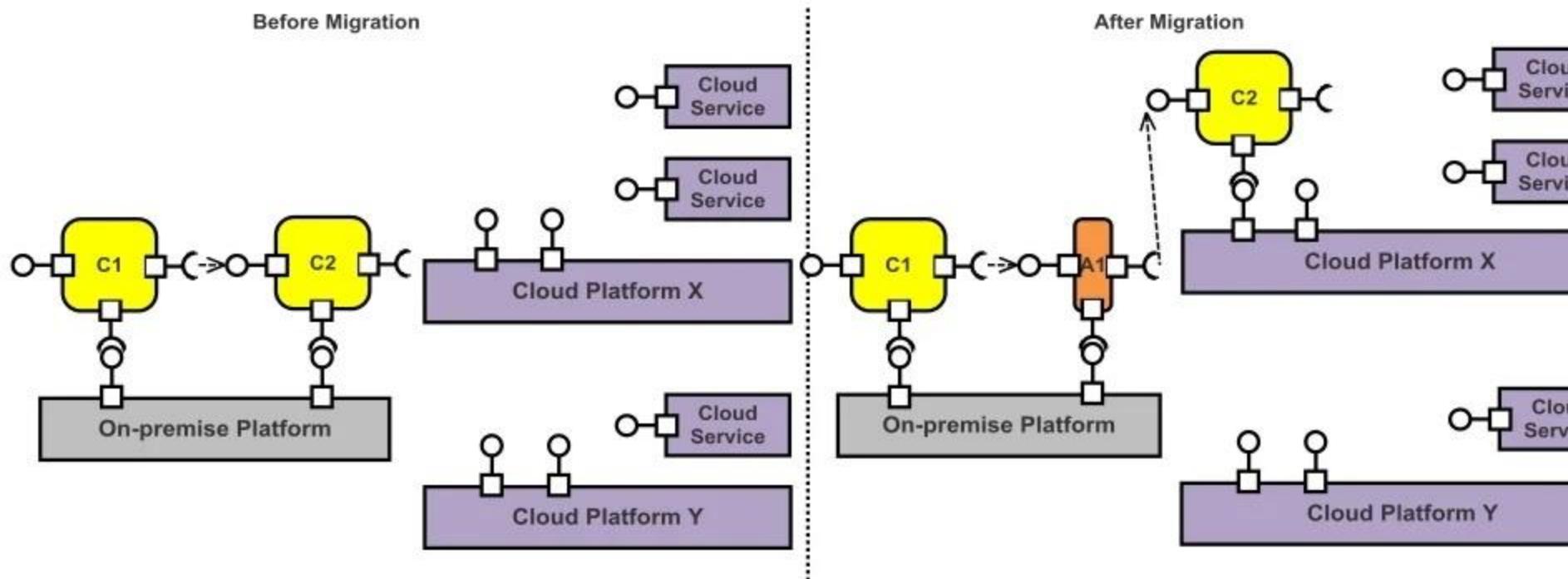
Benefits: Optimal scalability and performance, wider range of multi-cloud deployment options, agility to respond to business and IT change.

Risks: on-premise application is modernized in isolation, and not as part of a portfolio that ensures consistent architecture, Modernization is performed primarily for technical reasons resulting in continued sub-optimal response to business change, Component architecture is only determined bottom-up from existing APIs. Transaction and data integrity approaches may need to be re-evaluated because of multi-

MP6: Hybrid Refactor



MP7: Hybrid Refactor with on-premise Adaptation



MP7: Refactor with on-premise Adaptation

Definition: A re-architected application is deployed partially on a cloud environment and partially to its current on-premise platform.

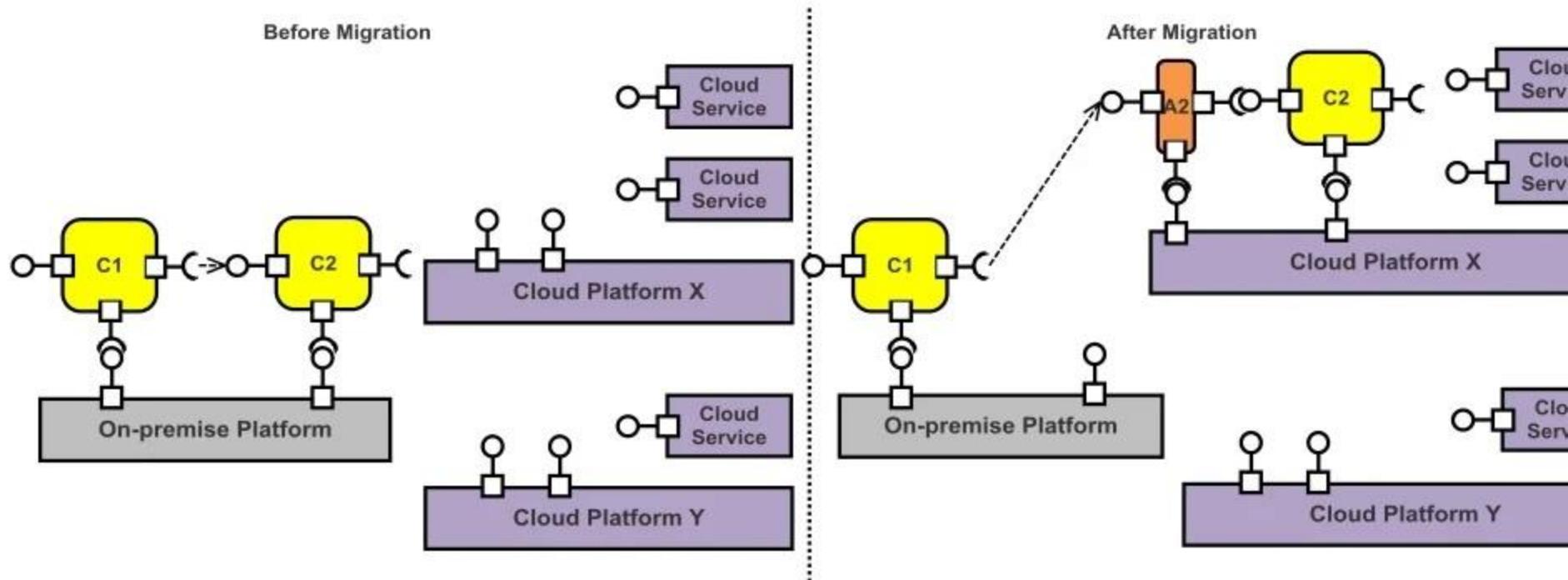
Problem: All components of the re-architected application may not be suitable for deployment on cloud. For example, due to sensitivity of data, lack of cloud capability to support current feature of application, license restrictions, or to support a gradual migration plan. However, as they are not co-located, some mechanisms are required to integrate the components.

Solution: A component adapter (e.g., on-premise façade) is adopted to provide integration of the on-premise components with re-hosted cloud-based components.

Benefits: Sensitive data remains isolated and in-house

Risks: Integration is dependent on specific cloud platform and may cause vendor lock-in.

MP8: Hybrid Refactor with Cloud Adaptation



MP8: Refactor with Cloud Adaptation

Definition: An interface is implemented to provide loose-coupled access to components re-hosted on cloud platform.

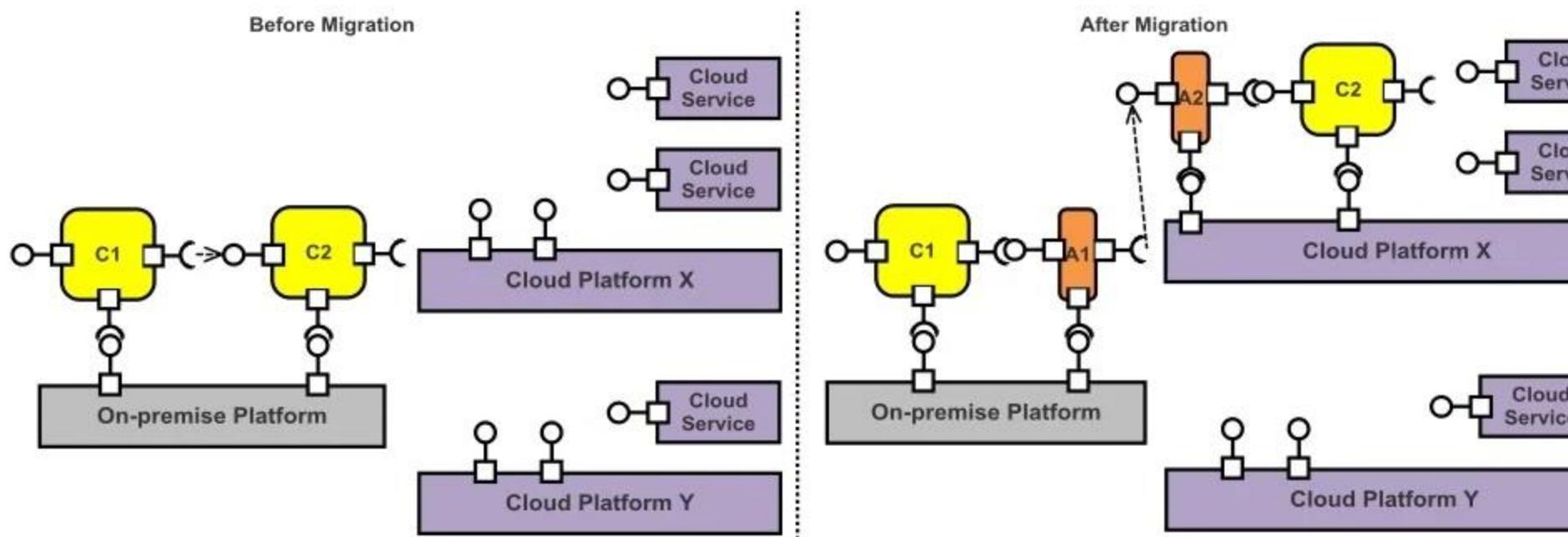
Problem: Components re-hosted as-is lacks appropriate service interfaces for integration

Solution: Build a façade, hosted in the cloud platform

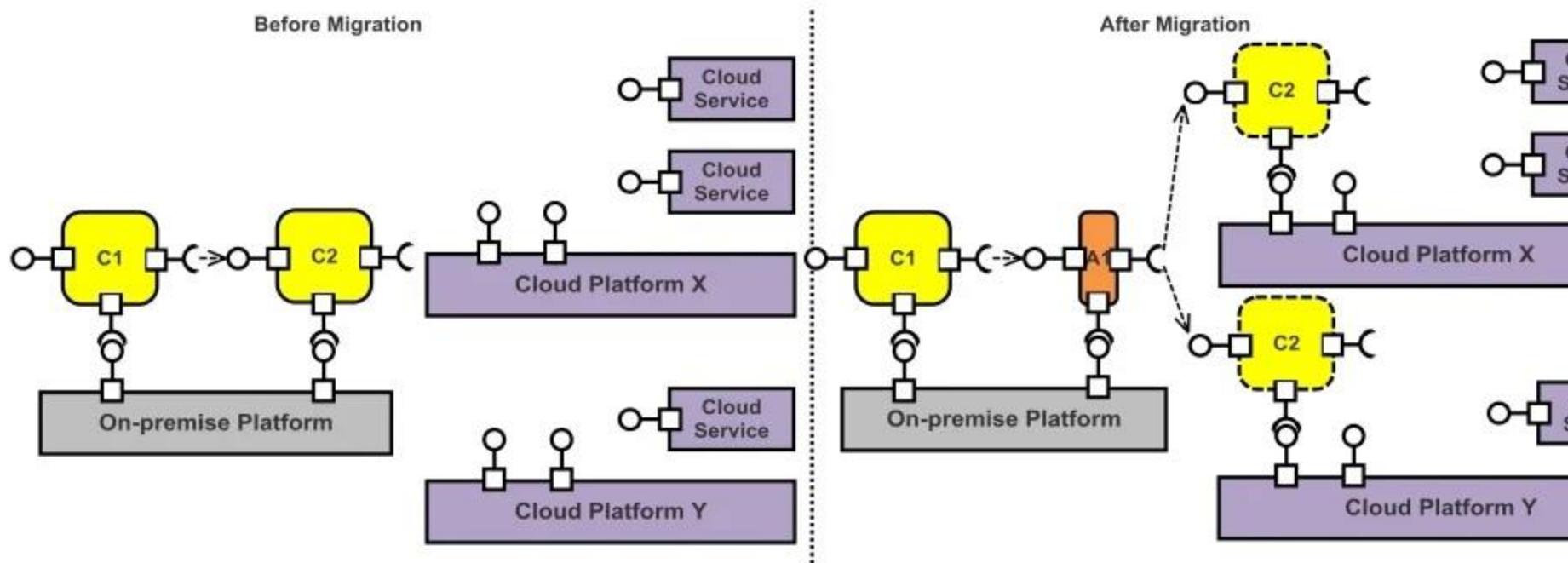
Benefits: Loose coupling, platform independent interoperability

Risks : Lack of suitable API on legacy application, Existing application process may not compliant with message-based interaction as a common style in the cloud. Façade is not provided as part of a well-formed service architecture

MP9: Hybrid Refactor with Hybrid Adaptations



MP10: Multi-Cloud Rebinding



MP10: Multi-Cloud Rebinding

Definition: A re-architected application is deployed partially on multiple cloud environments and enables the application to continue to function using secondary deployment when there is a failure with the primary platform.

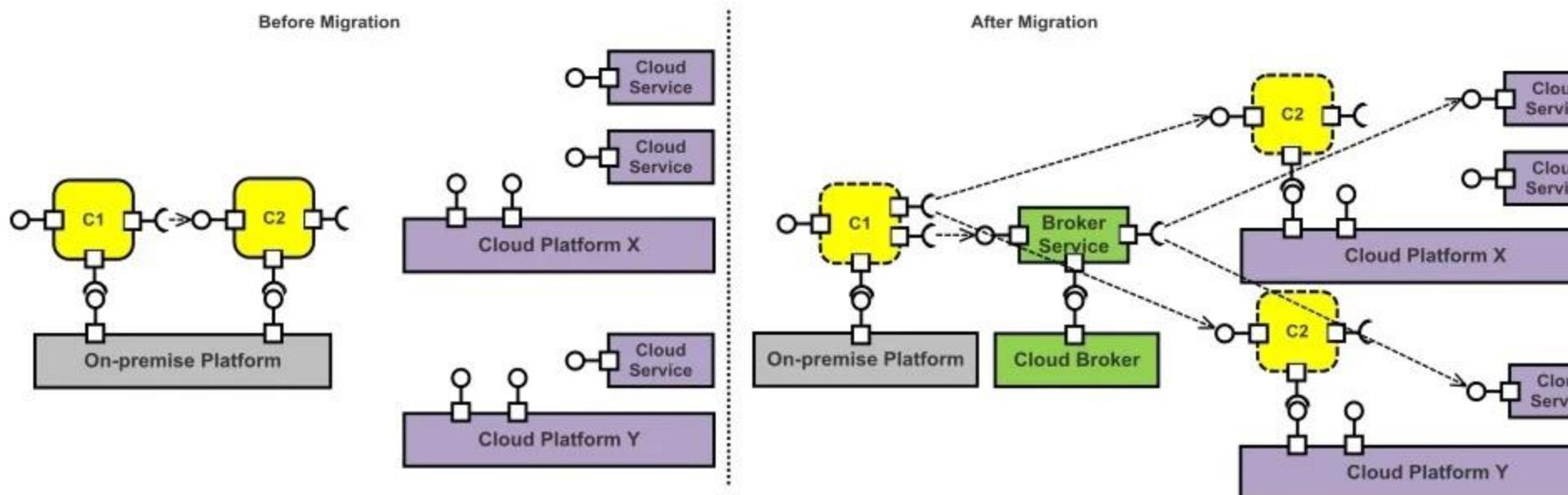
Problem: A natural disaster, such as a hurricane, or a failure such as a software bug or configuration error that impacts cloud services may cause a failure to a cloud platform and stop that from functioning.

Solution: The same architecture for resilient systems that route users to the closest data center can be used to account for failover scenarios. In particular, they can be configured to monitor the health of the services to which they are directing users, and if any service is unavailable, traffic will be routed to a healthy instance. An on-premise component adapter (e.g., service bus or elastic load balancer) is adopted to provide integration of the components in different cloud platforms.

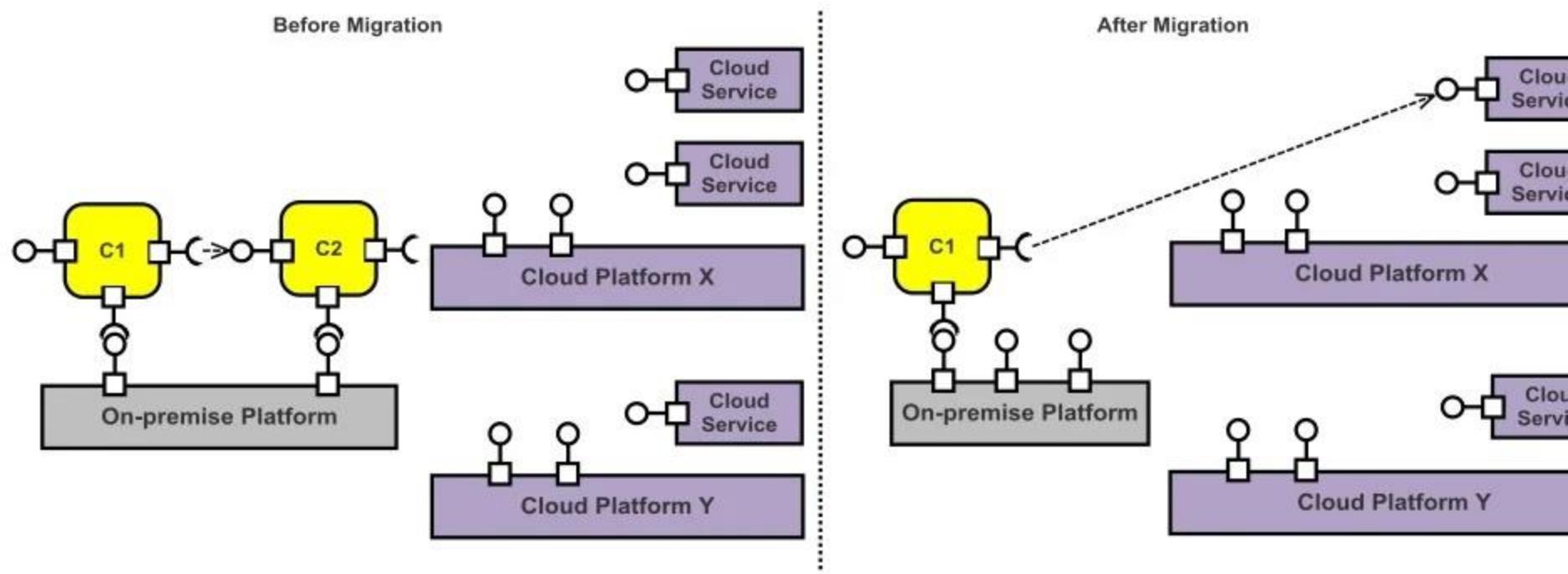
Benefits: As unhealthy services become healthy again, traffic can be delivered, returning system responsiveness to maximum levels.

Risks: This scheme does not guarantee instant or seamless failover. There will be downtime.

MP11: Multi-Cloud Rebinding with Cloud Brokerage



MP12: Replacement



MP12: Replacement

Definition: Individual capabilities in a re-architected solution are re-provisioned rather than re-engineered.

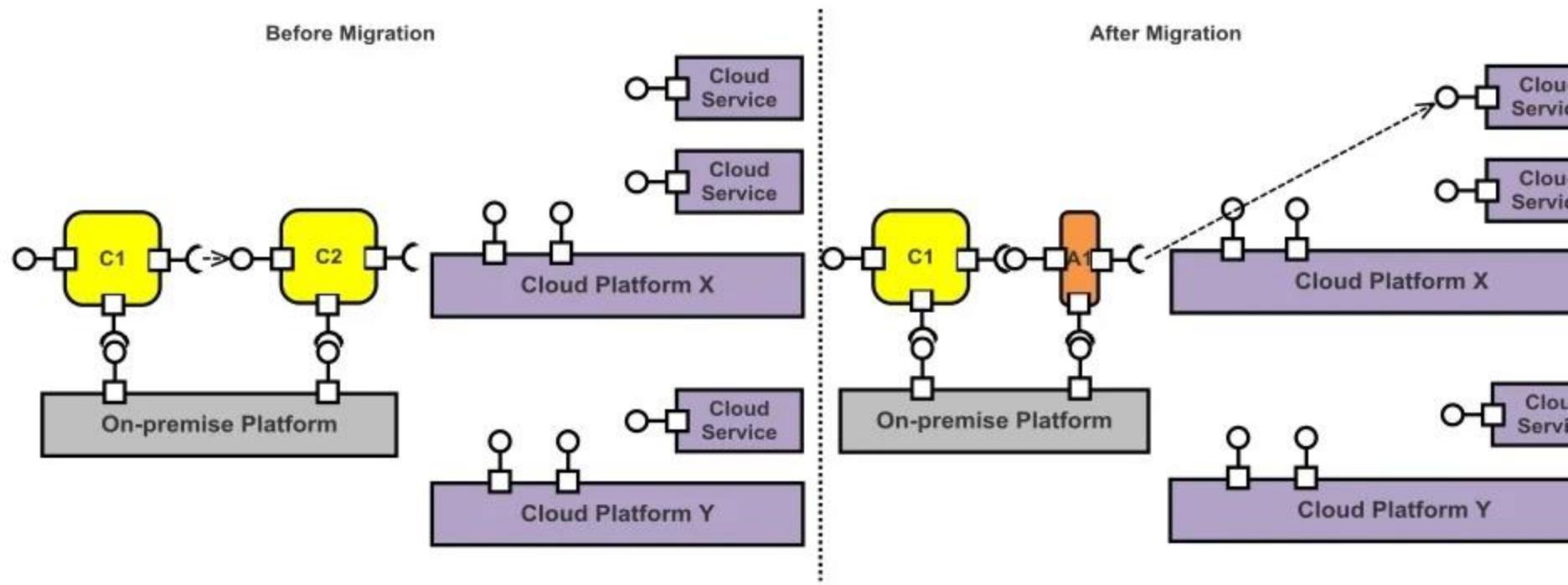
Problem: Some of existing components provided by the current application are not the best alternative to meet business requirements.

Solution: Analyze the requirements and identify a set of capabilities that can be replaced by existing cloud services. The provisioning of each capability is assessed by considering current systems analysis on the existing application to identify which of these capabilities could be supported by the re-architected system, alternative cloud services that provide a benefit over the re-engineering of the current capability are identified and replace existing components.

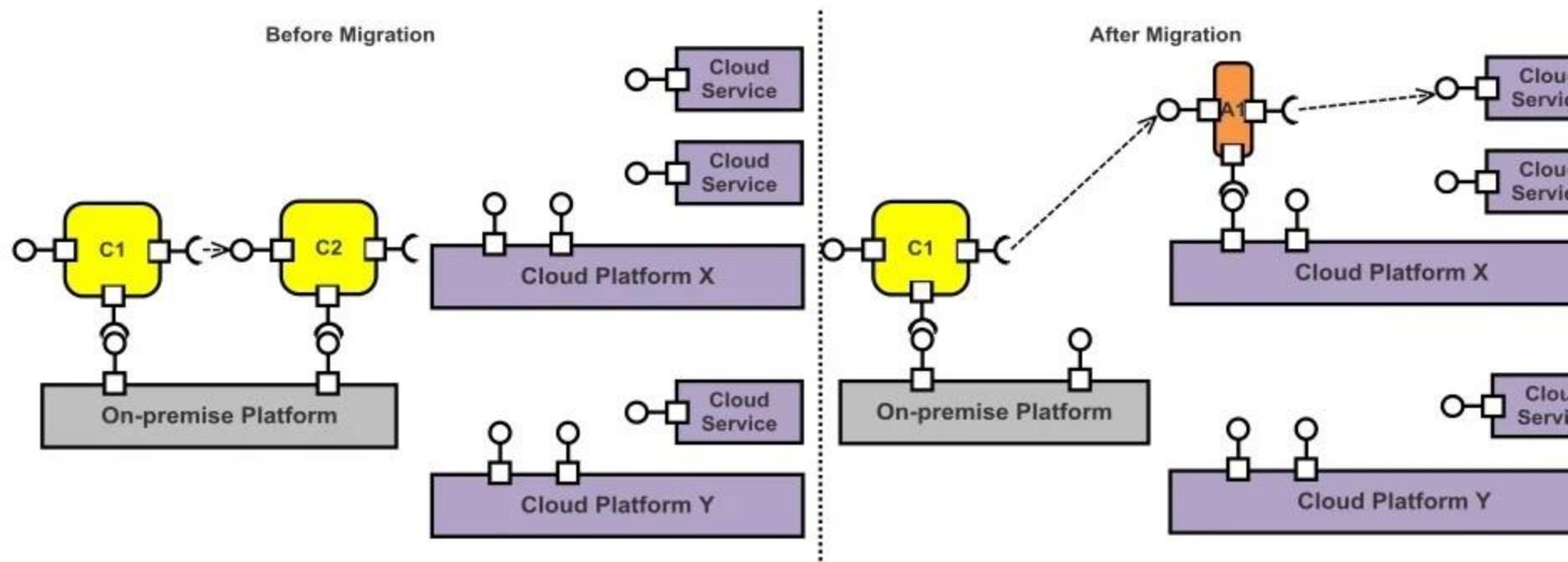
Benefits: The solution is improved though best-in-class cloud services, Re-engineering costs and effort are saved.

Risks: Cloud services presume specific communication protocol that make the replacement a challenging tasks.

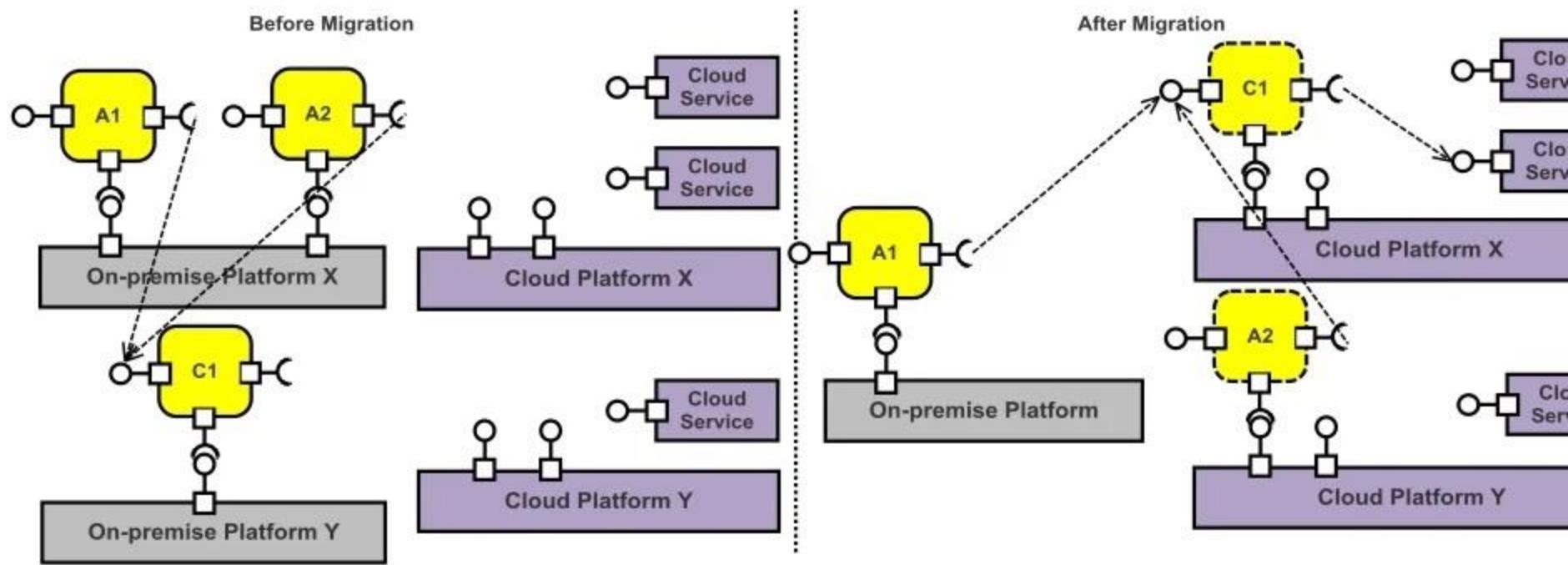
MP13: Replacement with on-premise Adaptation



MP14: Replacement with Cloud Adaptation



MP15: Multi-application Modernization



MP15: Multi-application Modernization

Definition: on-premise applications are re-architected as a portfolio and deployed on cloud environment.

Problem: The re-architecting of on-premise applications in isolation does not remove inconsistencies in data or duplicated functionalities, nor reduce the cost of their combined operation or maintenance.

Solution: Current applications are analyzed as a portfolio to identify opportunities for consolidation and sharing. The separation of the service architecture and the solution architecture enables the identification of components (capabilities) that are shared by more than one solution.

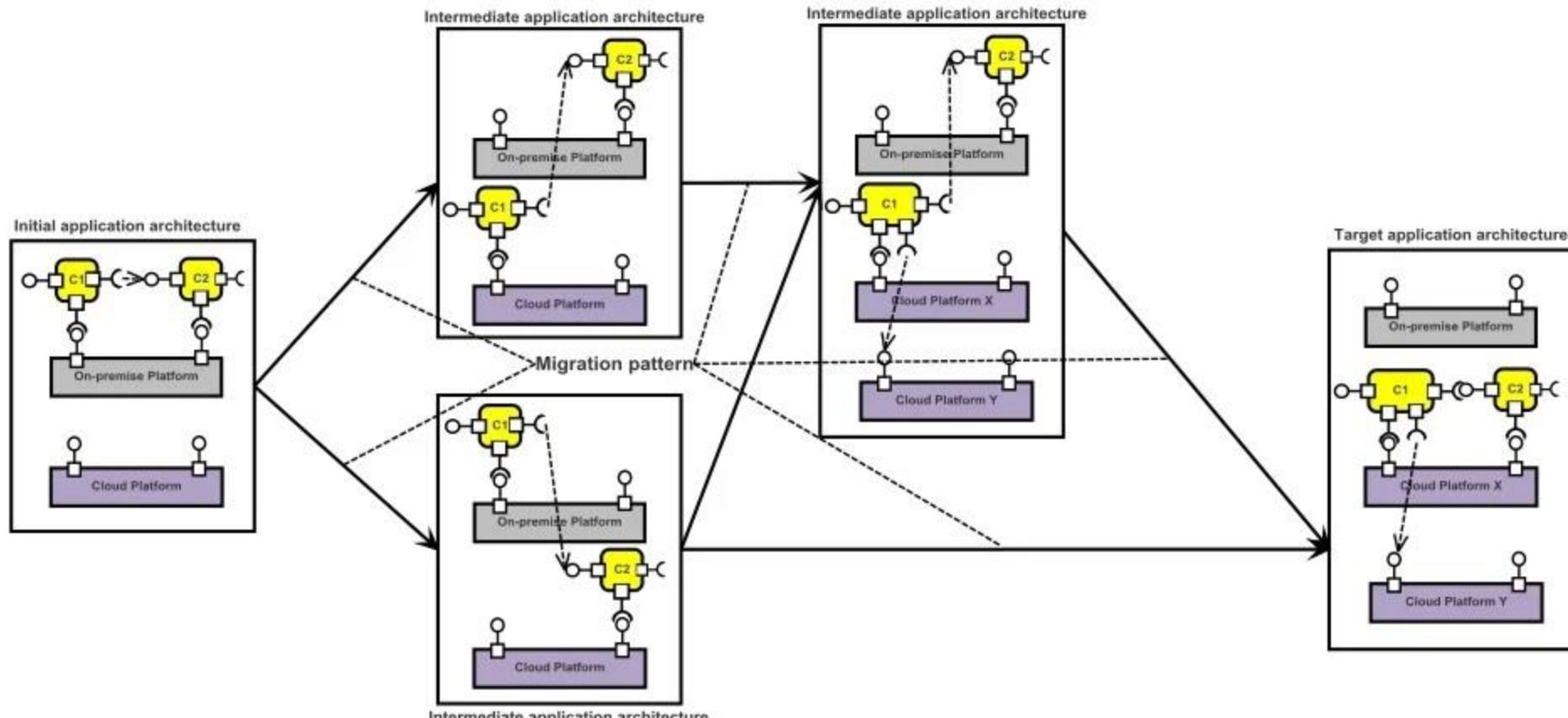
Benefits: Consistent information and rules in shared components, Reduced operation and maintenance costs for shared components, Foundation for more agile delivery of subsequent new applications.

Risks: Lack of business commitment to shared capabilities.

Cloud Migration through Pattern Composition

- The migration patterns can be seen as a sequence of activities by which an application is gradually migrated to the cloud.
- The migration patterns can be composed (i.e., executed sequentially) to move an on-premise application to the cloud.

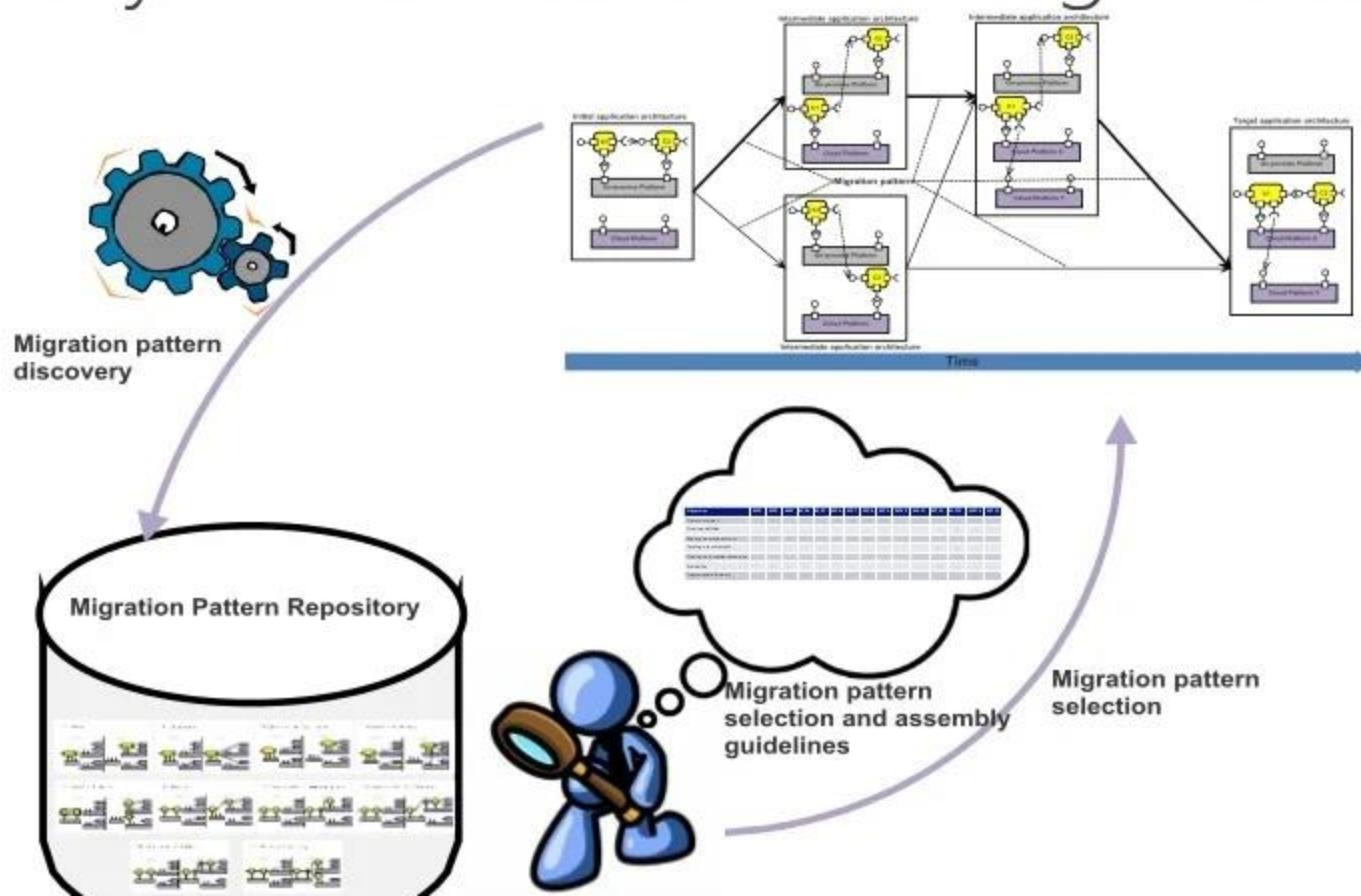
Migration Transition Graph



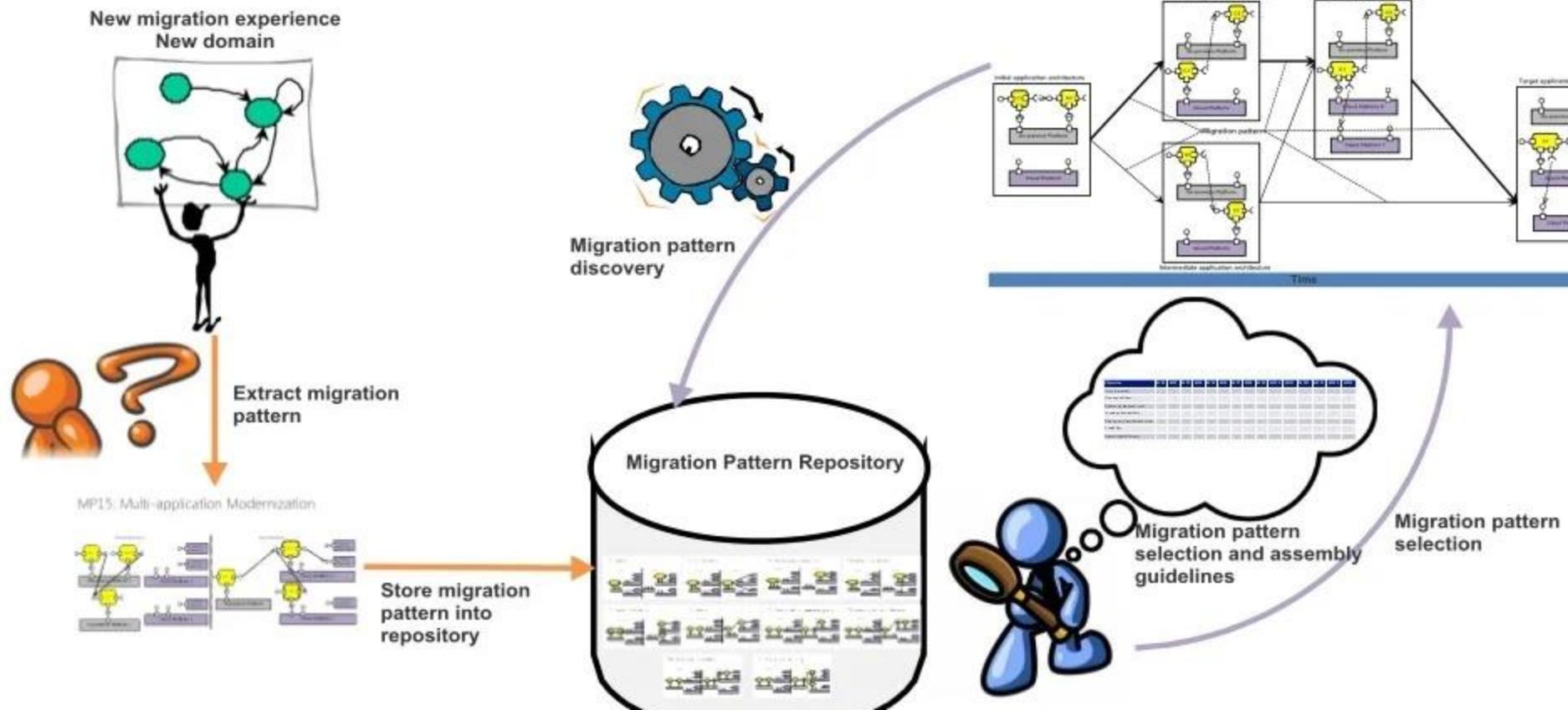
Migration Pattern Selection

Objective	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12	MP13	MP14
	Re-host	Cloudification	Relocation					Refactor	Rebinding			Replacement		
Time to market	😊	--	✗	✗	✗	--	--	--	--	✗	✗	😊	😊	😊
New capabilities	✗	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	--	--	--
Reduce operational cost	😊	😊	--	--	✗	--	--	--	--	✗	✗	😊	😊	😊
Leverage investments	😊	😊	--	--	--	😊	😊	😊	😊	😊	😊	✗	✗	✗
Free up on-premise resources	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊
Scalability	✗	--	--	--	😊	😊	😊	😊	😊	😊	😊	--	--	--
Operational efficiency	😊	--	--	--	😊	--	--	--	--	😊	😊	😊	😊	😊

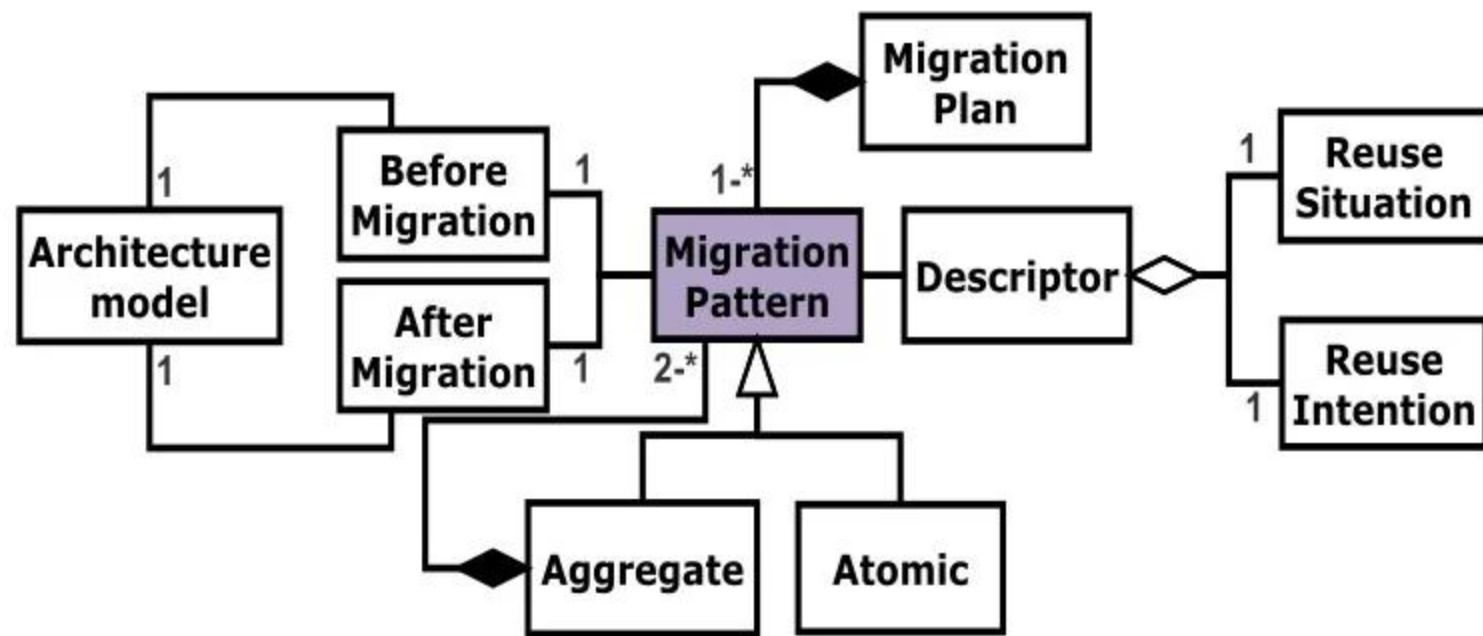
Assembly-based Situational Migration



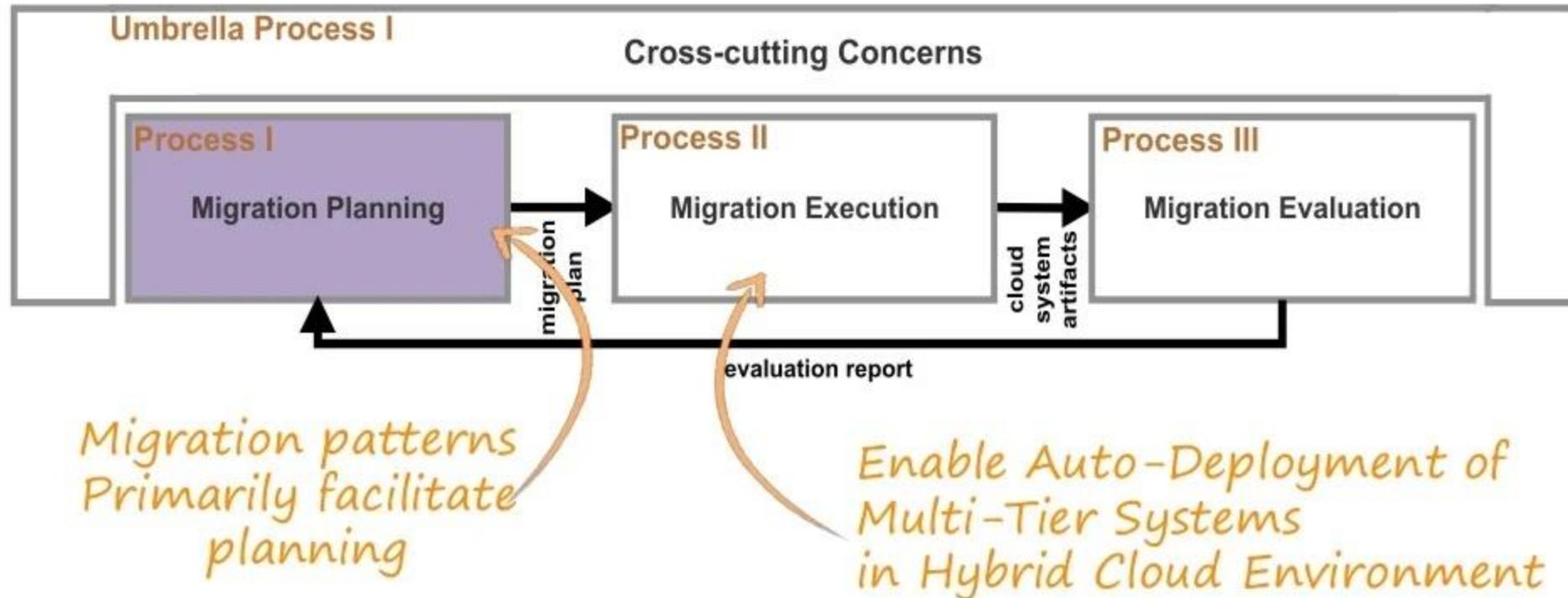
Assembly-based Migration Plan Construction



Migration Pattern Meta-Model



Migration Patterns in the context of Cloud-RMM



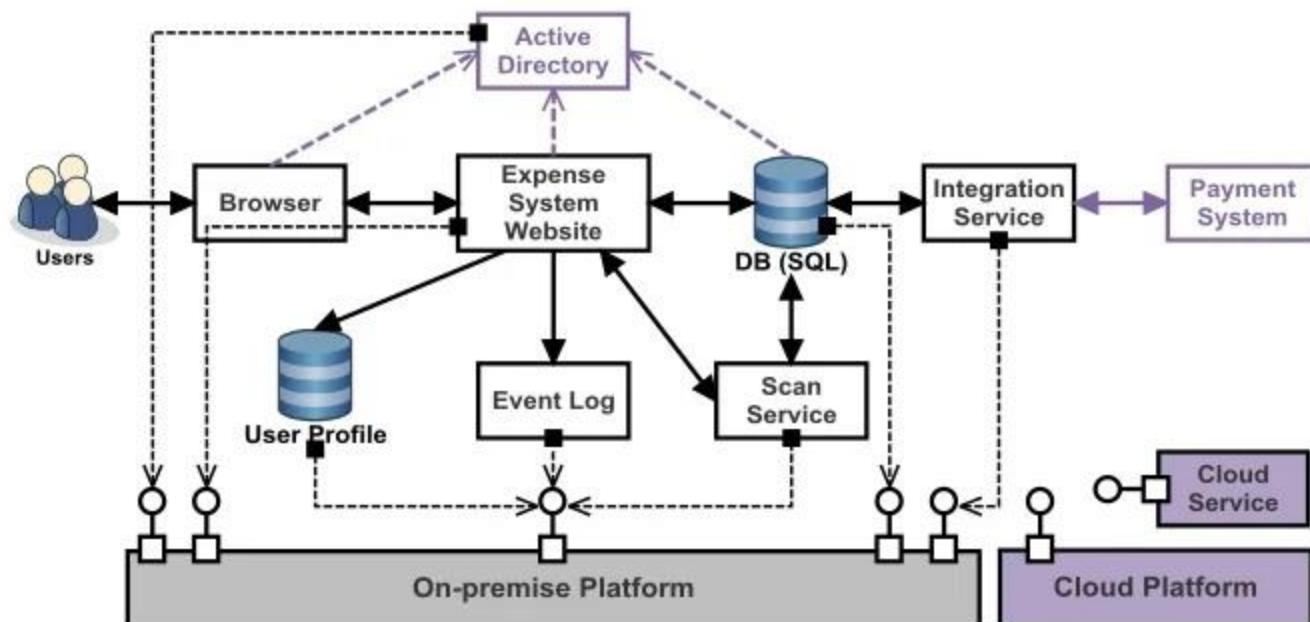
Recommendations

- ✓ Establish objectives and priorities
- ✓ Select migration patterns based on the objectives using decision support framework
- ✓ Consider different patterns at a time when cost is important

Empirical Validation

- IC4 industry partners
- Focused groups
- Evaluation Criteria
 - Completeness
 - Usability

Case Study 1: Enterprise Software Migration to the Multi-Cloud



Application Architecture (on-premise deployment)

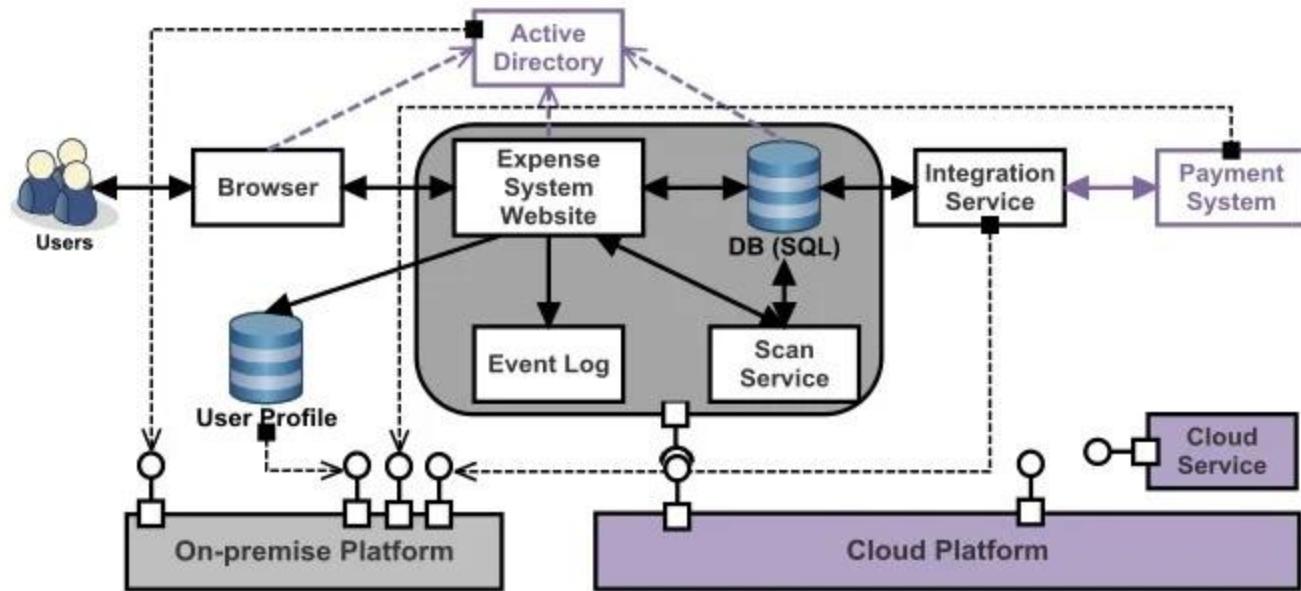
The Migration Plan

Migration Step	Requirement	Chosen Patterns
1	Minimal code changes to application and familiarity with platform	MP1
2	Granular control of resource usage and opportunity for auto-scaling	MP6
3	Lower cost although some limitations on feature availability	MP13
4	Replacing on-premise storage with cloud offerings	MP12
5	Integration with cloud utility services	MP14
6	Highly available service replacement	MP11
7	Better user experience, improved efficiency, and load leveling	MP3

Migration Step 1

Concern: Minimal code changes to application and familiarity with platform

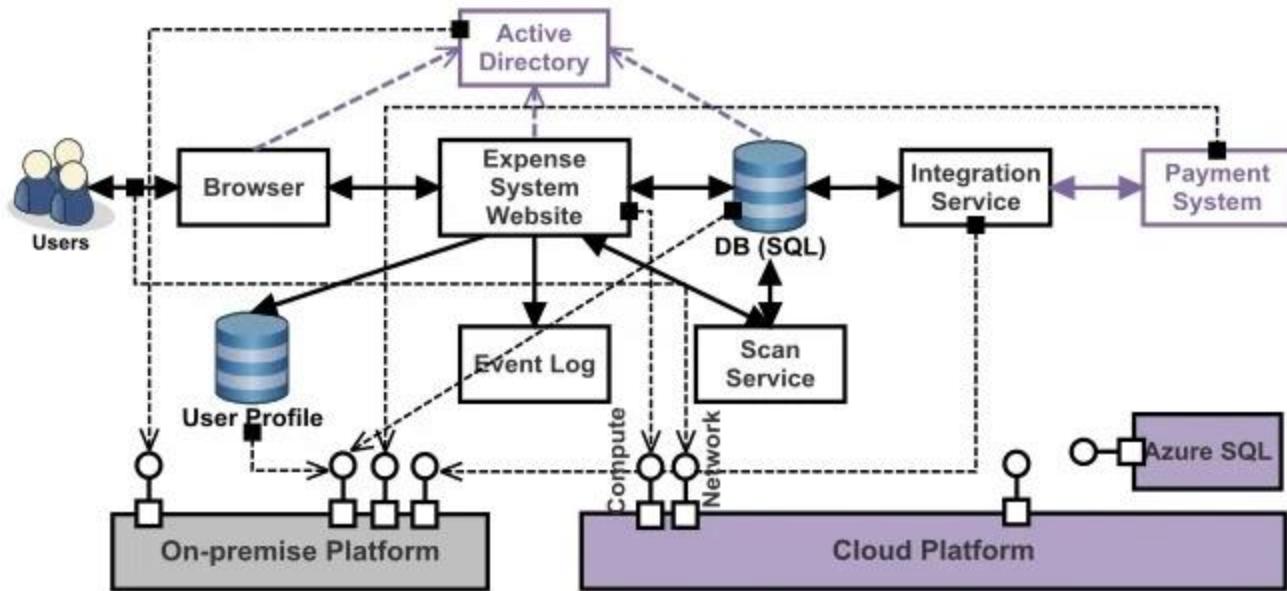
Selected pattern
MP1



Migration Step 2

Concern: Granular control of resource usage and opportunity for auto-scaling

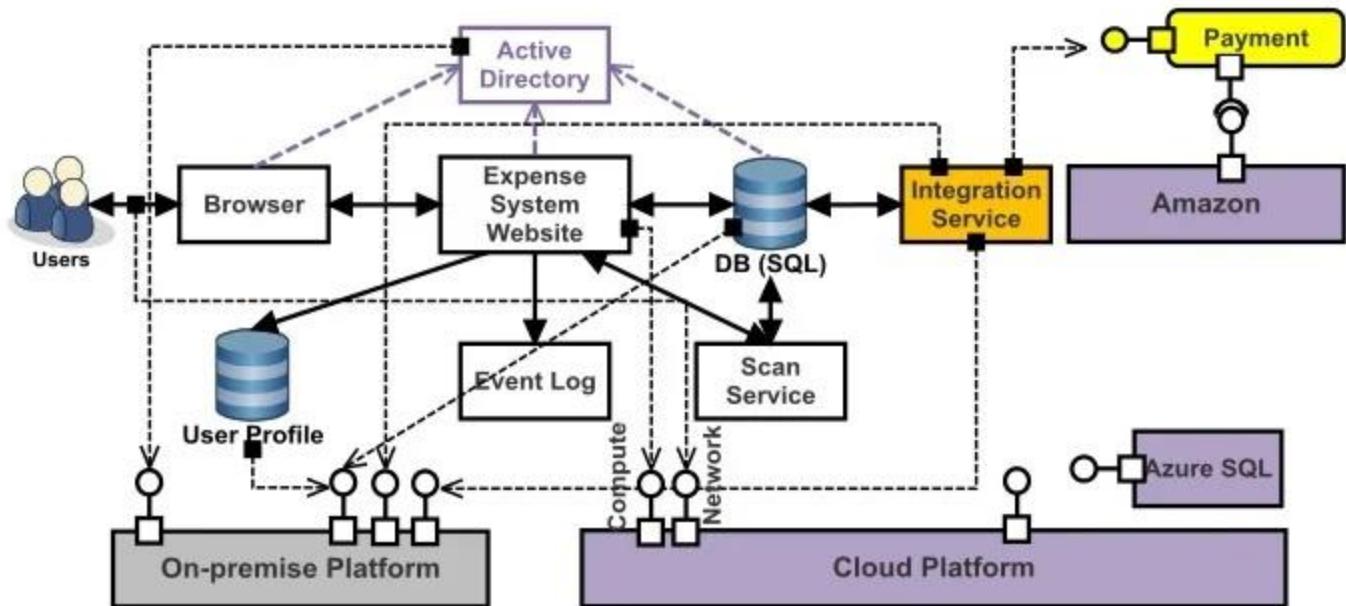
Selected pattern
MP6



Migration Step 3

Concern: Lower cost although some limitations on feature availability

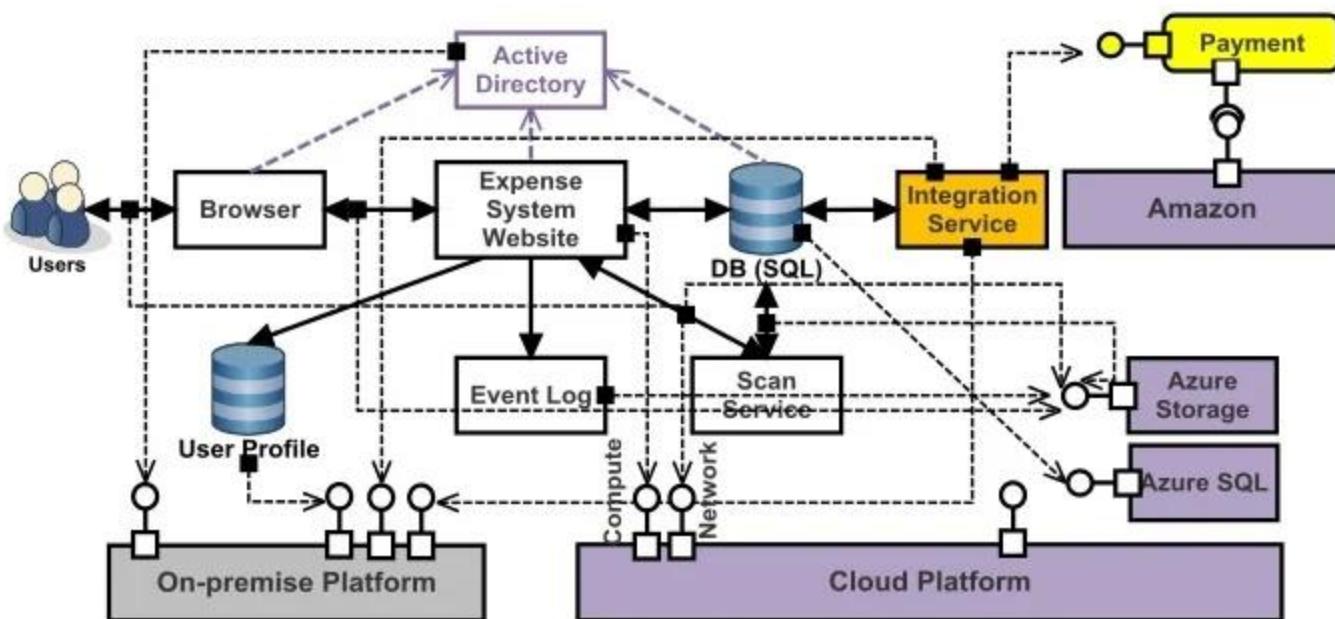
Selected pattern
MP13



Migration Step 4

Concern: Replacing on-premise storage with cloud offerings

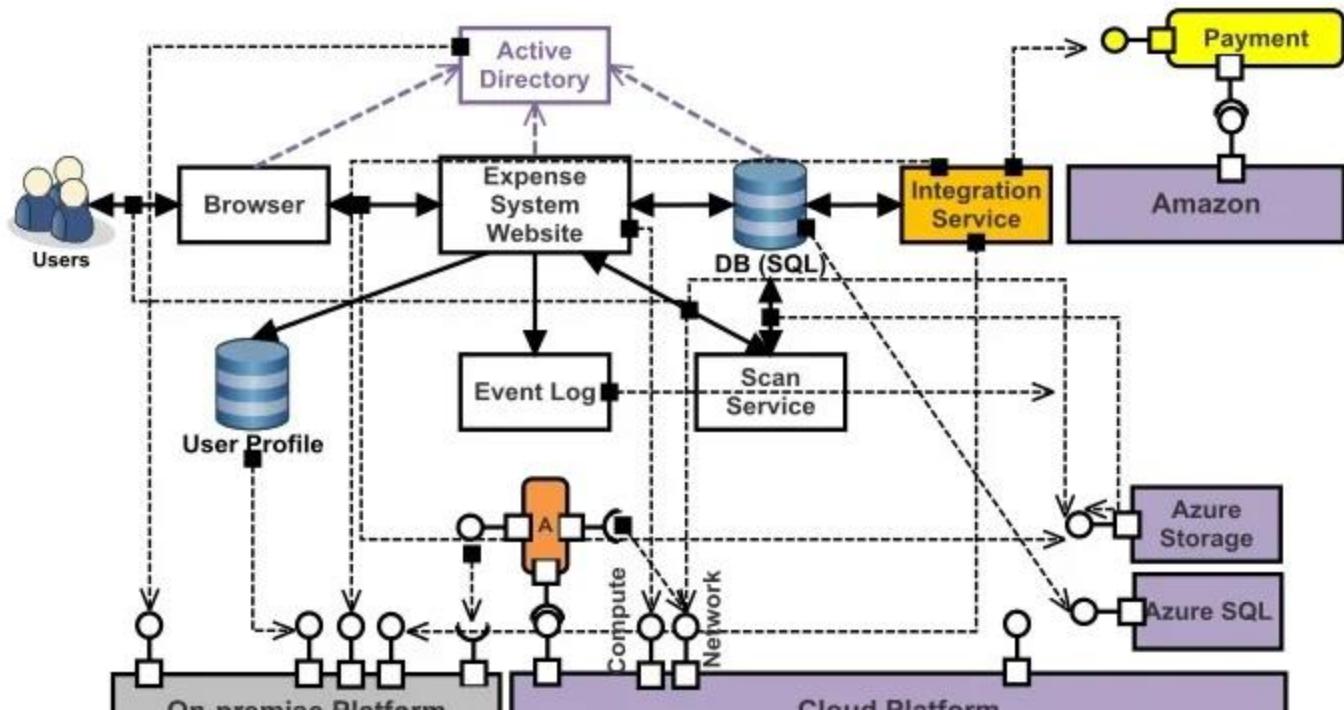
Selected pattern
MP12



Migration Step 5

Concern: Integration with cloud utility services

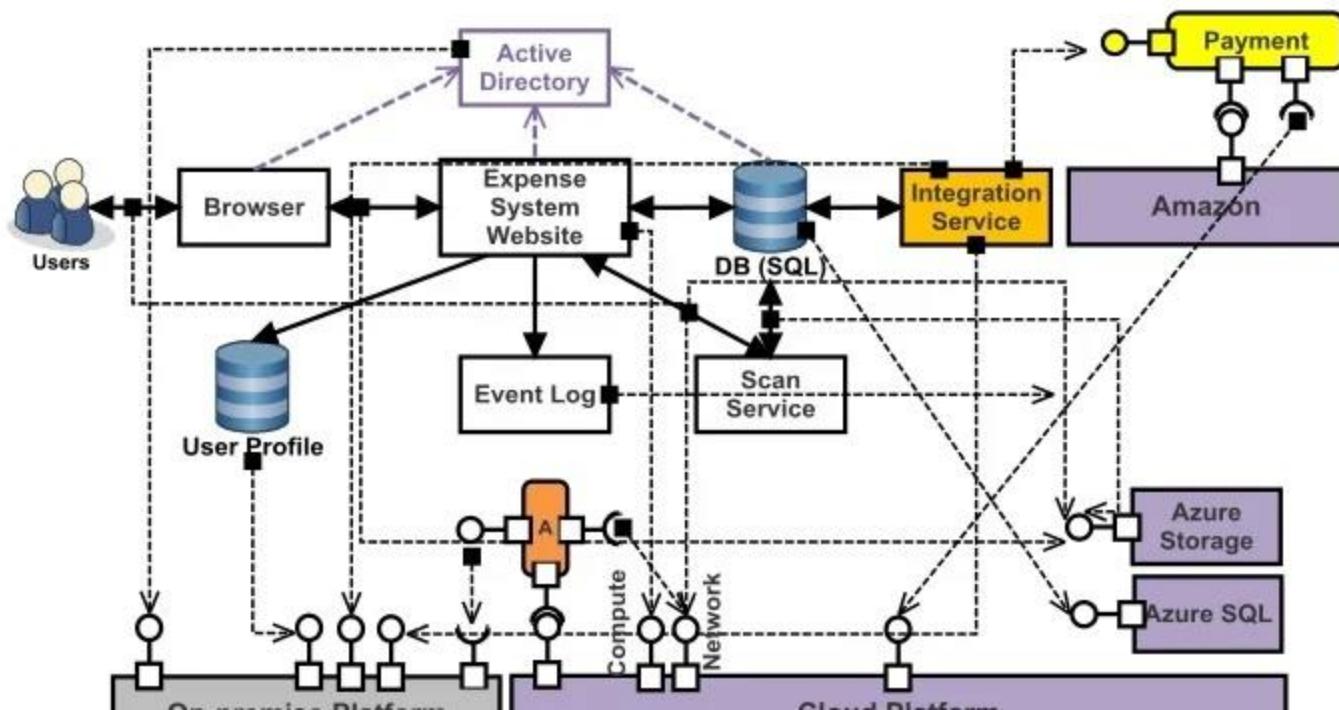
Selected pattern
MP14



Migration Step 6

Concern: Highly available service replacement

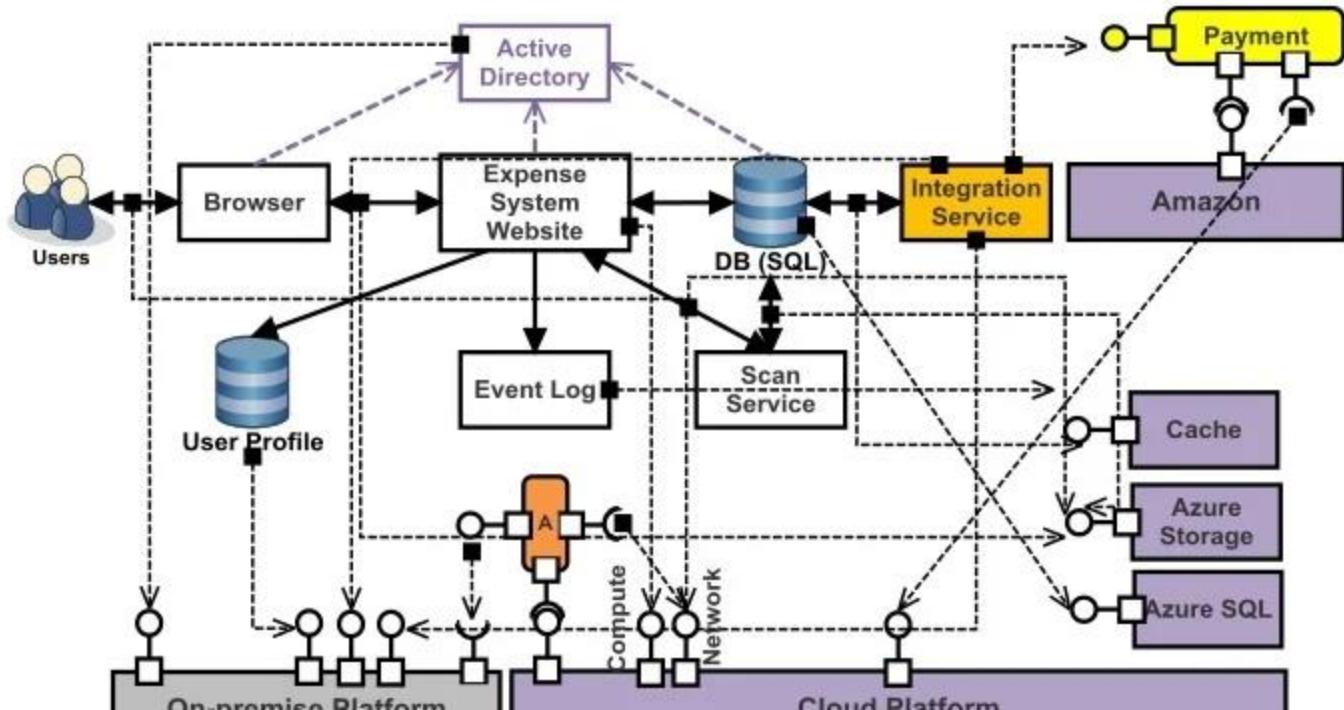
Selected pattern
MP11



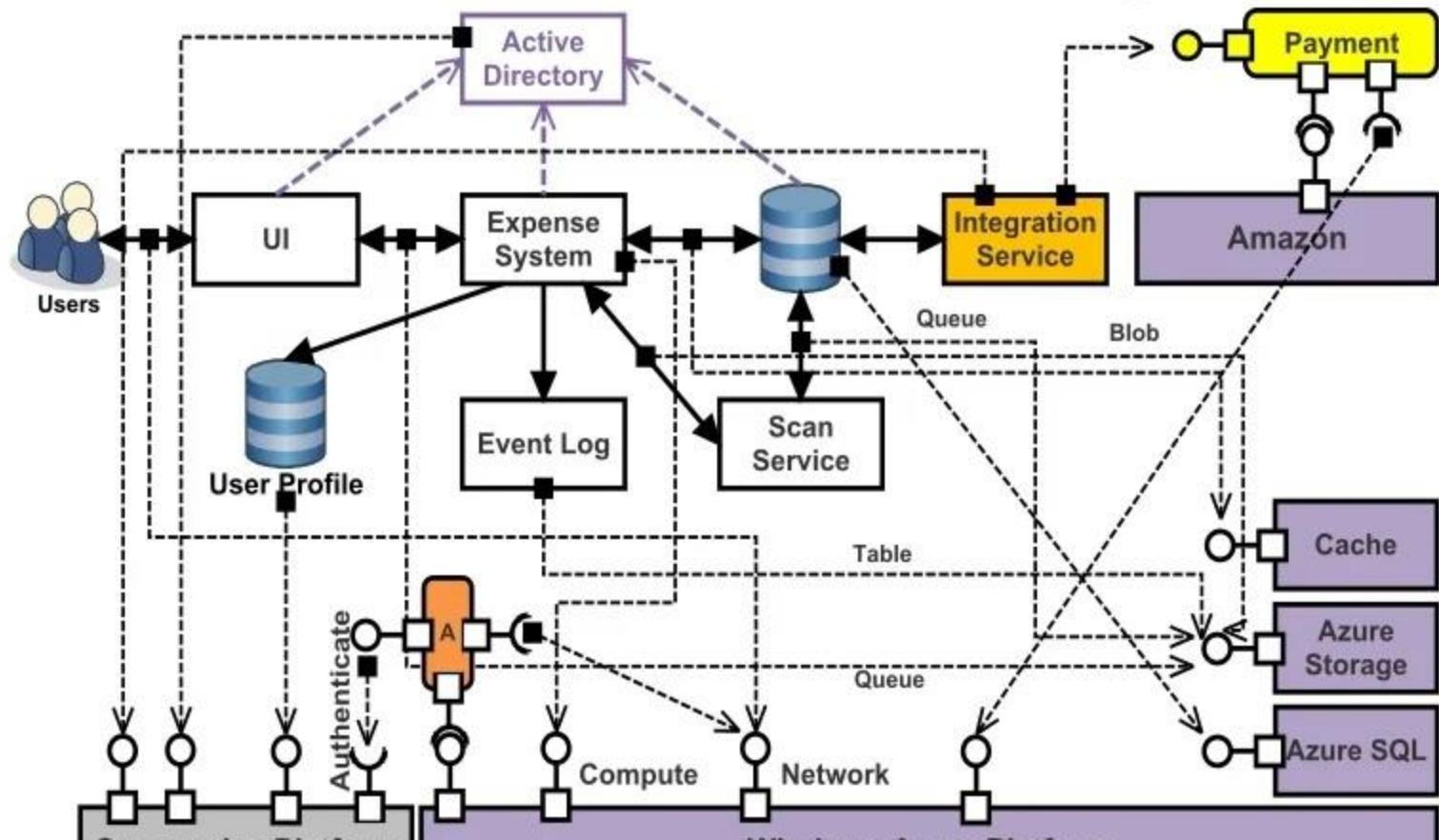
Migration Step 7

Concern: Better user experience, improved efficiency, and load leveling

Selected pattern
MP3



Application Architecture after Migration



Benefits

Incremental migration

New functionalities by cloud offerings

Hybrid deployment

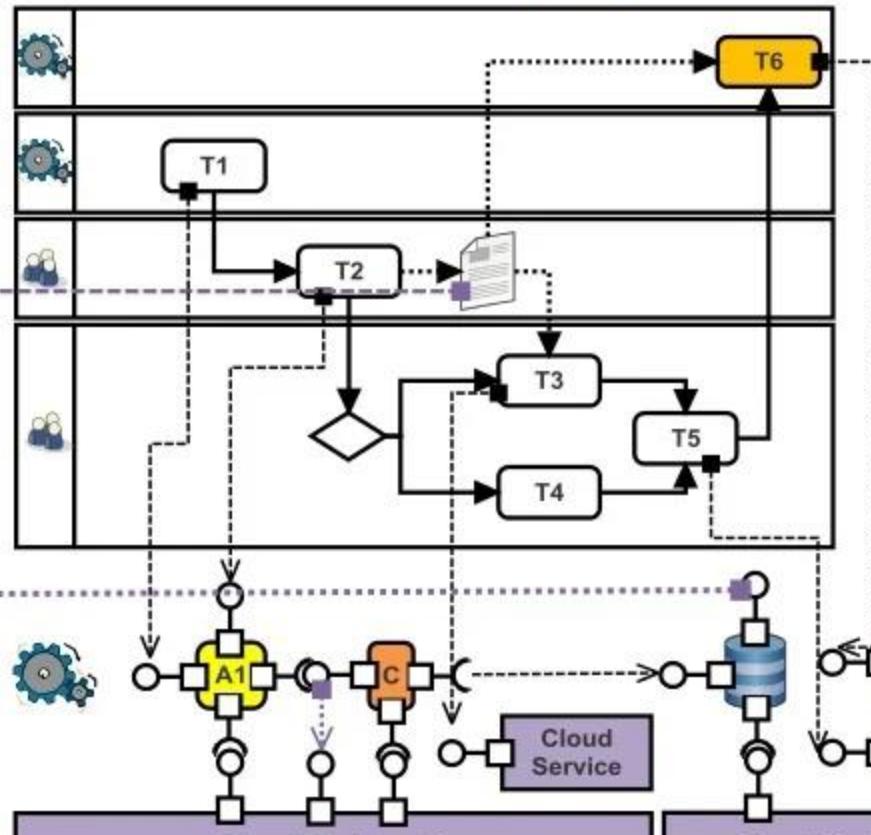
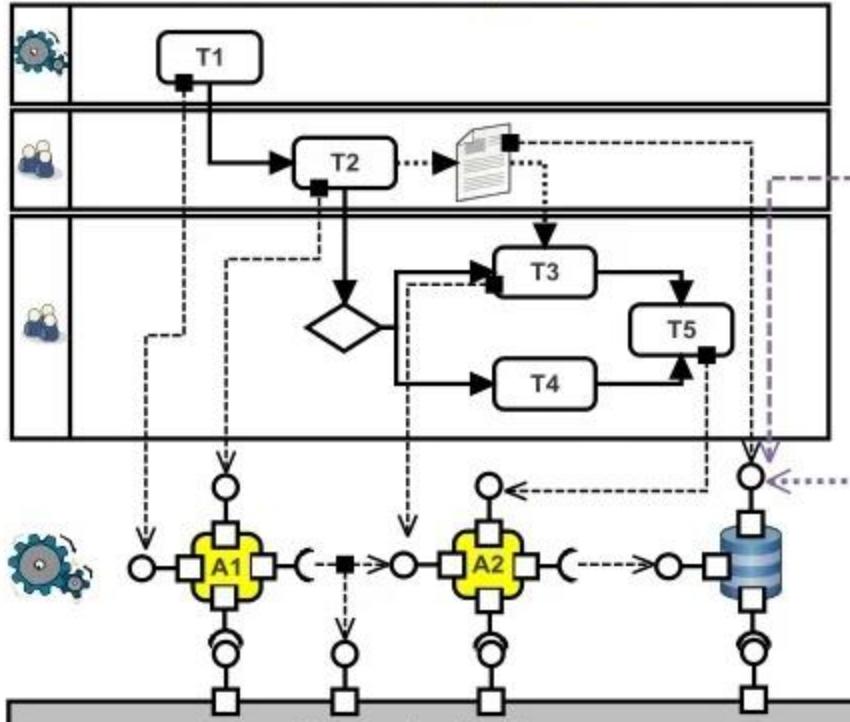
Multi-tenant architectures

Elastic software

SaaS

Case Study 2: Business Process Migration to the Multi-Cloud Deployment

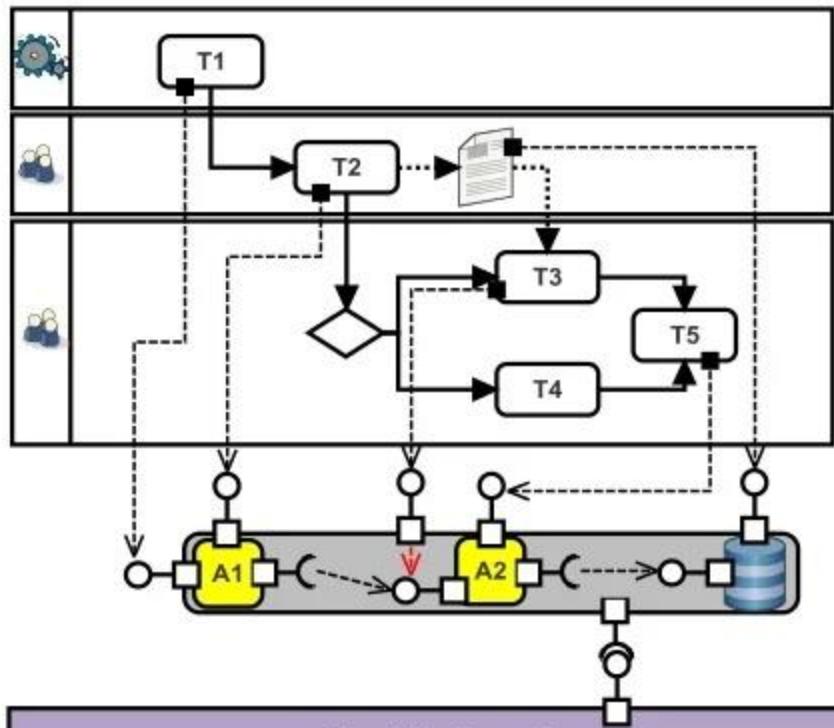
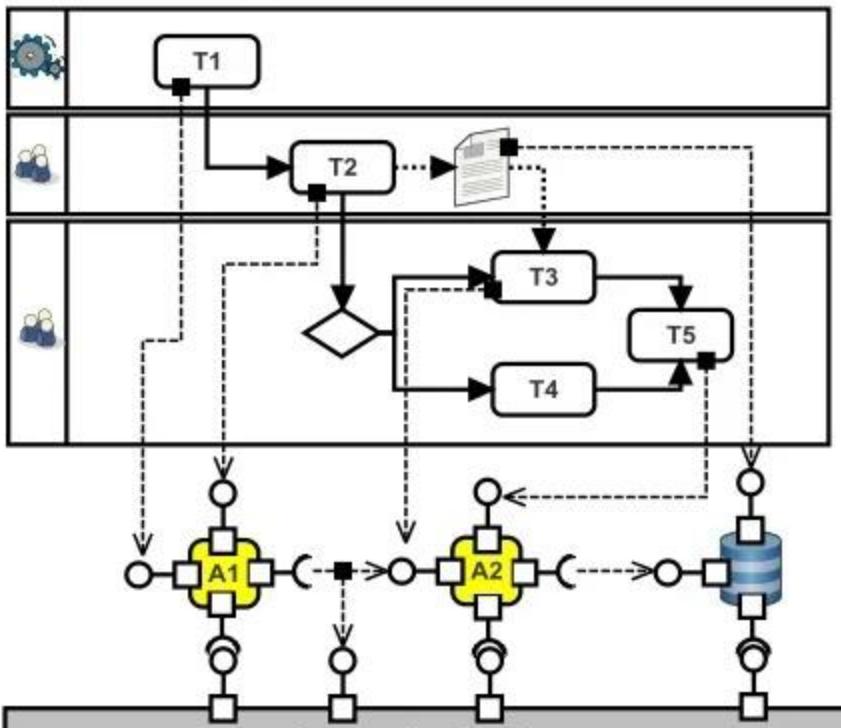
On-Premise Deployment



Migration Step 1

Concern: Minimal code changes to application and familiarity with platform

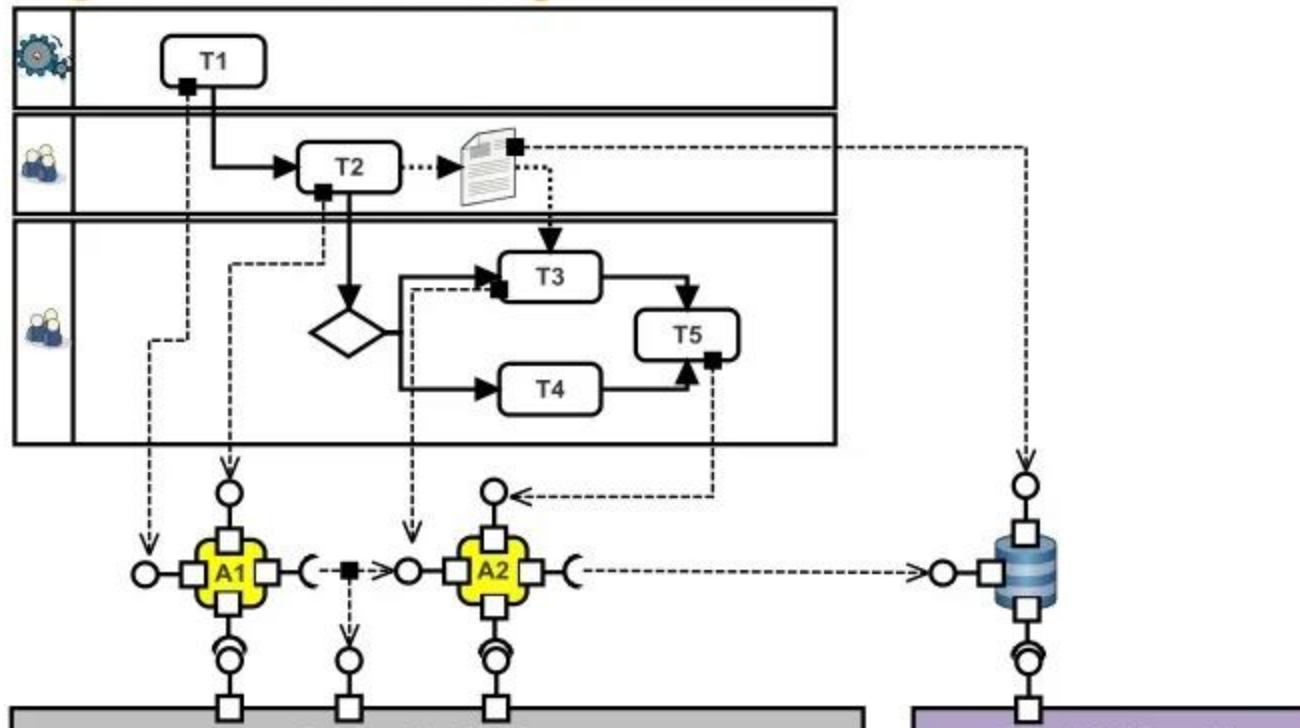
Selected pattern
MP1



Migration Step 2

Concern: Granular control of resource usage and opportunity for auto-scaling

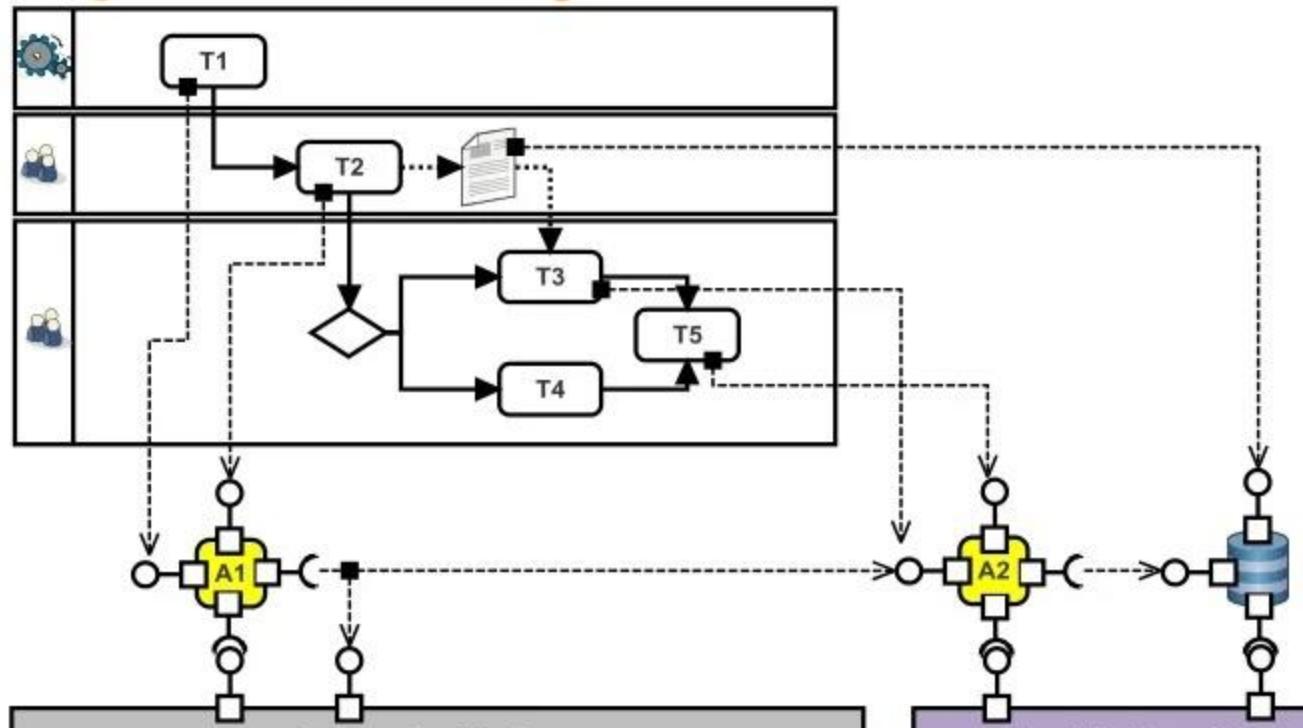
Selected pattern
MP6



Migration Step 3

Concern: Granular control of resource usage and opportunity for auto-scaling

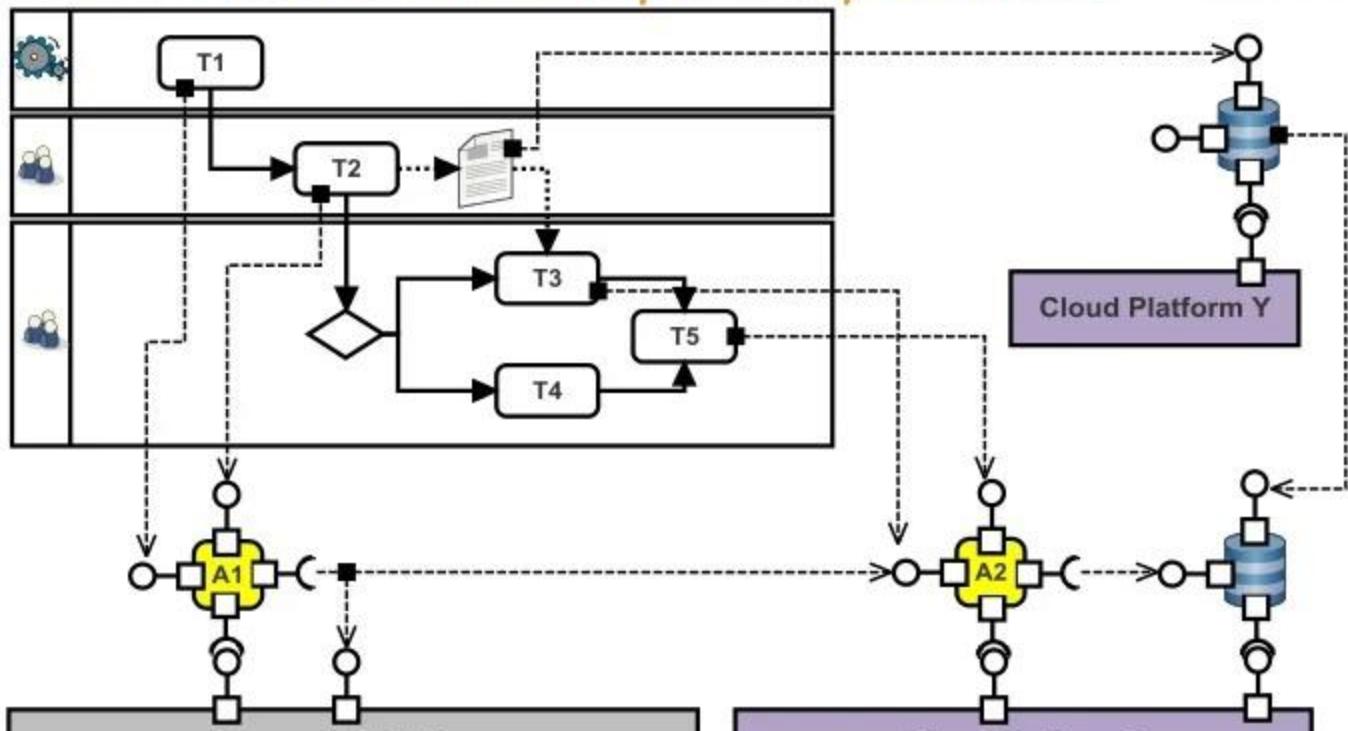
Selected pattern
MP6



Migration Step 4

Concern: Enhancing availability without architecture evolution and capital expenditure

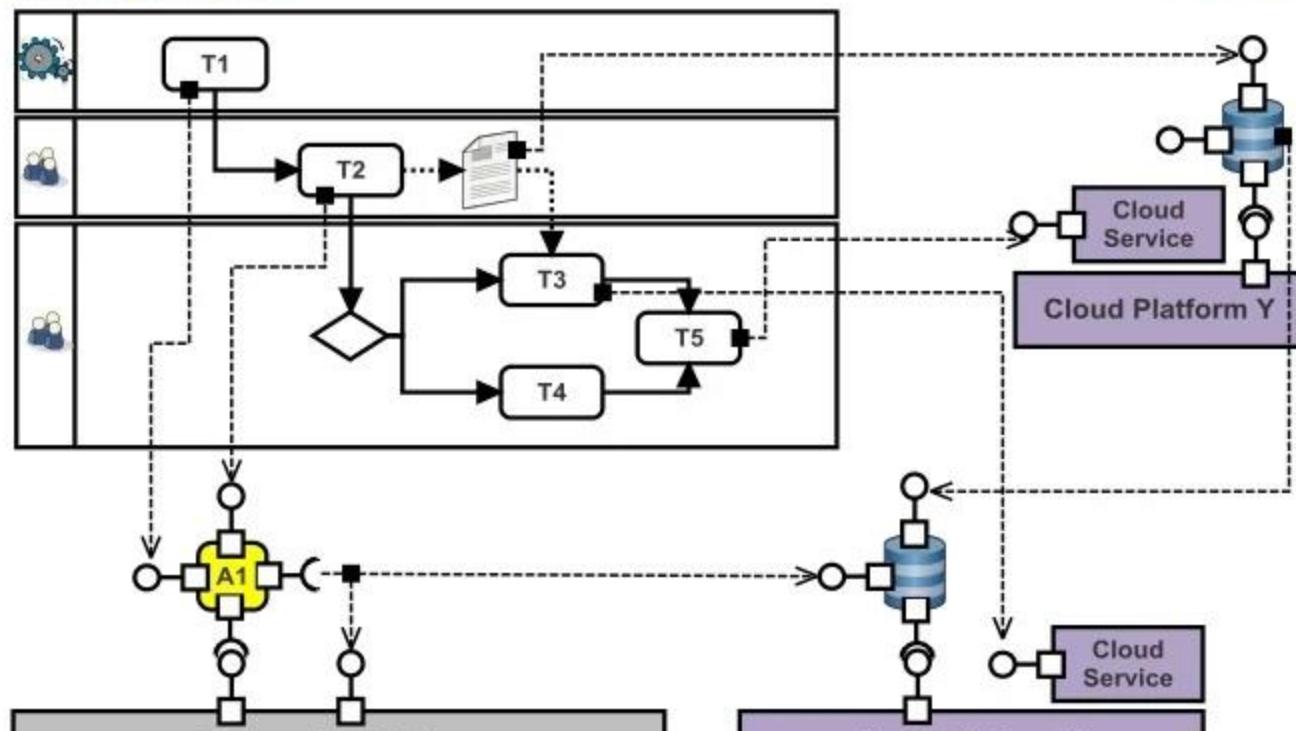
Selected pattern
MP4



Migration Step 5

Concern: solution is improved through best-in-class cloud services

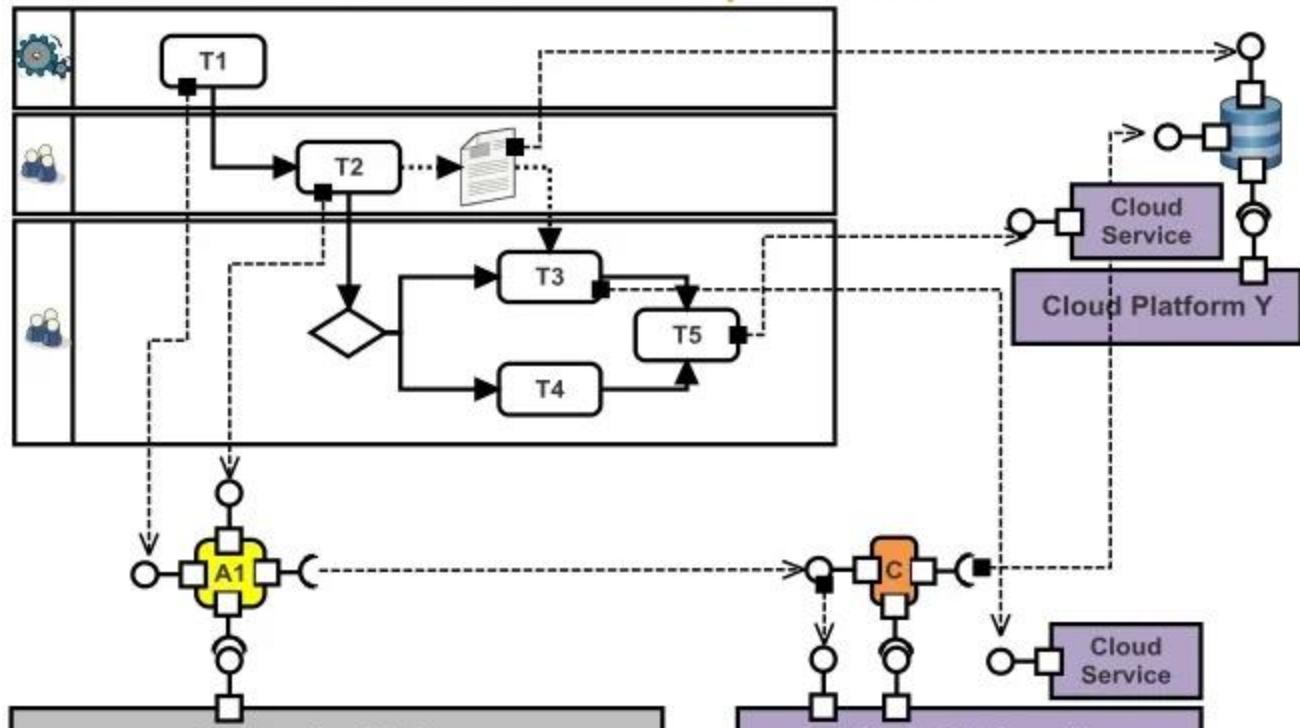
Selected pattern
MP12



Migration Step 6

Concern: loose-coupled integration with cloud utility services and re-hosted components

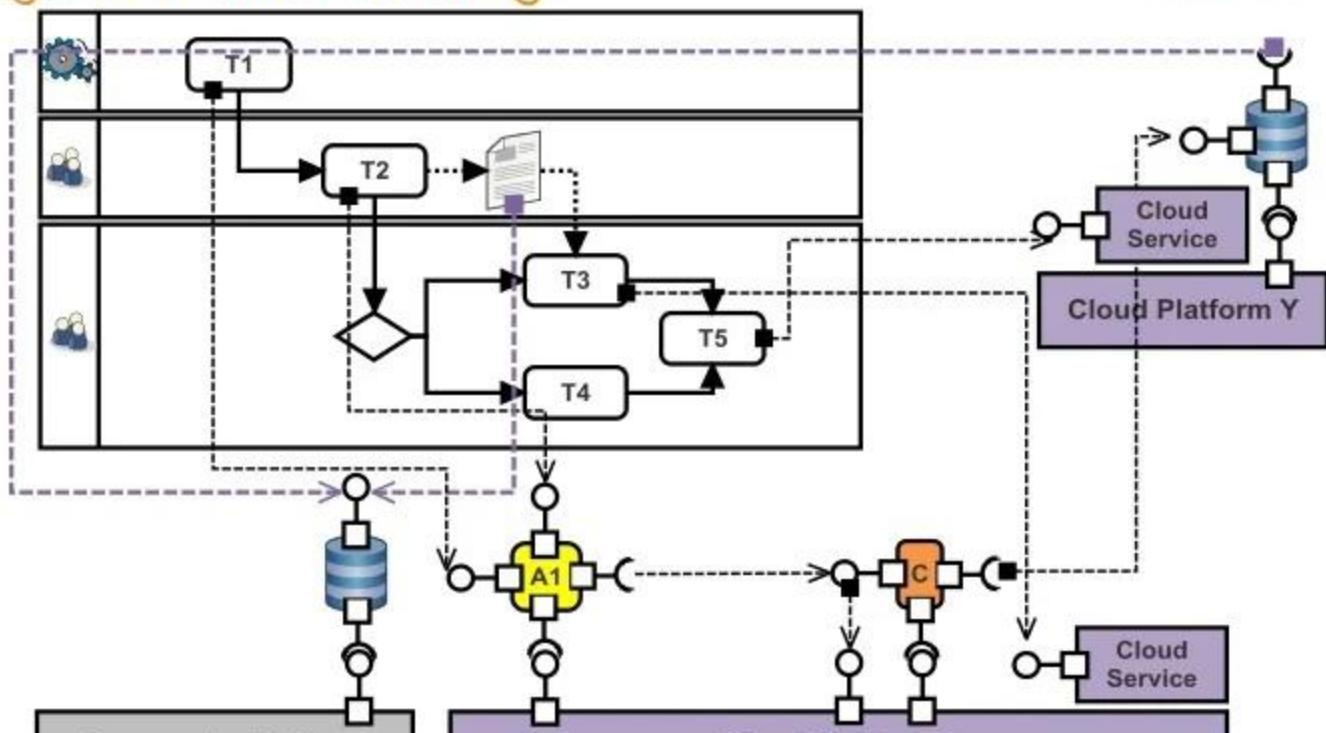
Selected pattern
MP8



Migration Step 7

Concern: better user experience, improved efficiency, and load leveling

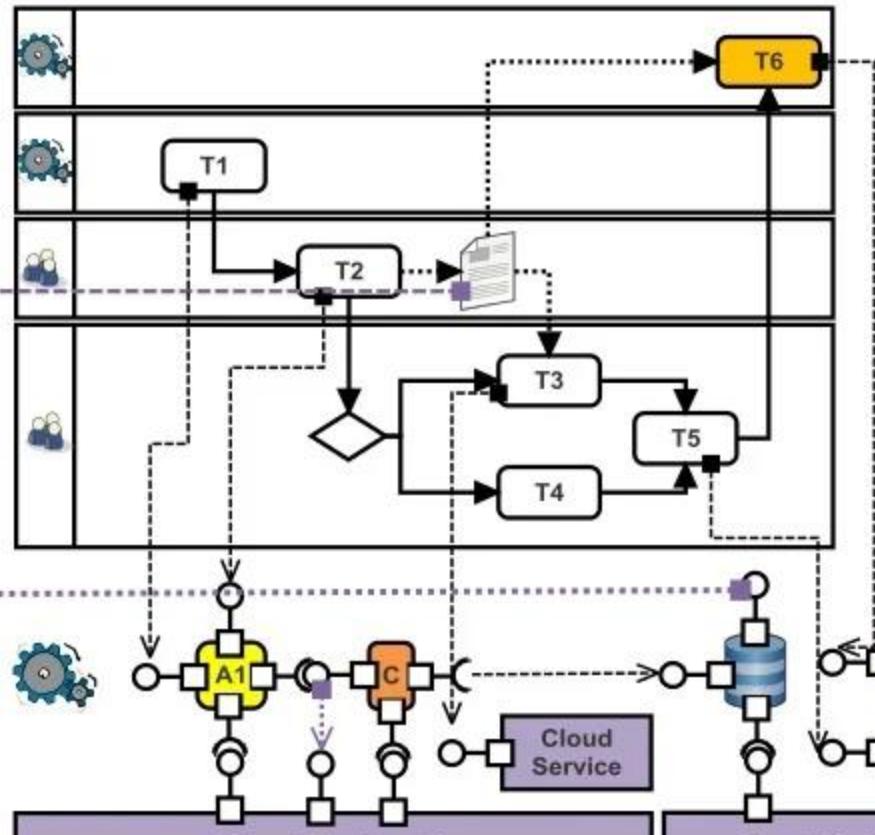
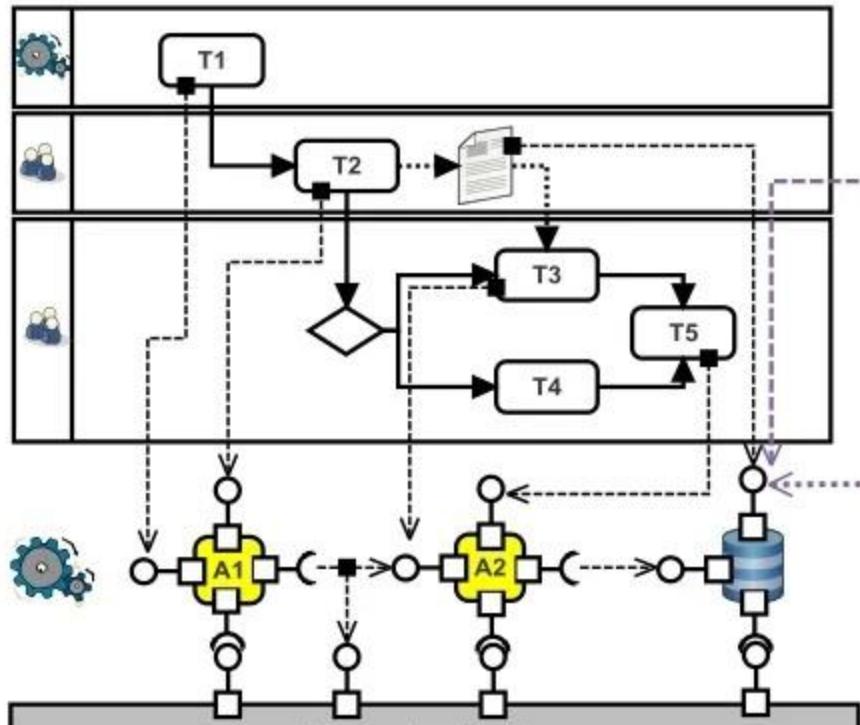
Selected pattern
MP3, MP6



Concern: business expansion and BPaaS

Migration Step 8

Selected pattern
MP15



Benefits

Incremental migration

Business expansion

Hybrid deployment

Multi-tenant business processes

Elastic business processes

BPaaS

Final Remarks

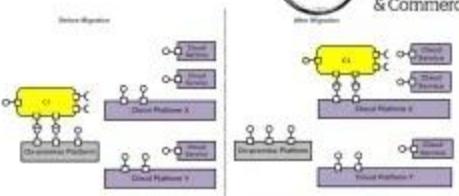
- Cloud migration requires an engineering approach based on well-defined migration patterns
- Application architecture facilitate visual characterization of the pattern
- Migration patterns are reusable, composable, discoverable
- Migration plan can be communicated with non-technical stakeholders
- The patterns can support migration team in the migration planning
 - highlighting useful component migration mechanisms
 - implementation requirements and challenges

The Message!

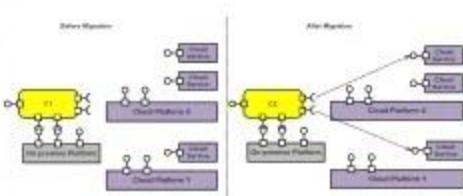
Cloud migration requires an engineering, verifiable, measurable, transparent and repeatable approach rather than an ad-hoc approach based on trial and error.



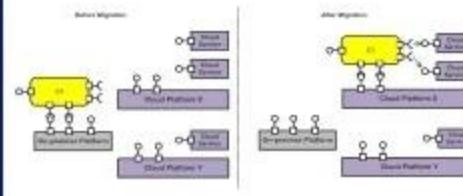
MP1: Re-host



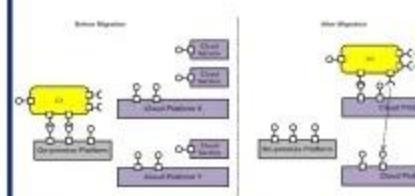
MP2: Cloudification



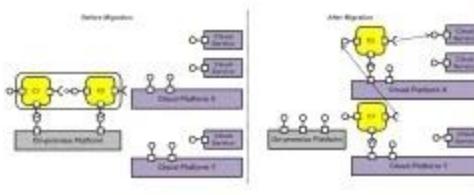
MP3: Relocation and Optimization



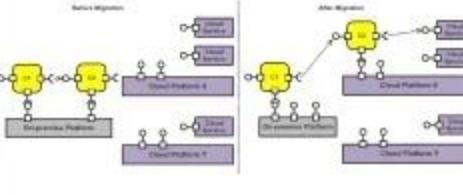
MP4: Multi-Cloud Relocation



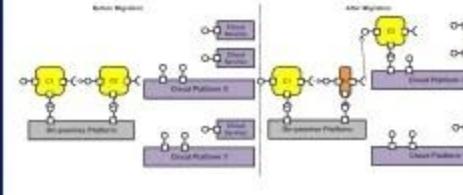
MPS: Multi-Cloud Refactor



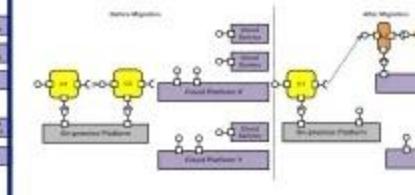
MP6: Refactor



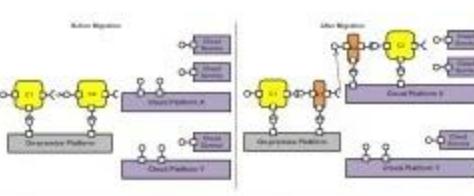
MP7: Refactor with On Premise Adaptation



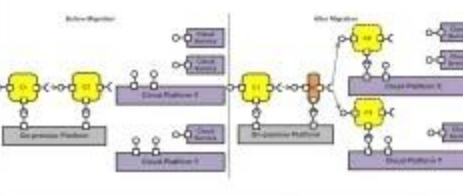
MP8: Refactor with Cloud Adaptation



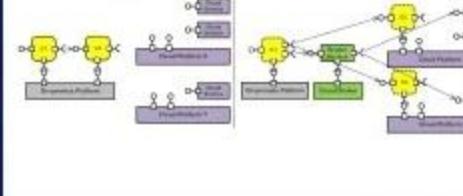
MP9: Refactor with Adaptations



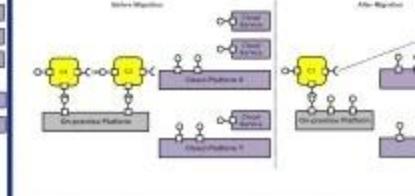
MP10: Multi-Cloud Rebinding



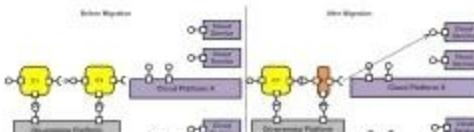
MP11: Multi-Cloud Rebinding with Cloud Brokerage



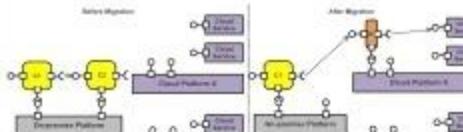
MP12: Replacement



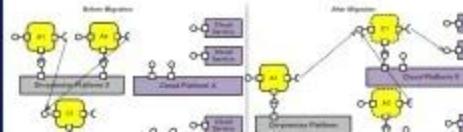
MP13: Replacement with On Premise Adaptation



MP14: Replacement with Cloud Adaptation



MP15: Multi-application Modernization



Migration Transition Graph

