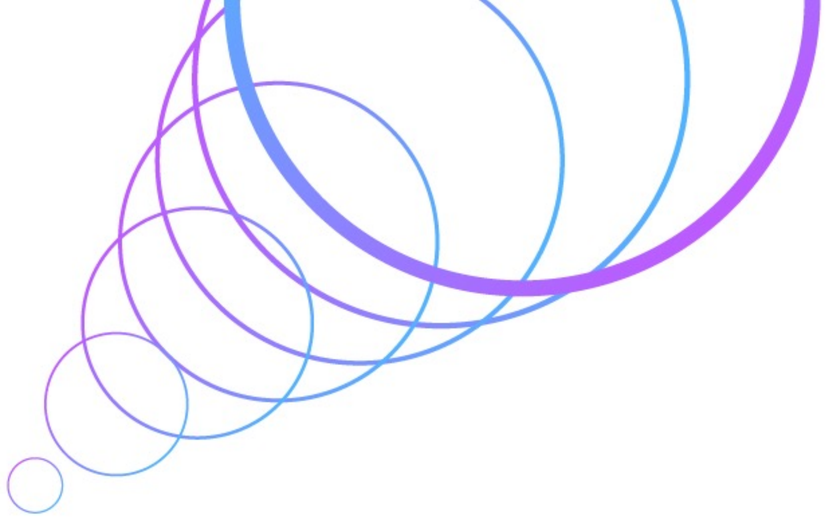
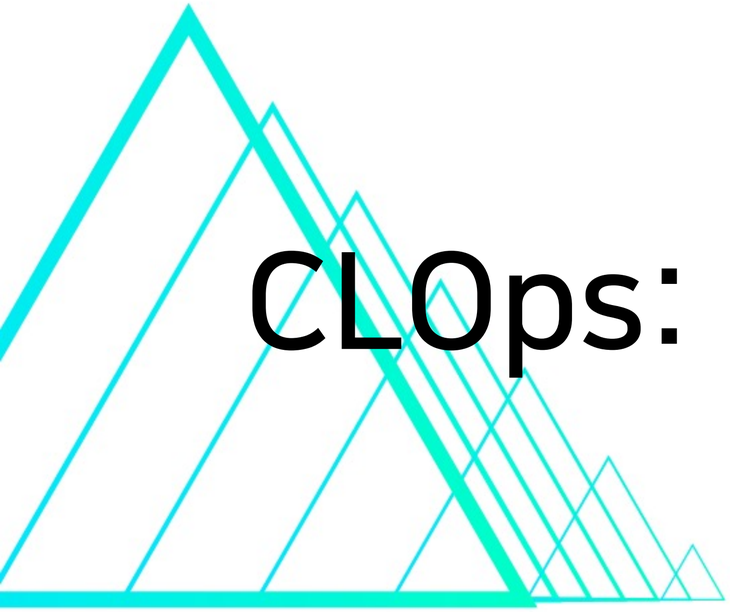




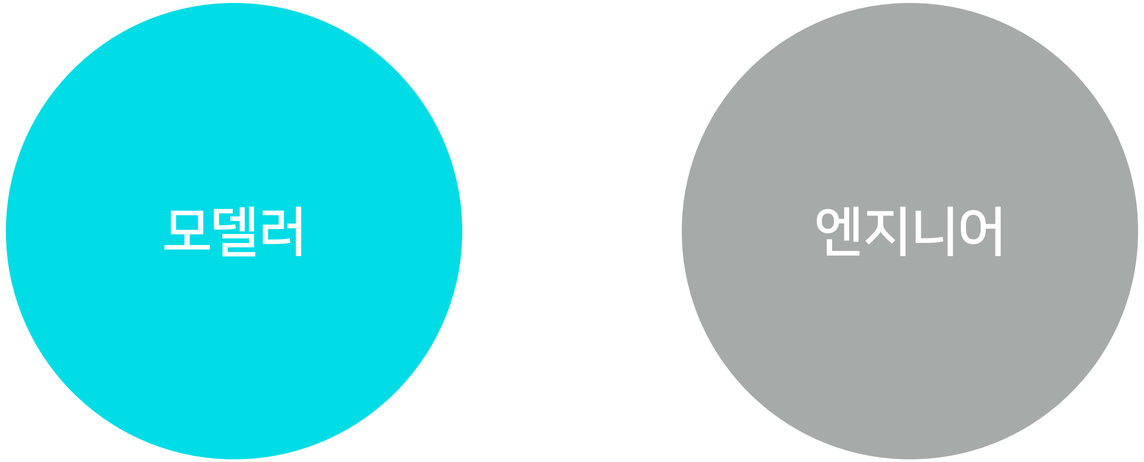
CLOps: 넌 모델링만해, 난 서빙할테니

이현동 ML System, NAVER CLOVA
칼 길리우스 ML System, NAVER CLOVA
한지승 ML System, NAVER CLOVA

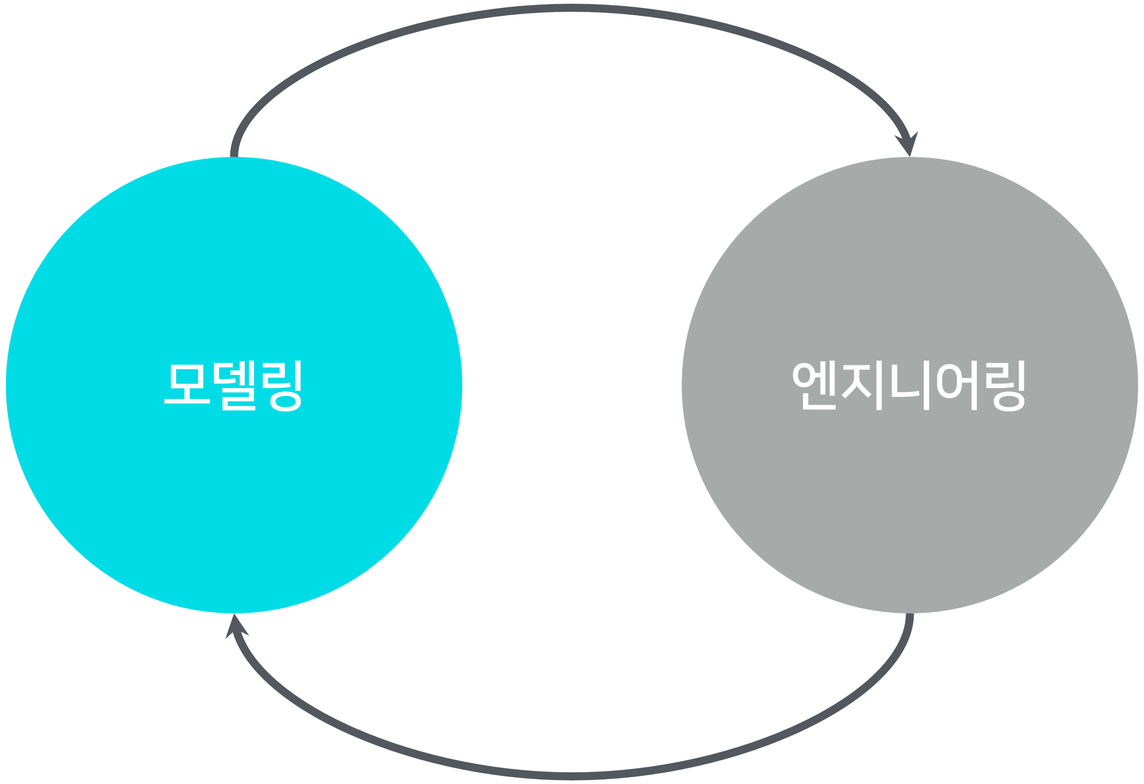
CONTENTS

1.Background

1.1 모델러와 엔지니어



1.2 모델링과 엔지니어링



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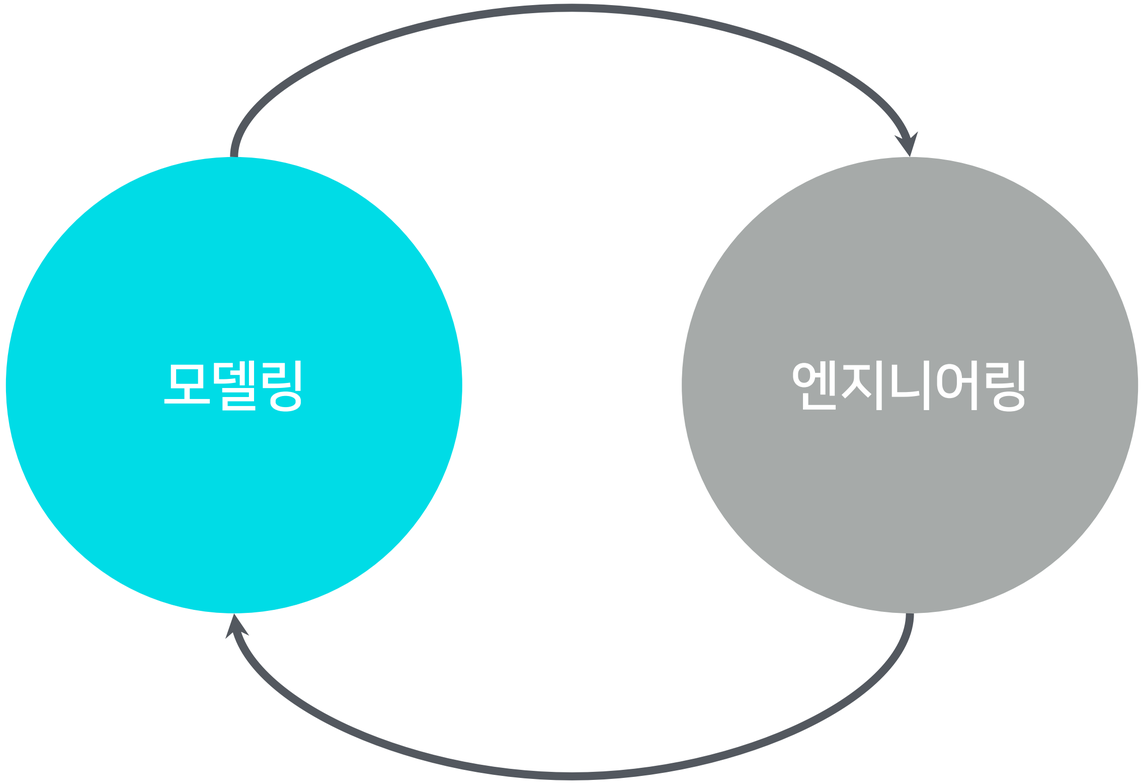

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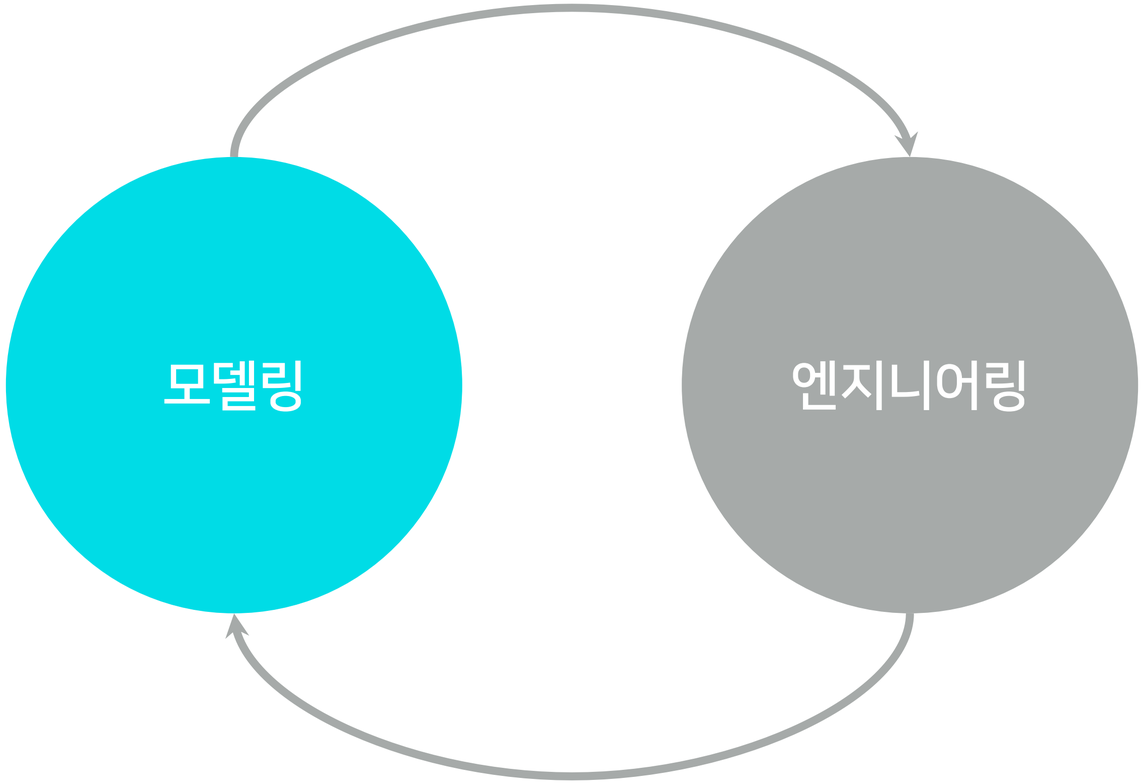

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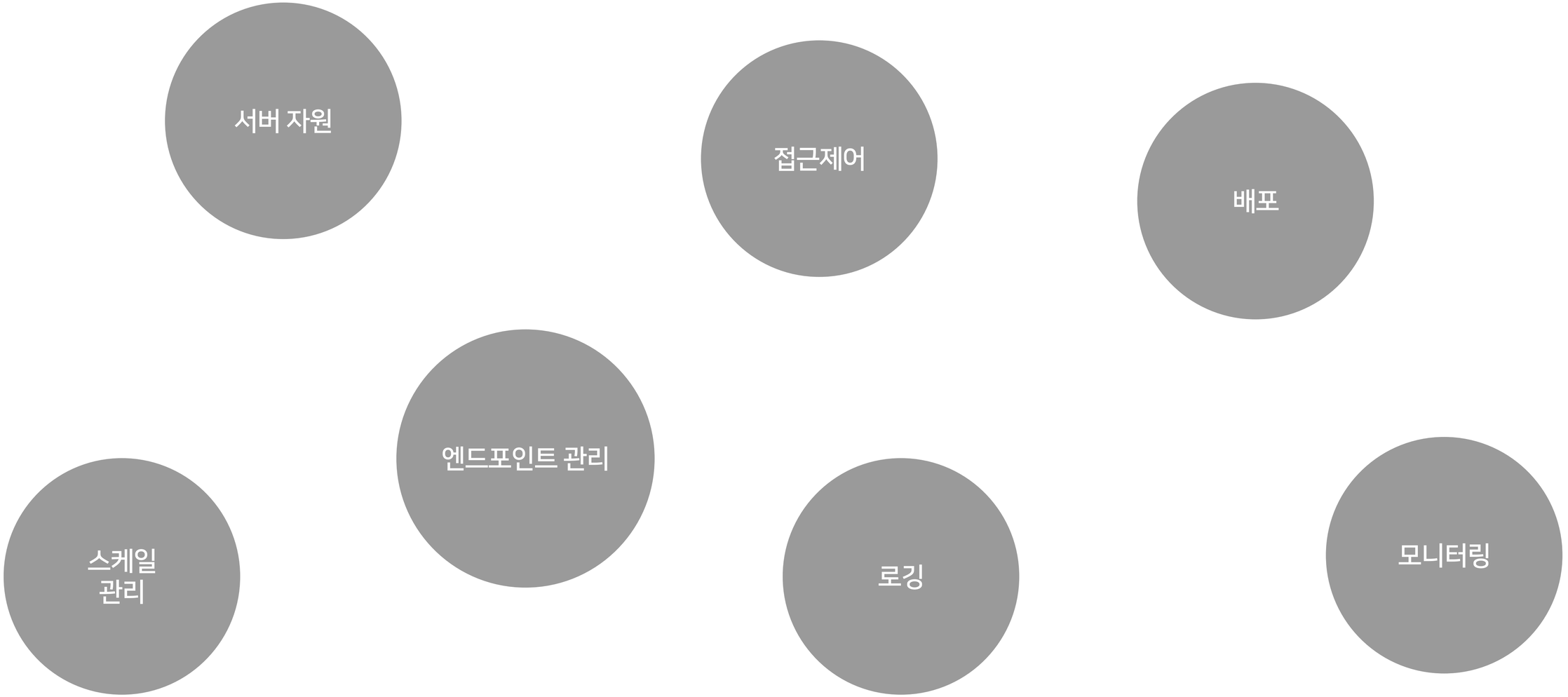

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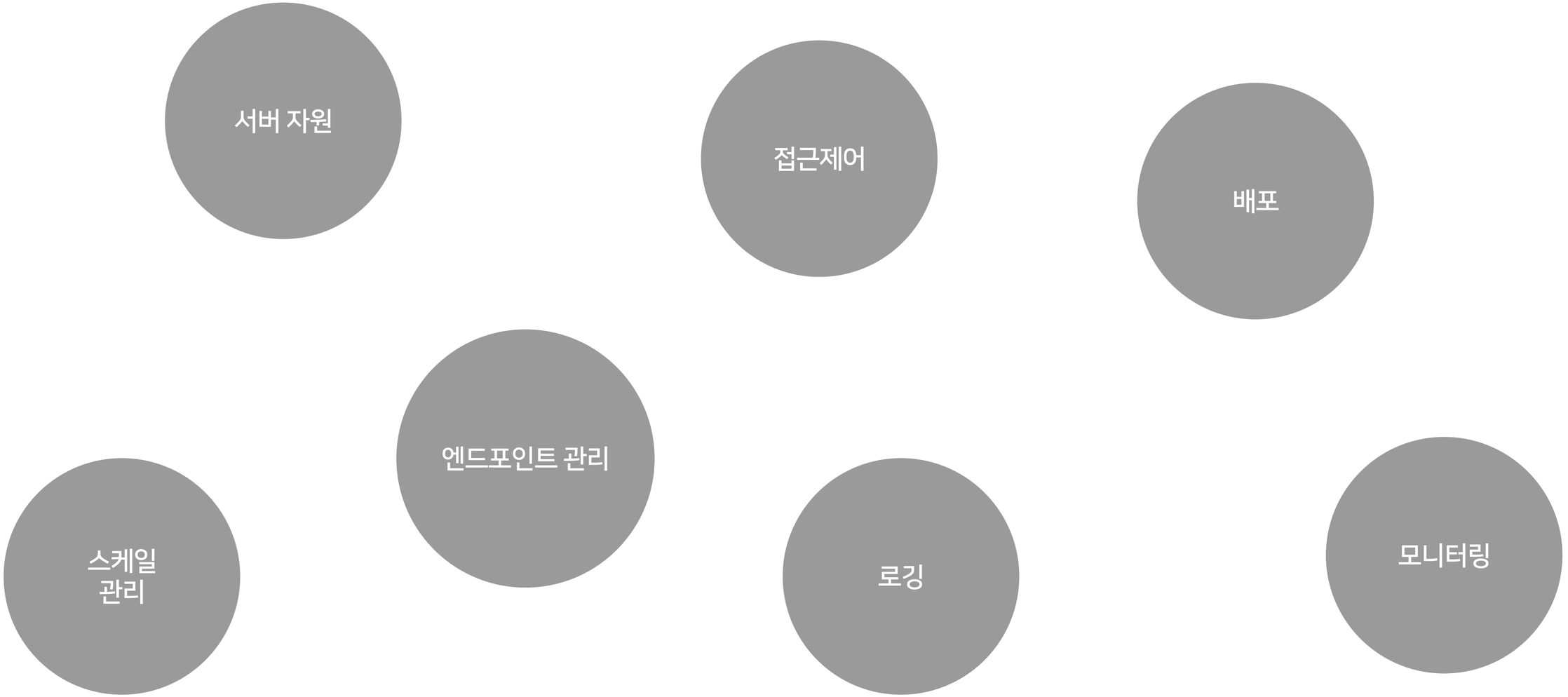
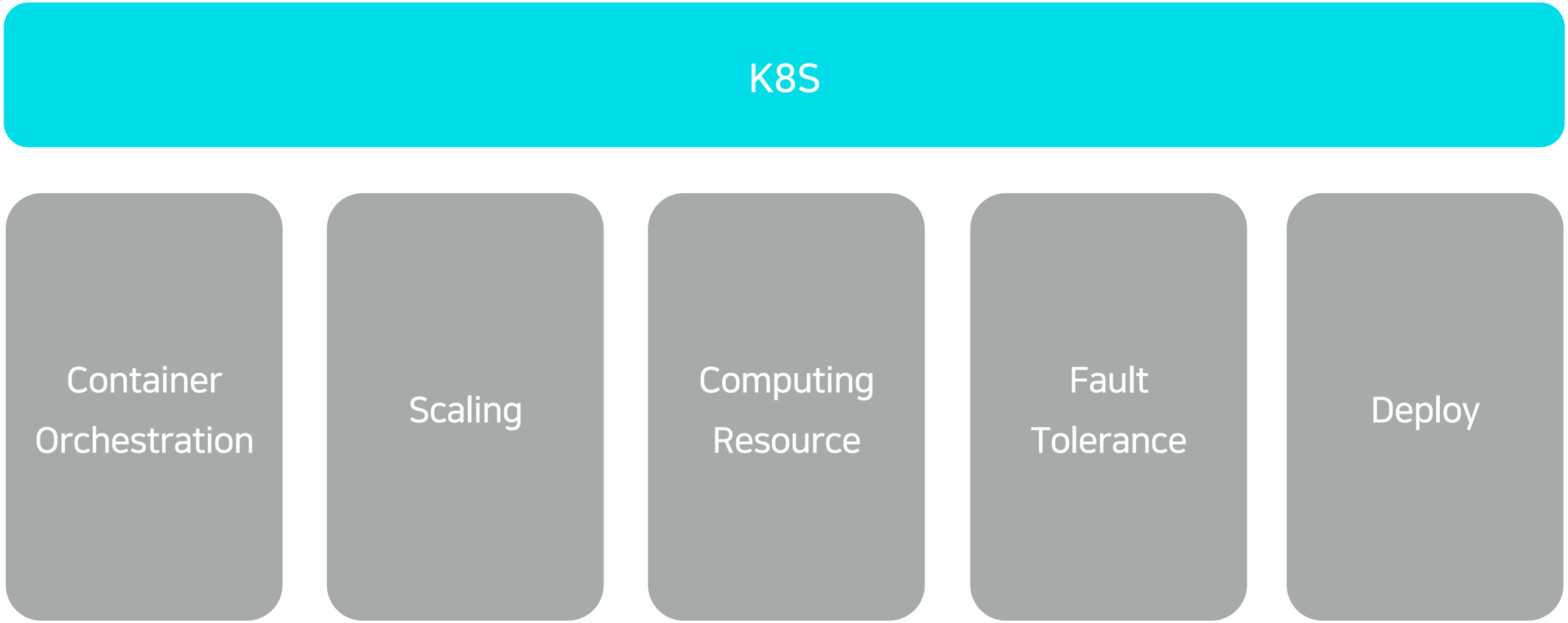


1.3 K8S를 선택한 이유



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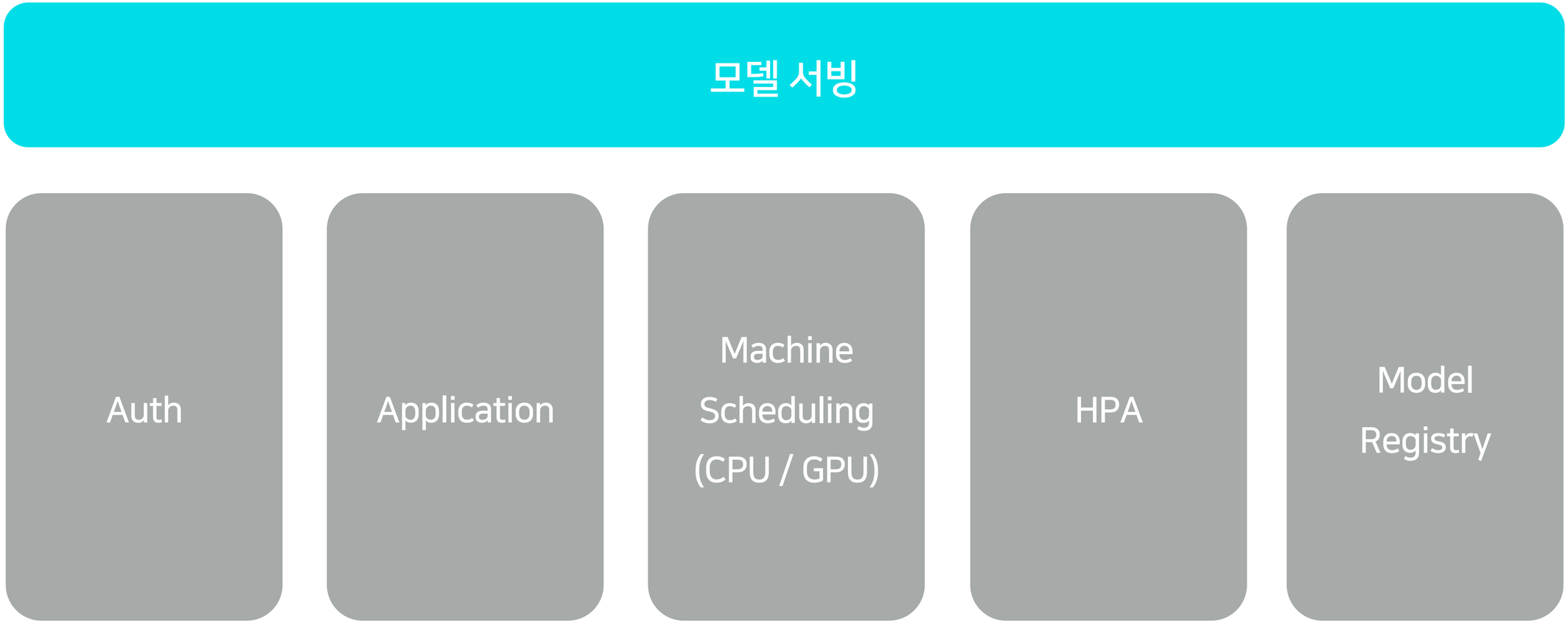

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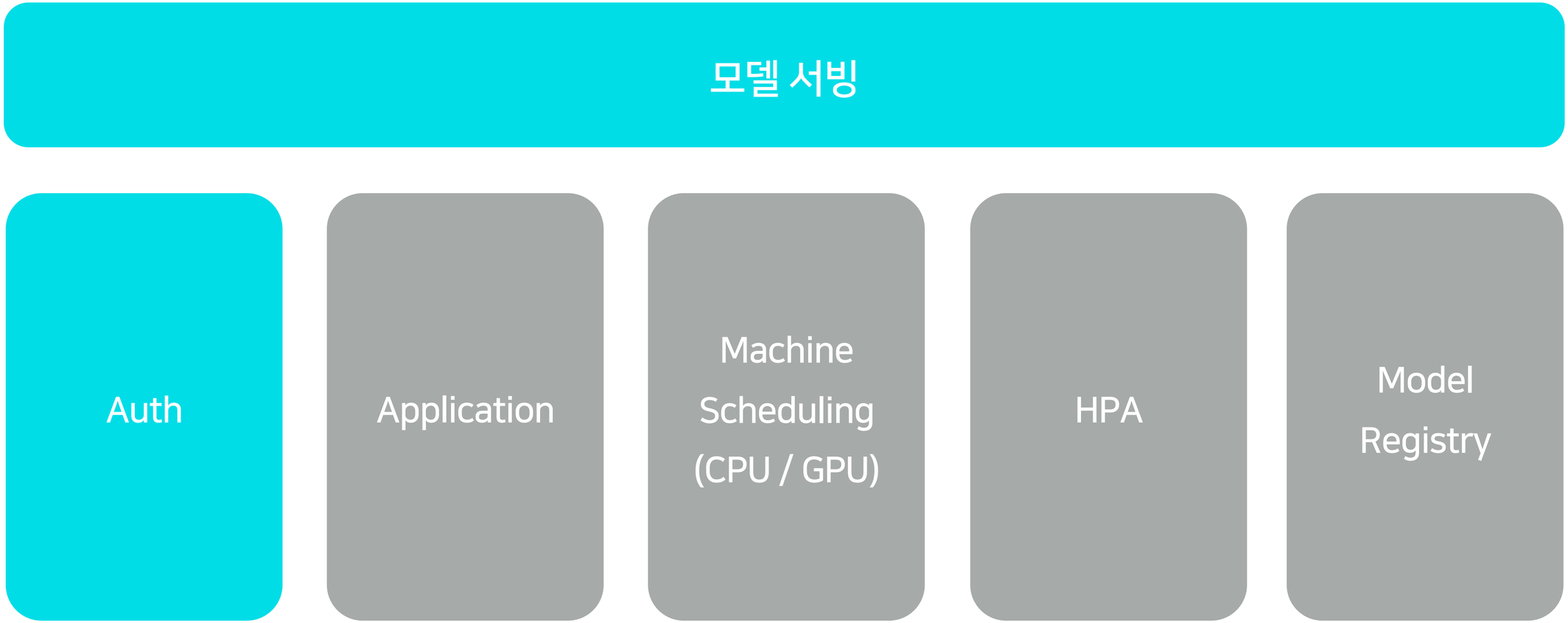

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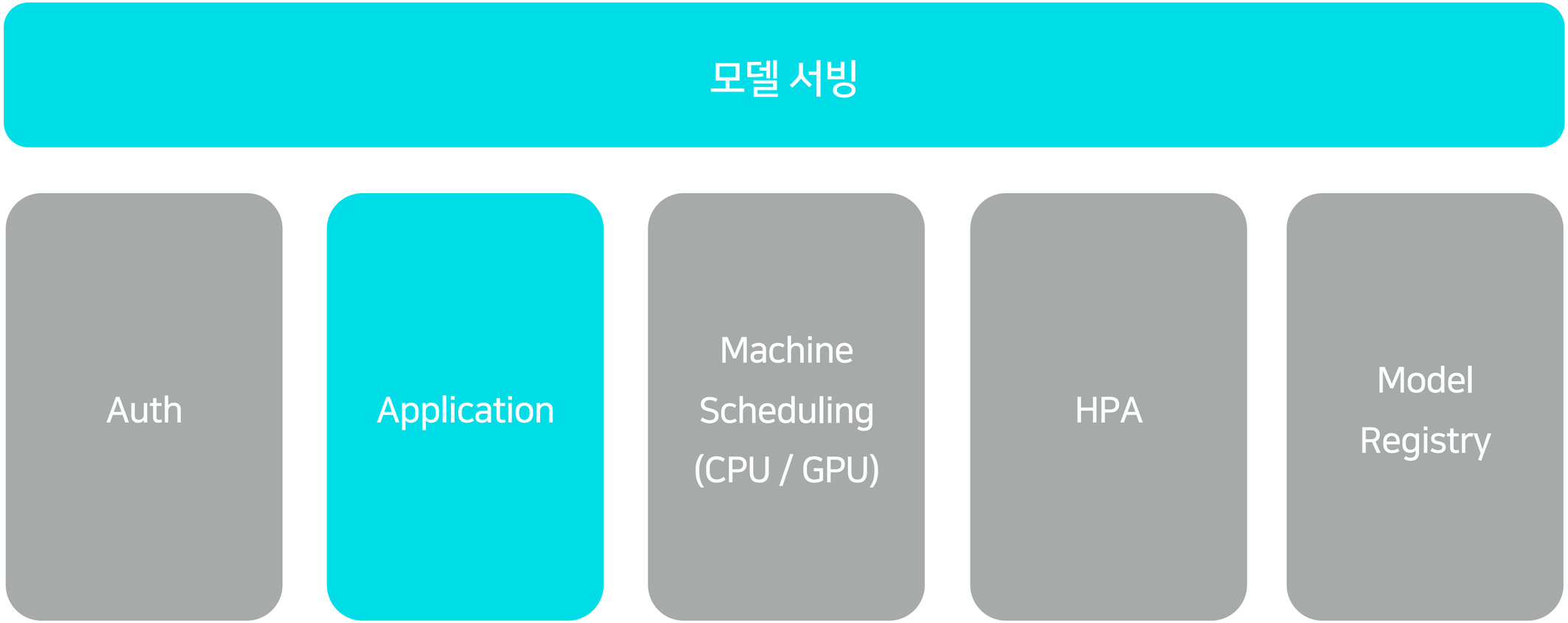

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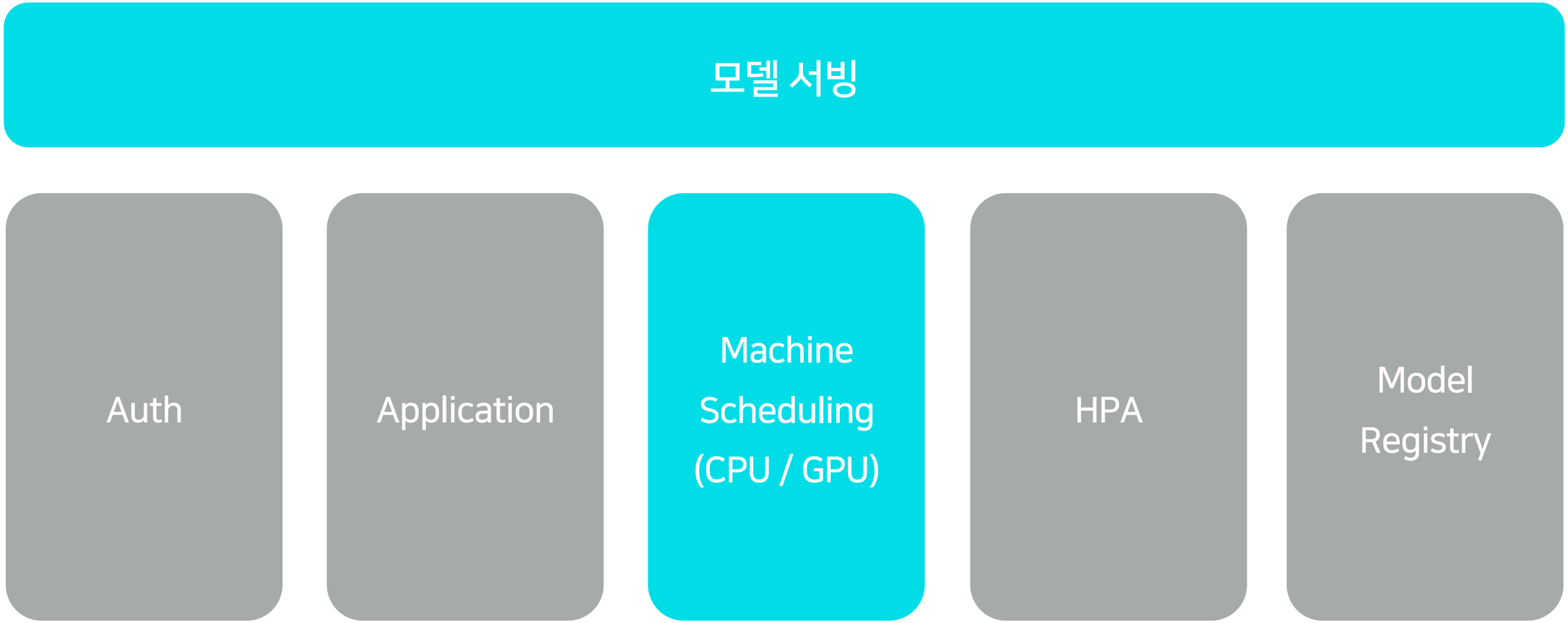

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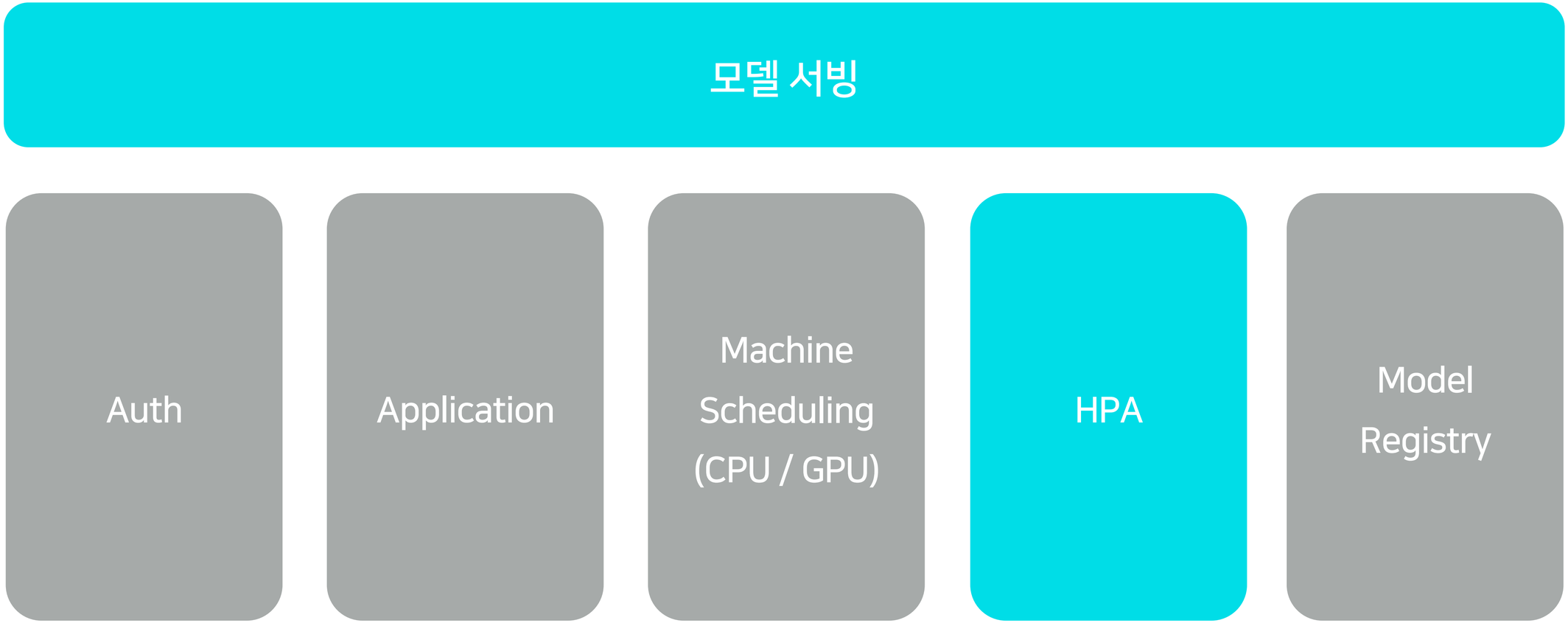

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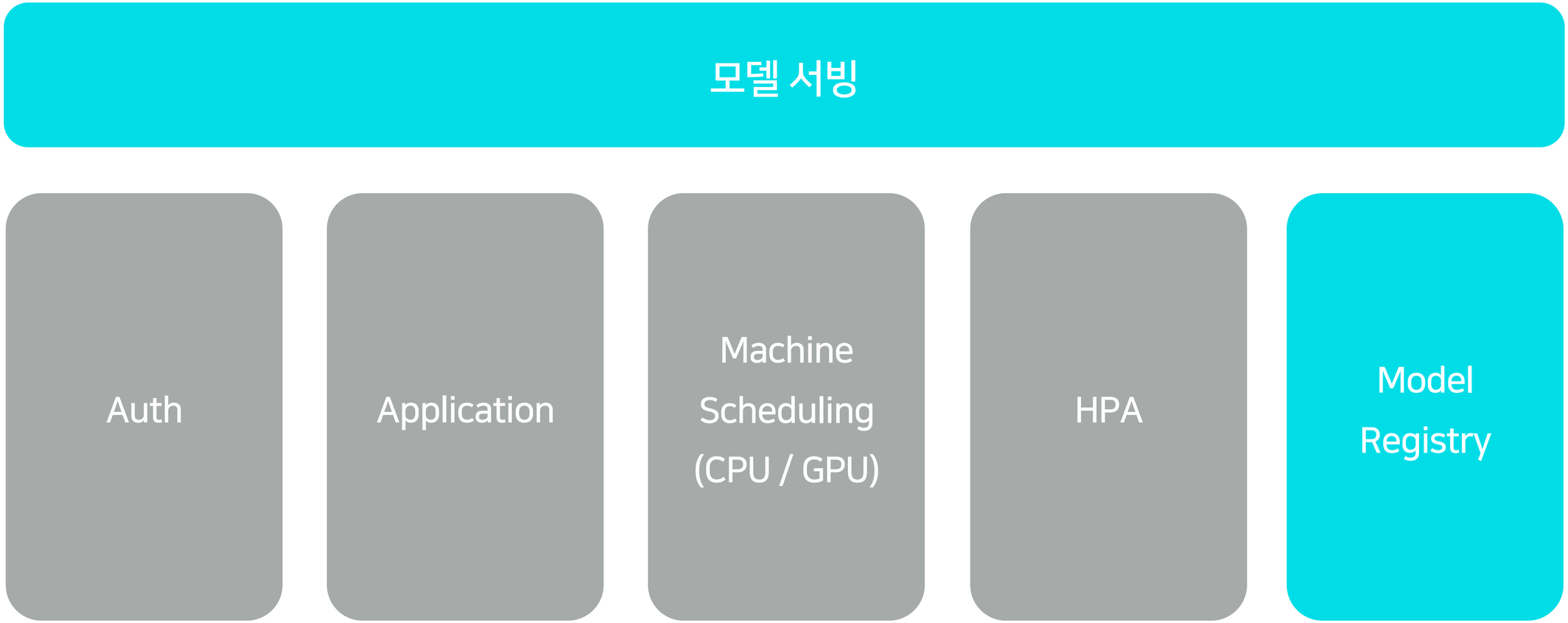
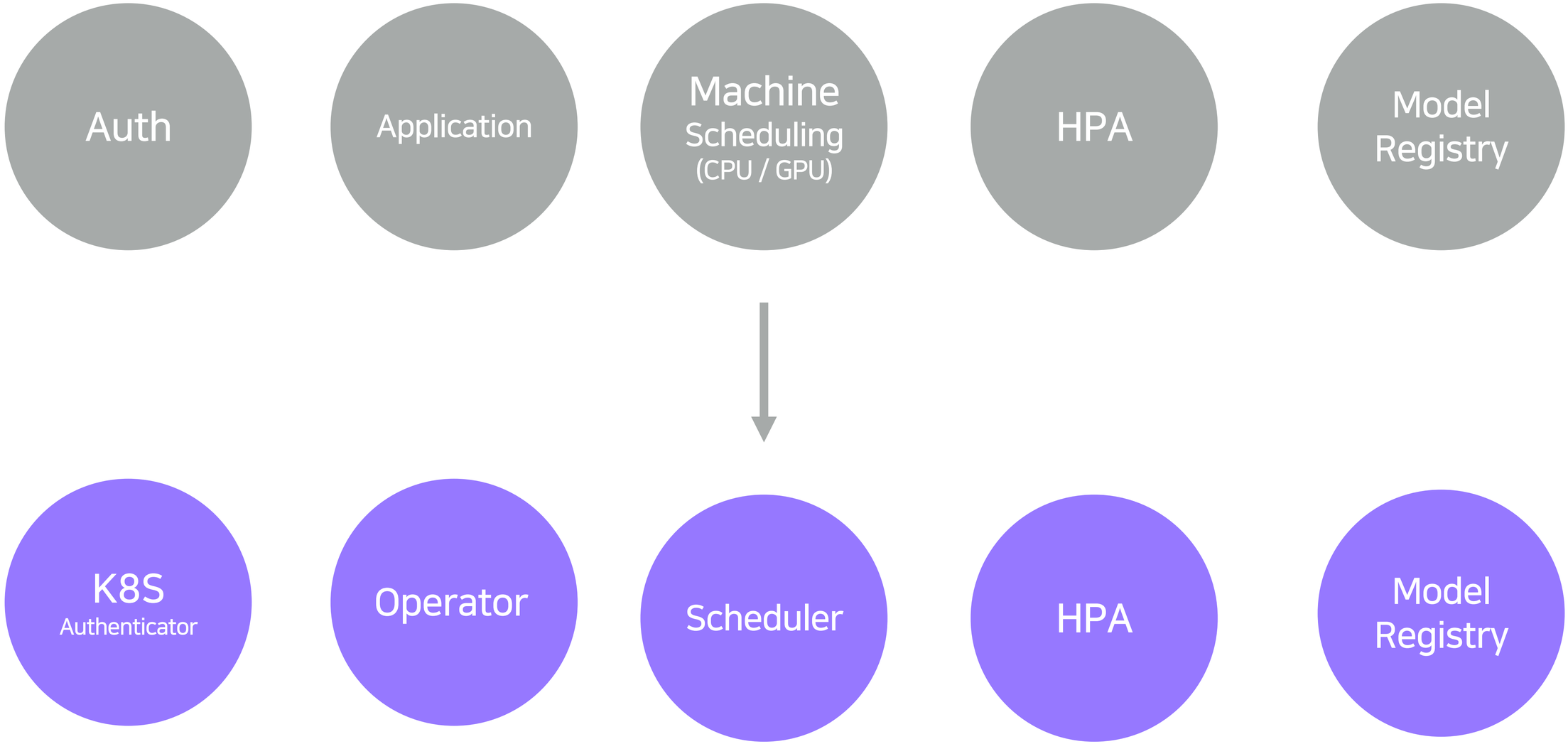


DEVIEW 2021

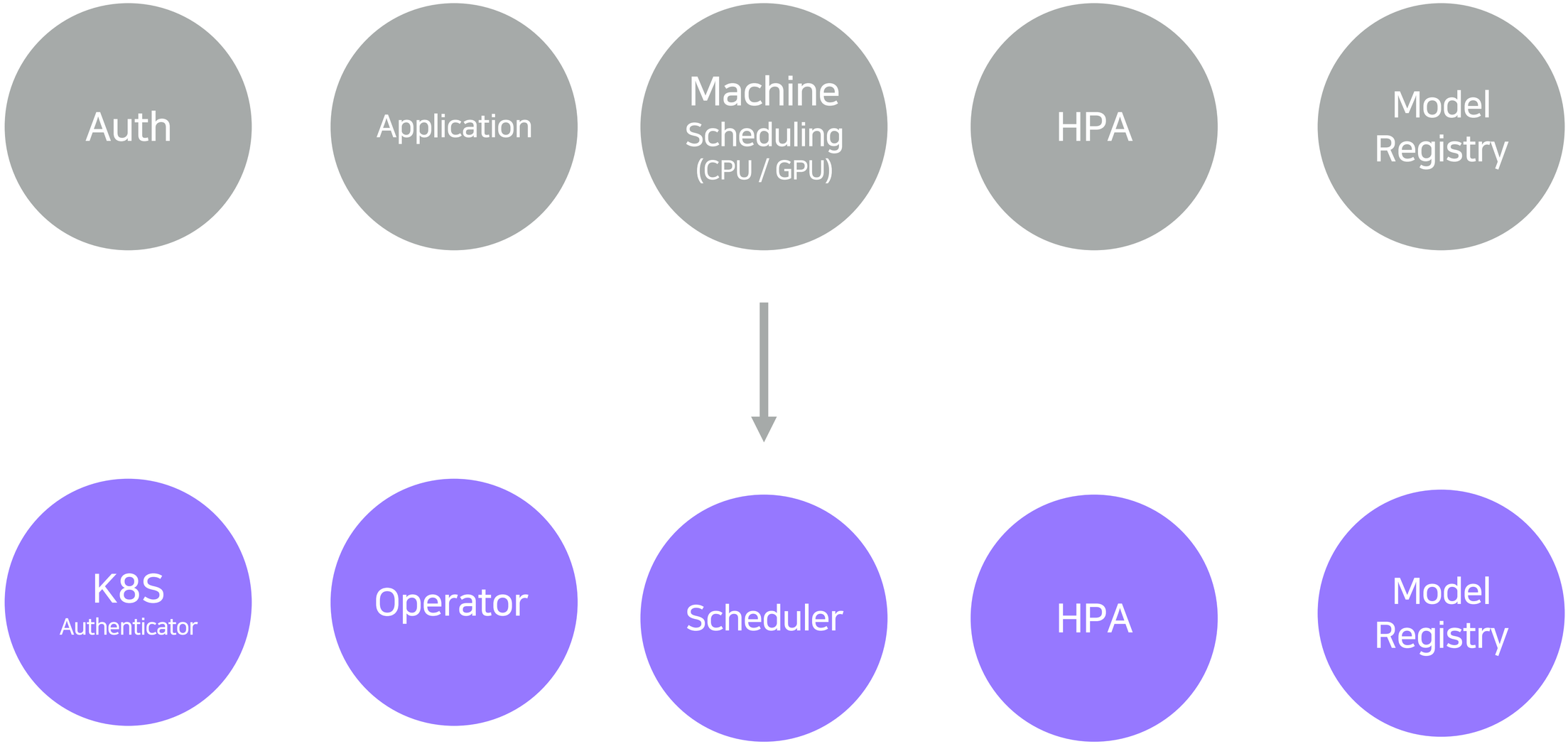
2.Architecture & Components

2.1 CLOps

2.2 Overview


Auth
Application
Machine
Scheduling
(CPU / GPU)
HPA
Model
Registry
K8S
Authenticator
Operator
Scheduler
HPA
Model
Registry

2.2 Overview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Application
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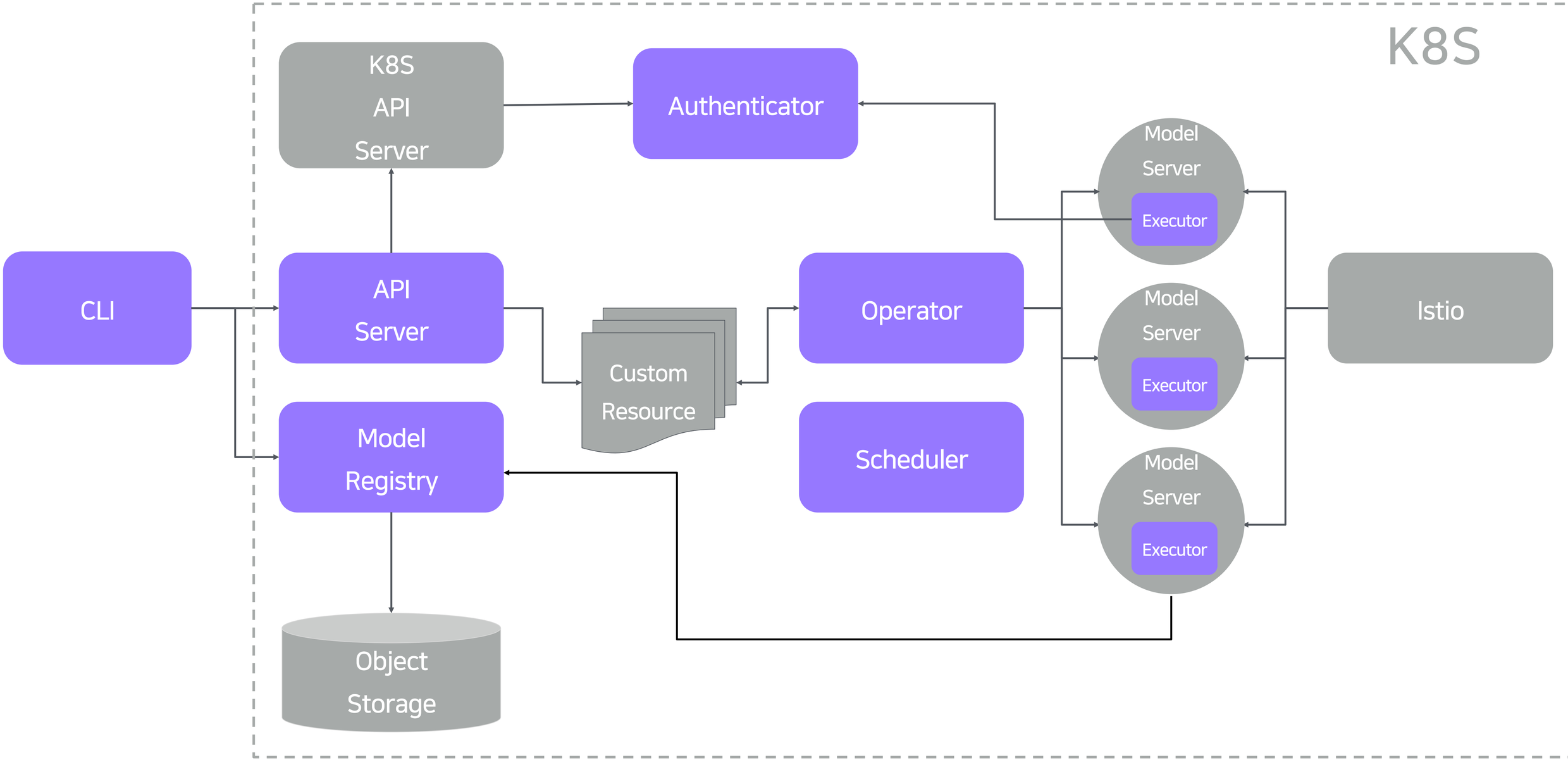
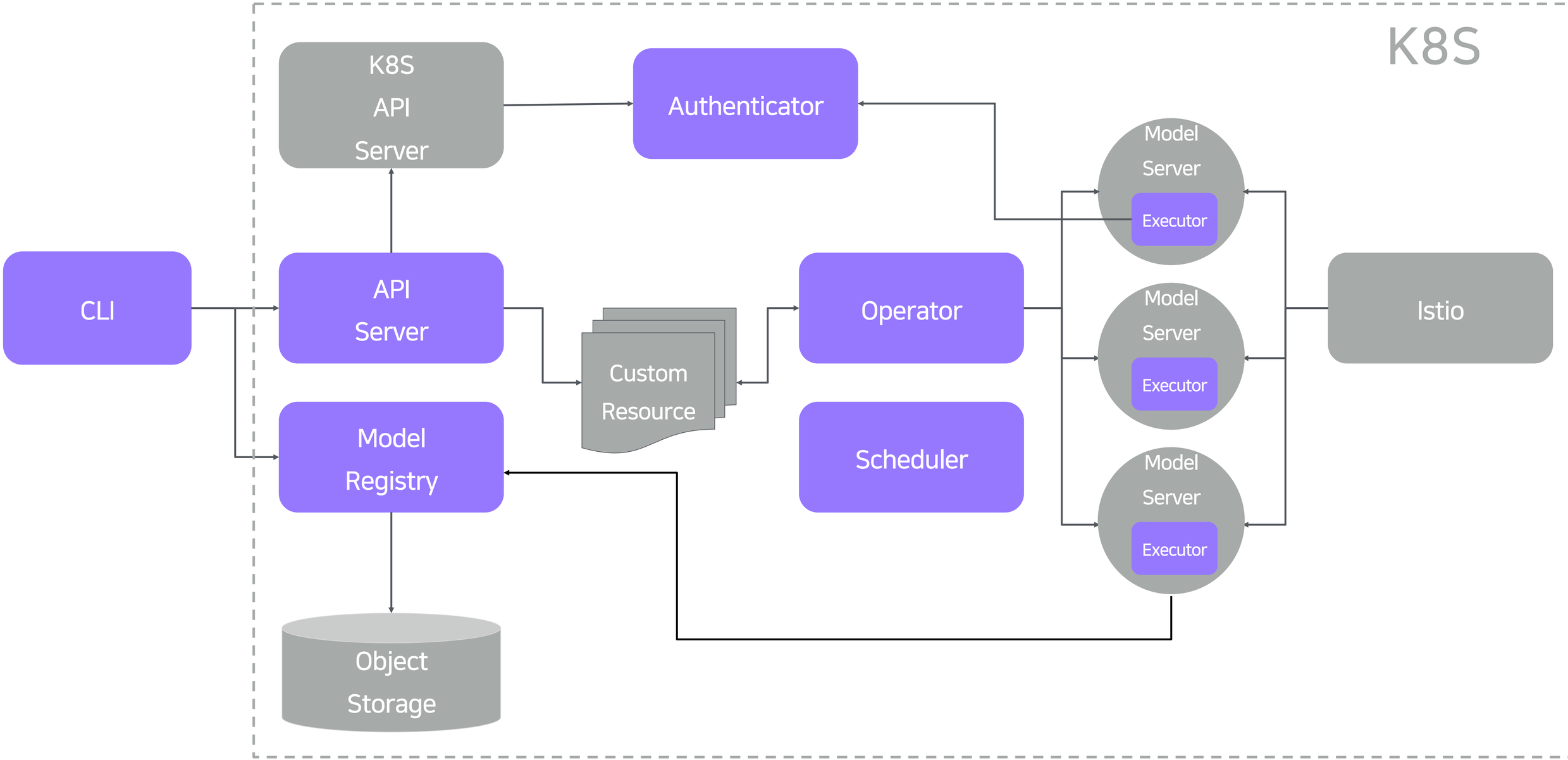
2.2 Overview


K8S
K8S API Server
Authenticator
Model Server
Executor
CLI
API Server
Custom Resource
Operator
Istio
Model Server
Executor
Model Registry
Scheduler
Model Server
Executor
Object Storage

2.2 Overview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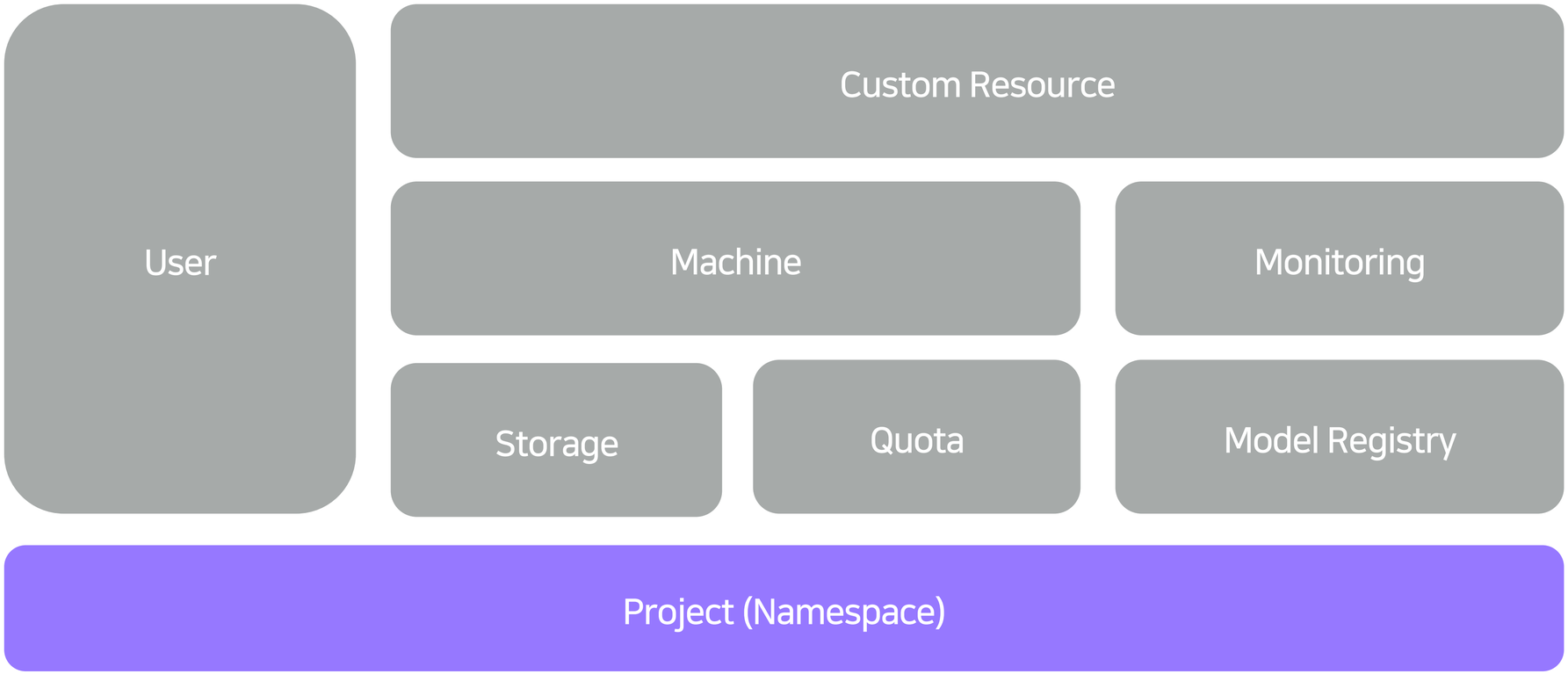
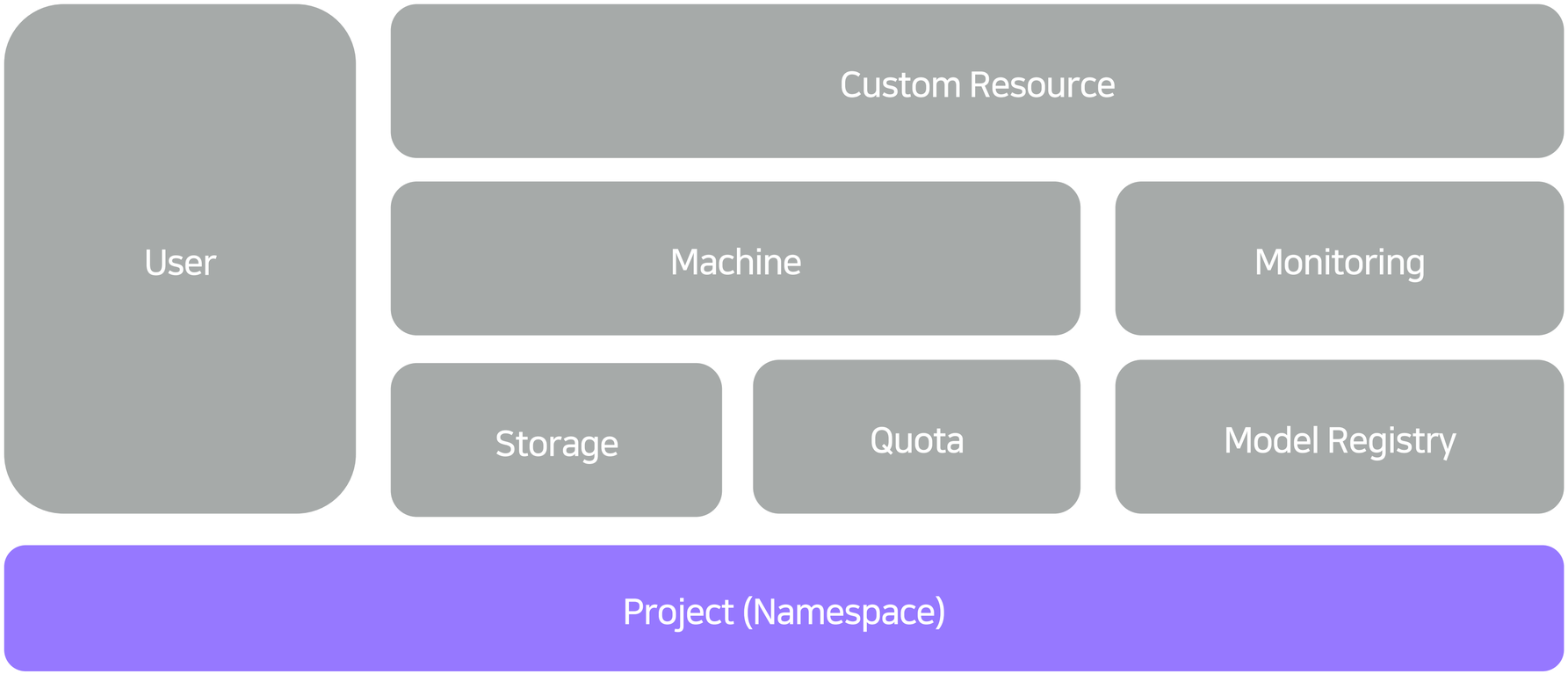

User
Custom Resource
Machine
Monitoring
Storage
Quota
Model Registry
Project (Namespace)

2.2 Overview


User
Custom Resource
Machine
Monitoring
Storage
Quota
Model Registry
Project (Namespace)

2.3 Authenticator – Why

DEVIEW 2021

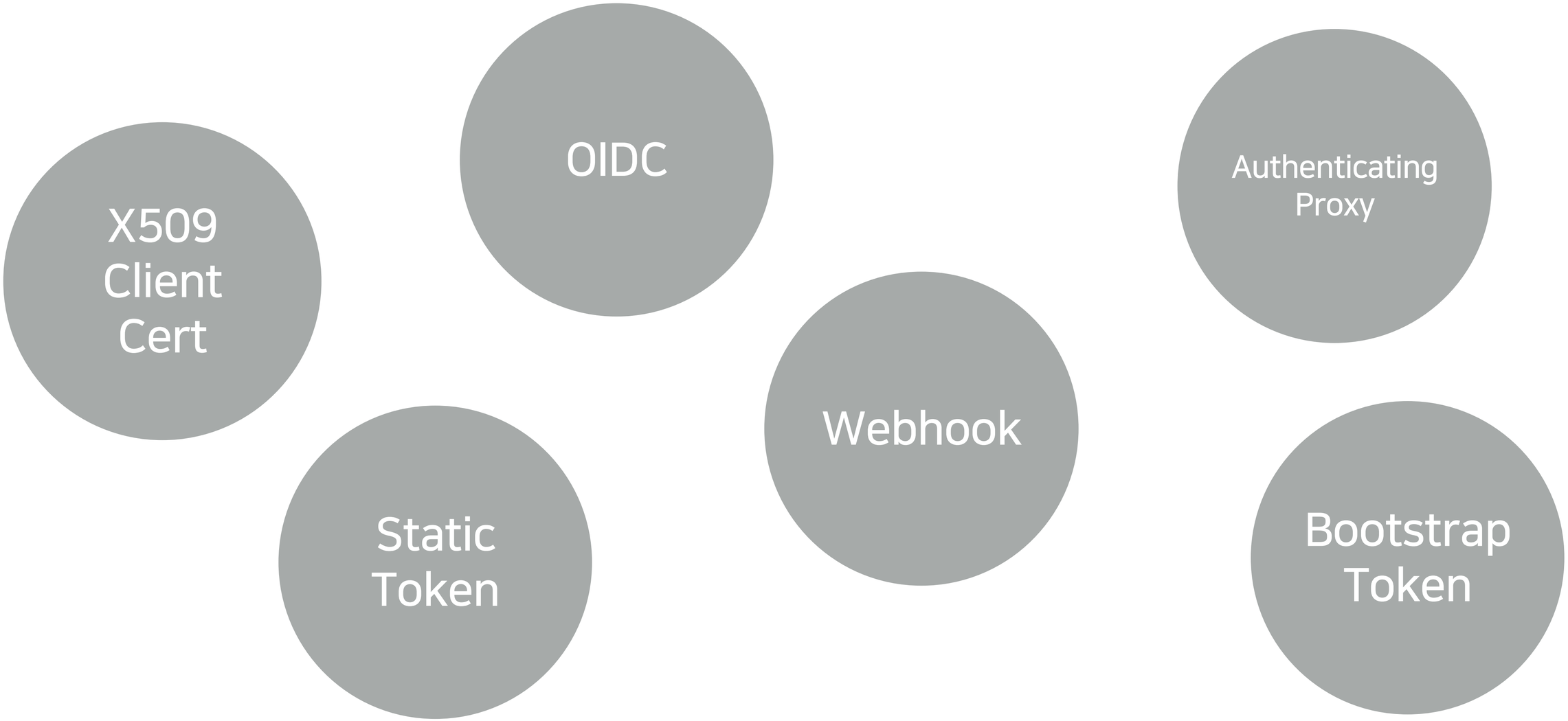
접근 제어

- 인가된 사용자에 의해서만 CLOps 사용 가능

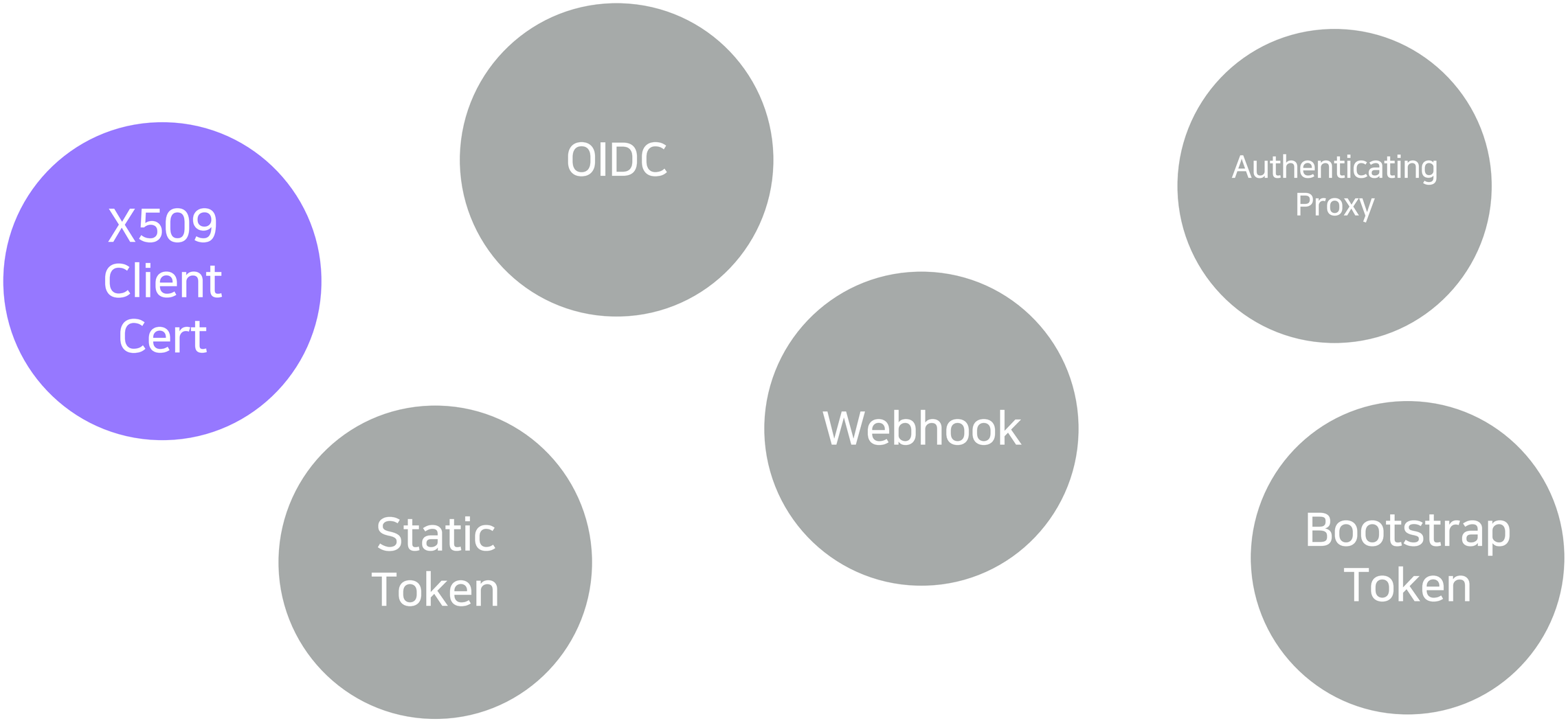
프로젝트별 권한 관리

- 권한에 따라 각각 다른 기능 사용 가능

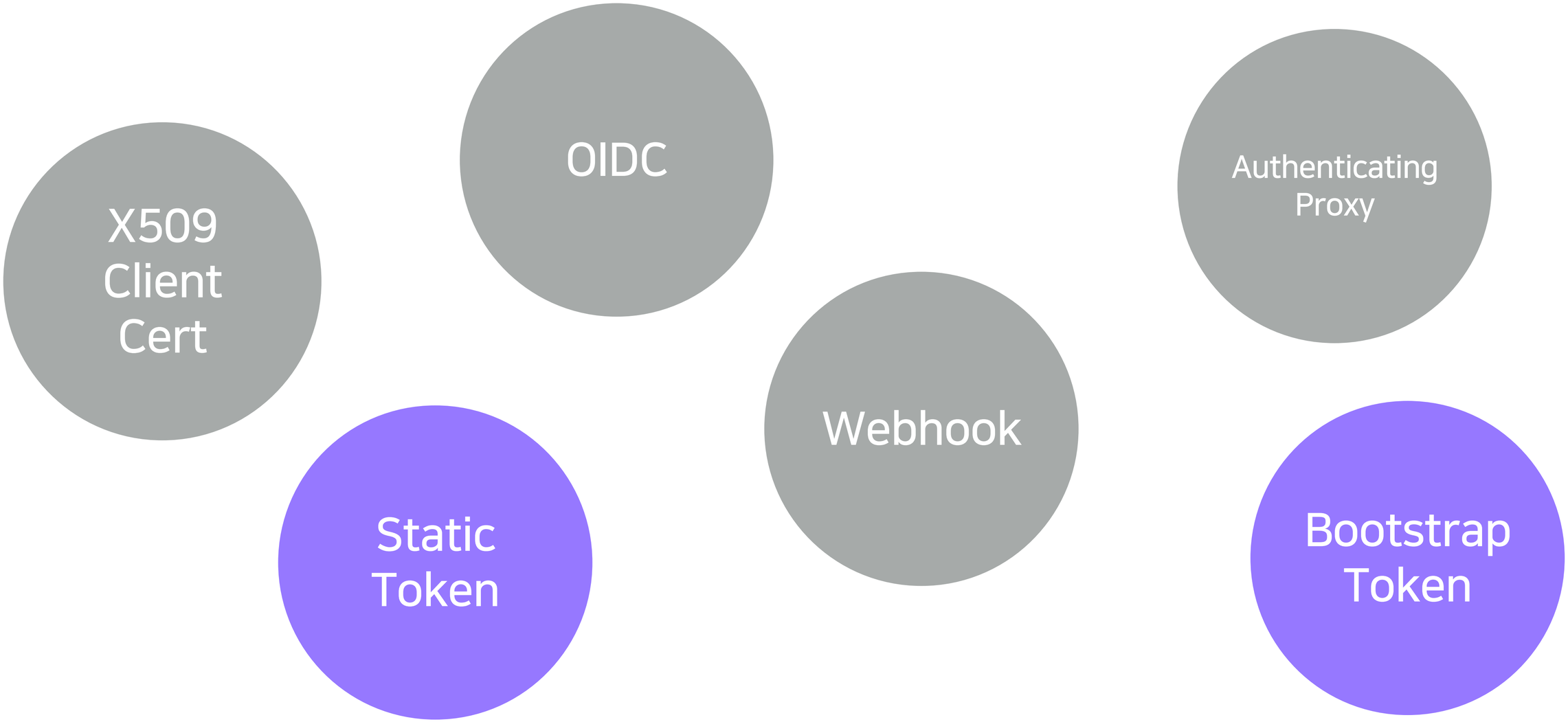
2.3 K8S Authenticator - Detail



2.3 K8S Authenticator - Detail



2.3 K8S Authenticator - Detail



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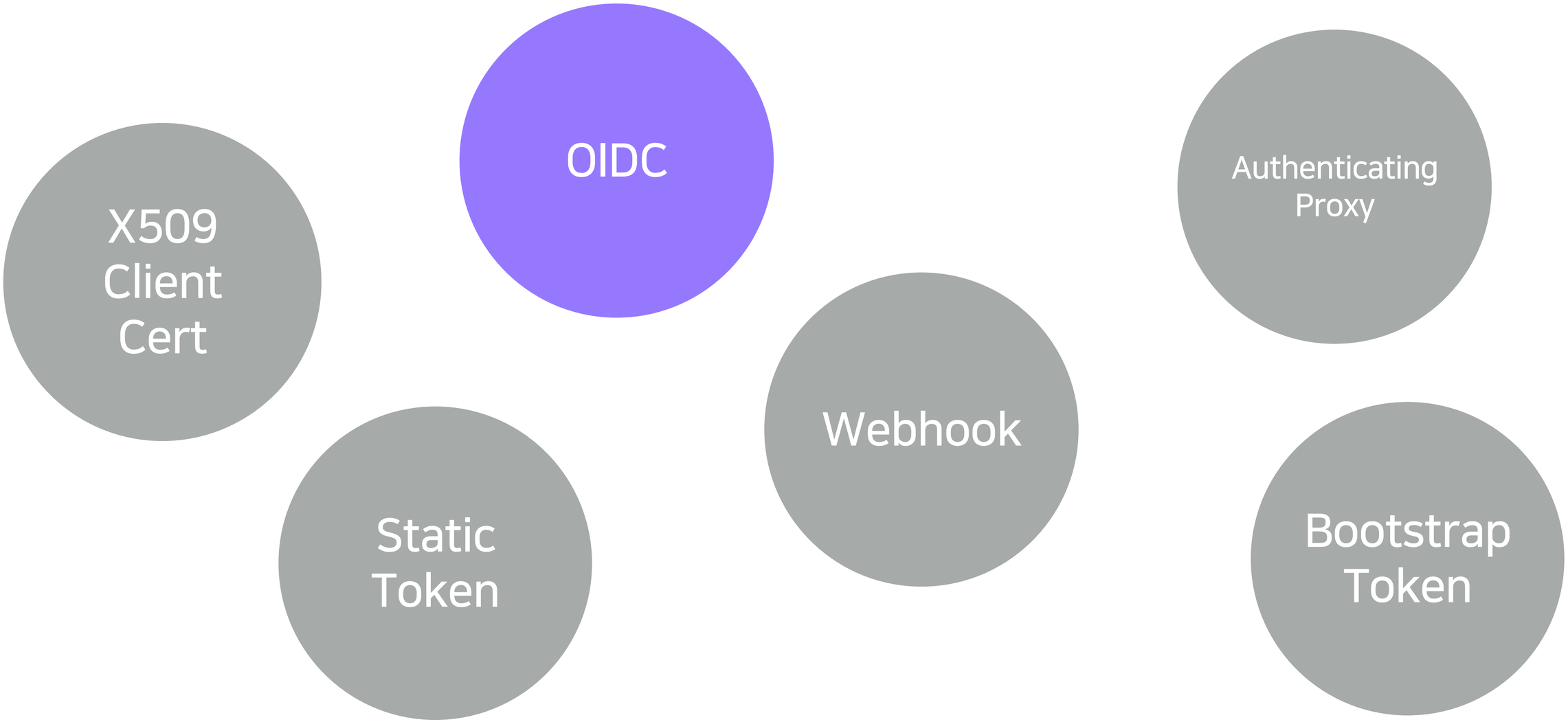
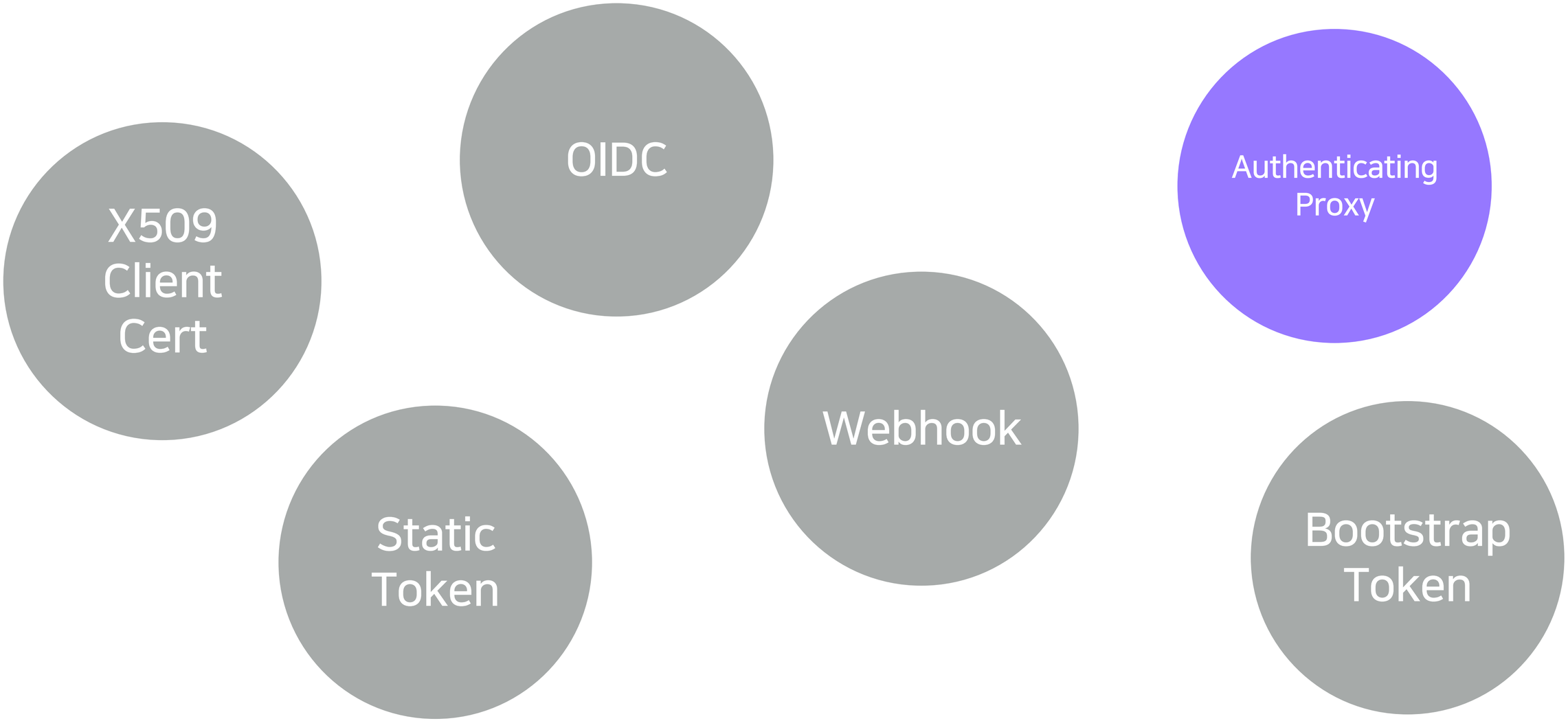
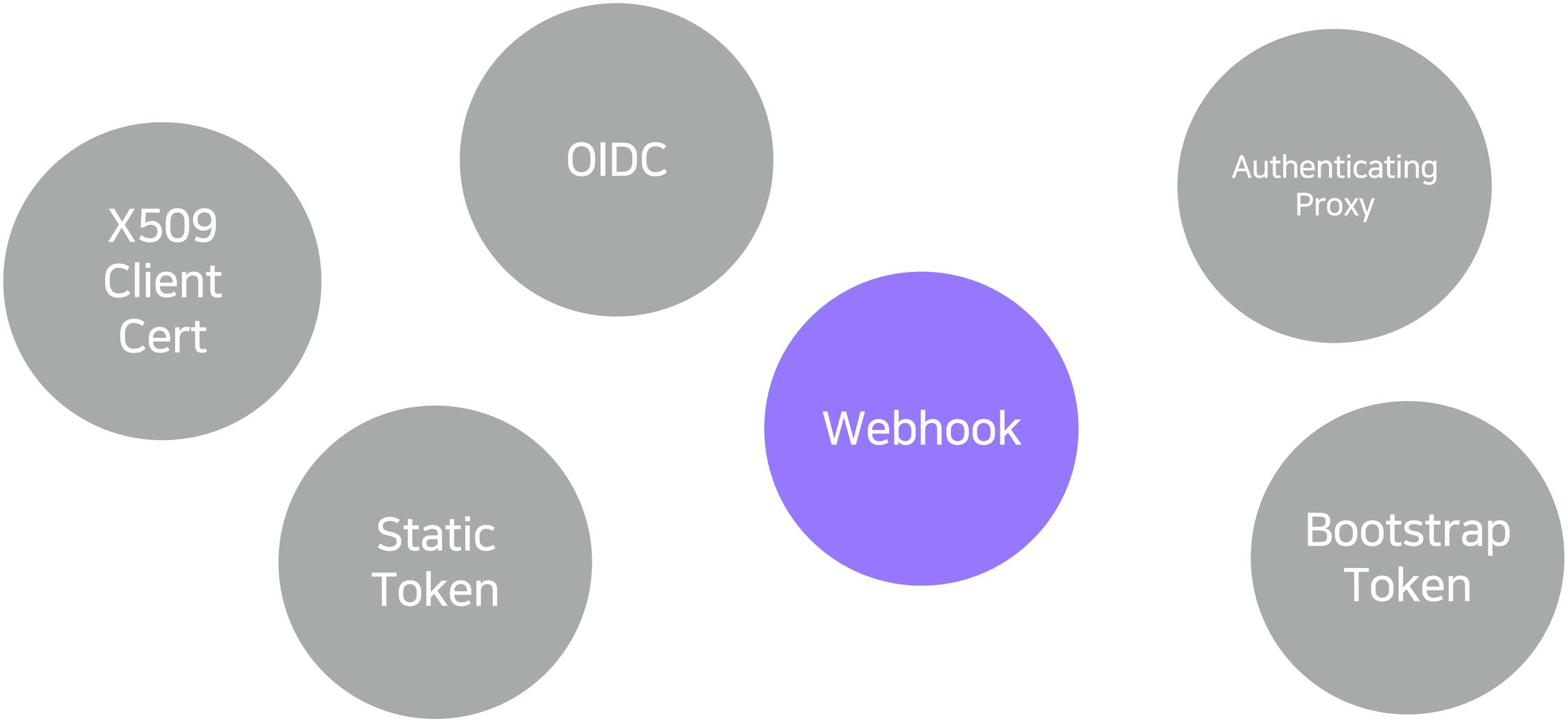


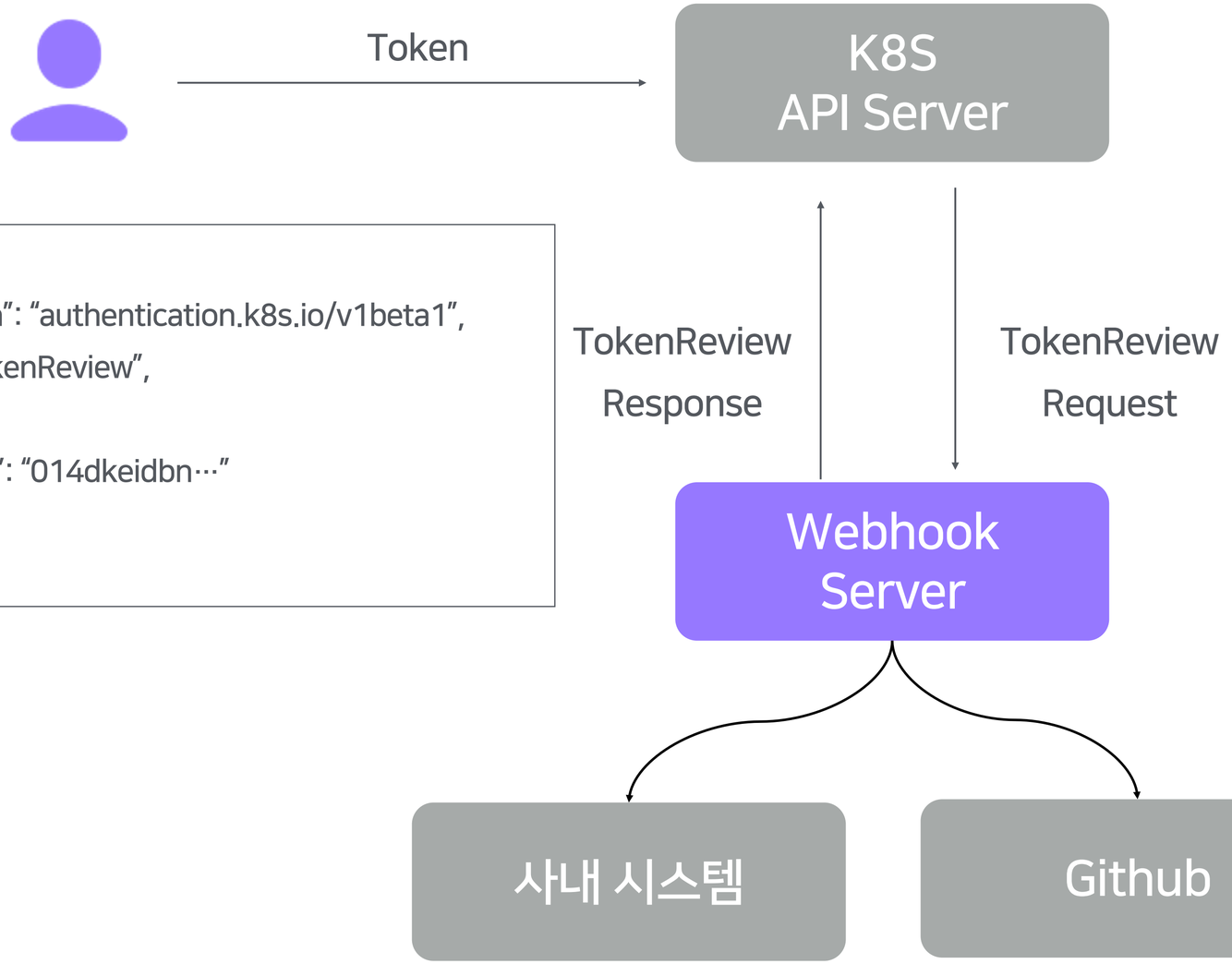
2.3 K8S Authenticator - Detail



2.3 K8S Authenticator - Detail



2.3 K8S Authenticator - Detail




```
{
    "apiVersion": "authentication.k8s.io/v1beta1",
    "kind": "TokenReview",
    "spec": {
        "token": "014dkeidbn…"
    }
}
```

```
{
    "apiVersion": "authentication.k8s.io/v1beta1",
    "kind": "TokenReview",
    "status": {
        "authenticated": true,
        "user": {
            "username": janedoe@example.com,
            "uid": "40",
            "groups", ["developers", "admin"]
        }
    }
}
```

2.3 K8S Authenticator - Detail

Configuration

- --authentication-token-webhook-config-file

```
clusters:
- name: webhook-token-auth-cluster
  cluster:
    server: https://{host}
    insecure-skip-tls-verify: False

users:
- name: webhook-token-auth-user

current-context: webhook-token-auth
contexts:
- context:
    cluster: webhook-token-auth-cluster
    user: webhook-token-auth-user
  name: webhook-token-auth
```

2.4 Operator - Why

모델 서빙을 위한 필요 기능 자동화

- 모델 애플리케이션 구현 외 서빙 및 운영 기능을 쉽게 배포 목표
- (모델러) 모델 배포를 위한 애플리케이션 및 설정만 선언

SDK

- Kubebuilder (https://github.com/kubernetes-sigs/kubebuilder)
- Operator-sdk (https://sdk.operatorframework.io)

2.4 Operator - Detail

DEVIEW 2021

Resource

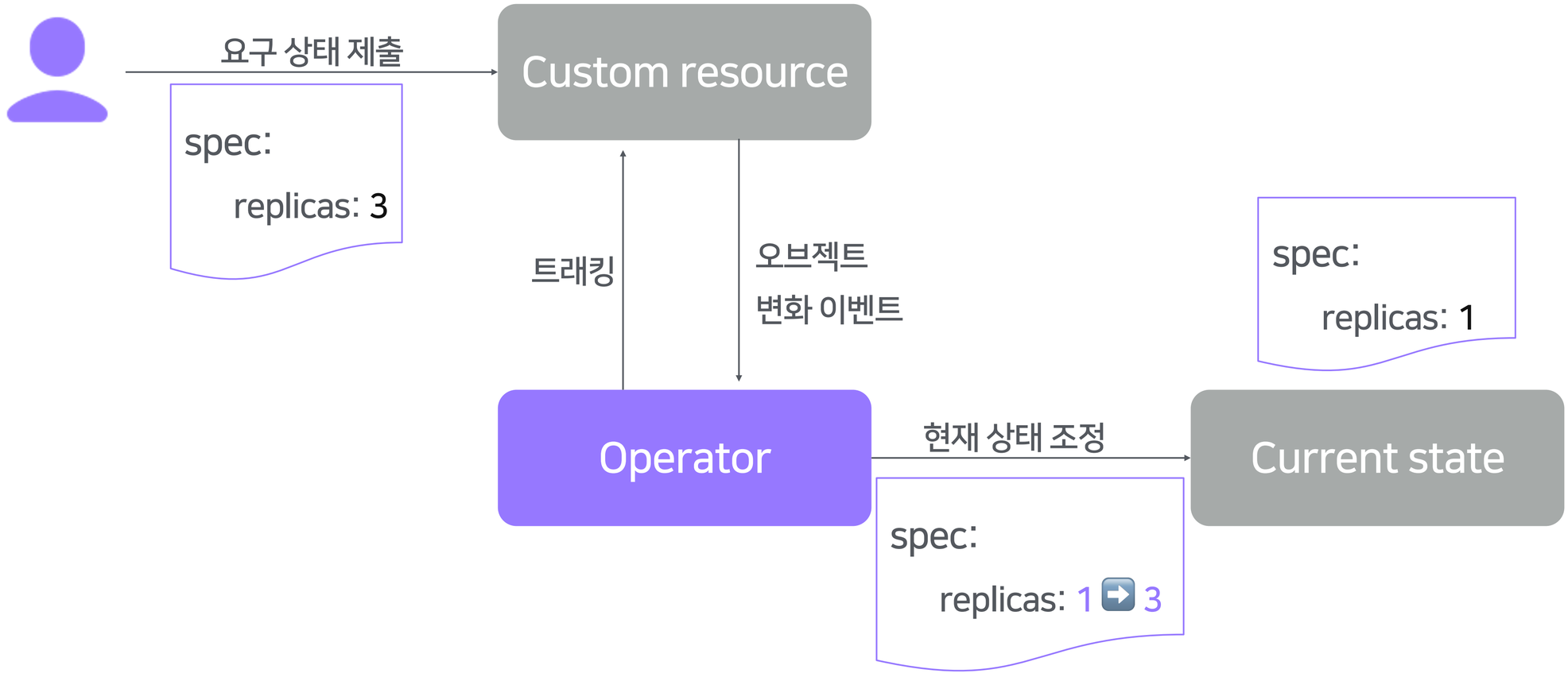
- 리소스는 “의도를 담은 레코드”
- 사용자가 K8S API 사용을 하기 위한 인터페이스 역할
- 코어 리소스로 Deployment, Service, DaemonSet 등을 제공

Custom Resource (CR)

- 기본 리소스 외 어플리케이션 제공자가 정의한 쿠버네티스 리소스
- 모든 오브젝트 리소스는 동일한 형태로 안정적으로 확장 가능한 구조

2.4 Operator - Detail

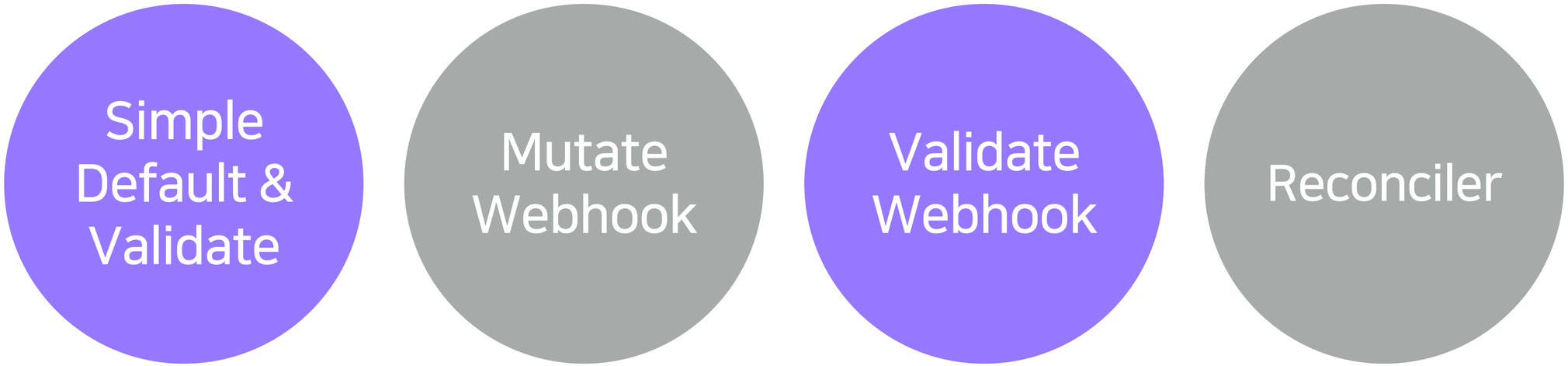
오브젝트 리소스의 현재 상태(current state)를 사용자의 요구 상태(desired state)와 동기화를 보장하기 위해 끊임없이 조정(reconcile)하는 행위자



2.4 Operator - Detail

오퍼레이터 메커니즘

- 정의 기반 단순 기본값 및 검증 => 필드 변경(기본값) 설정 => 검증 => 조정



2.4 Operator - Detail

Simple Default & Validate

- CRD Struct에 정의된 단일 필드에 대한 기본값 설정 및 검증

Mutate(Default) Webhook

- (리소스 생성) 타 리소스 및 복합 필드에 대한 기본값 설정 Webhook

Validate Webhook

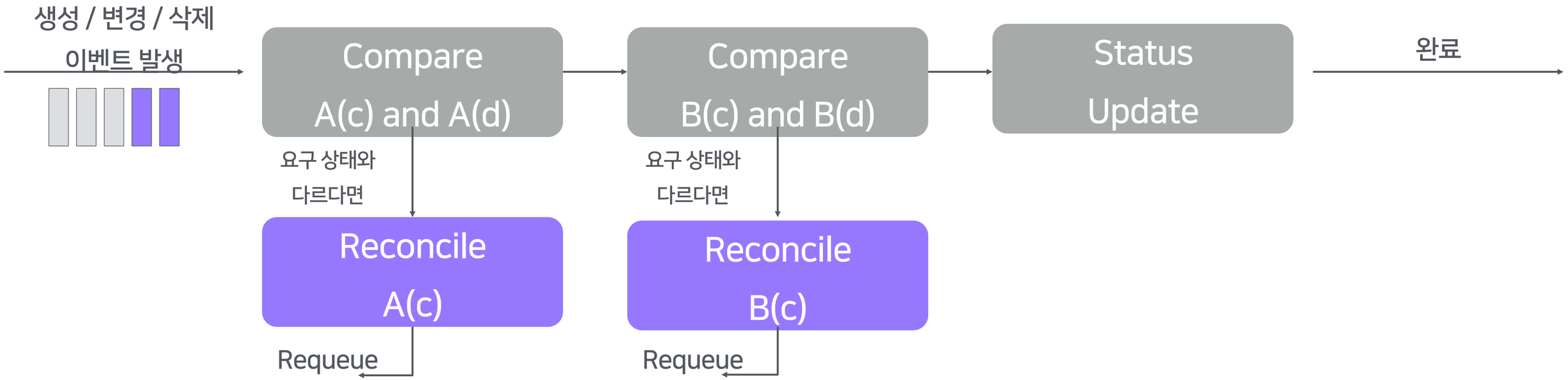
- 타 리소스 및 복합 필드에 대한 필드 검증 Webhook
- 리소스 생성, 업데이트, 삭제 시점에 따른 필드 검증

2.4 Operator - Detail

DEVIEW 2021

Reconciler

- 기본값 및 검증을 통과한 요구 상태를 현재 상태와 비교 및 동기화
- 현재 상태(c), 요구 상태(d)



2.4 Operator - Detail

DEVIEW 2021

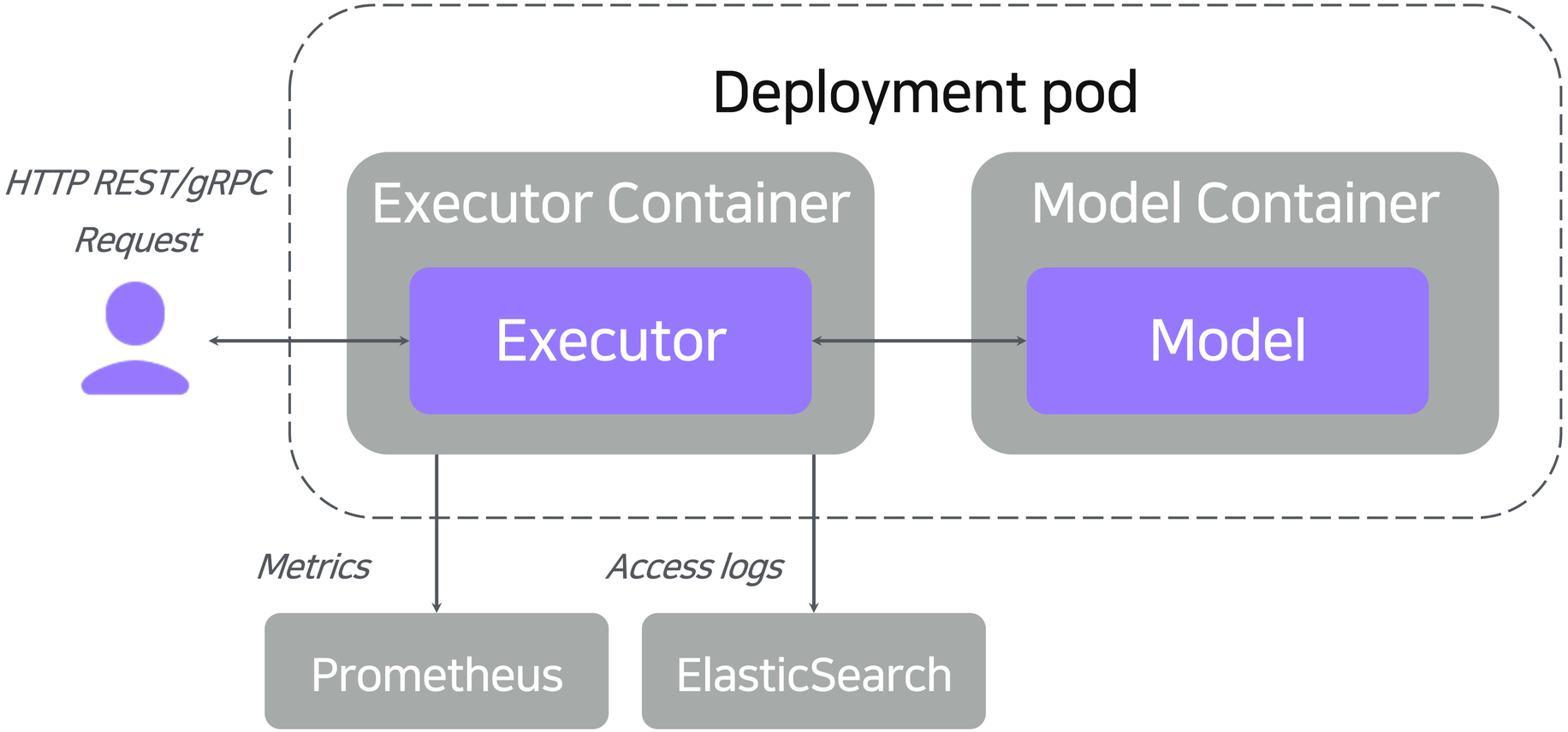
모델 배포 일반화 및 부가기능 주입

- 모델 어플리케이션 변경 없이 사이드카 형태로 Executor 주입
- 모델 엔드포인트 일반화
- 로깅, 메트릭과 같은 미들웨어 추가 용이
- 모델레지스트리 마운트, 요청 형태 제어, 요청량 제어 등
- 복잡한 모델을 그래프 추론 관리 및 조정

2.4 Operator - Where

- 모델 엔드포인트 일반화 및 미들웨어 주입

```
spec:
    predictor:
        registries:
        - name: detector
          mountPath: /data
        containers:
        - name: main
          image: alpine
    graph:
        entrypoint: main
```



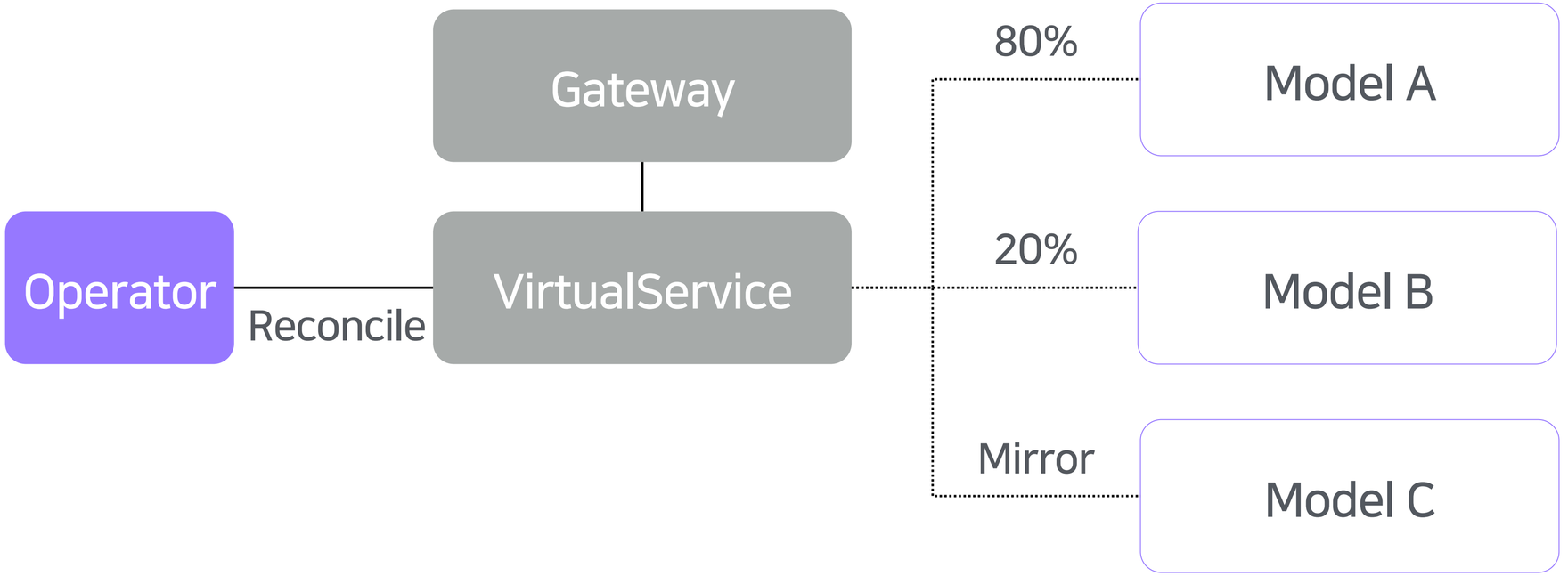
2.4 Operator - Where

DEVIEW 2021

트래픽 제어

- (모델러) 모델 트래픽 설정
- (오퍼레이터) A/B(N) Test, Mirror, Timeout, Retry 제어

```
spec:
    routes:
    - name: model-a
      weight: 80
    - name: model-b
      weight: 20
    mirror:
    - name: model-c
```



2.4 Operator - Where

DEVIEW 2021

로깅 포워드

- (모델러) 로깅 포워드 타겟 설정
- (오퍼레이터) 컨테이너 내 로깅을 타겟으로 포워딩 사이드카 주입

이미지 빌드

- (모델러) CLOps CLI 도커 빌드 입력
- (오퍼레이터) 이미지 빌드 파이프라인 실행 및 로컬 데이터 전송 자동화

2.4 Operator - Where

DEVIEW 2021

이외에도.. (추후 슬라이드에서 설명 예정)

- 오토스케일러
- 모델 레지스트리 및 캐시
- 모델 요청 형태 제어 (Sync / Async)
- 요청량 제어 (Provider / Consumer)

2.4 Operator - TIP

DEVIEW 2021

멱등성(Idempotent) 보장

- 여러번 실행하더라도 결과가 달라 지지 않도록 구현
- 요구 상태에 따른 변화는 항상 똑같아야한다.

컨트롤러 리소스 참조 관계

- 상위 리소스와의 관계를 ‘SetControllerReference’ 함수를 통해 참조 설정
- 리소스가 삭제될 때, 함께 Garbage Collection(GC)를 위한 필수사항

2.4 Operator - TIP

DEVIEW 2021

Custom Resource 필드 타입

- int32 / *int32, string / *string 차이 이해 필요
- Golang의 기본값 인식에 따른 비정상 작동 방지

리소스 비교 및 Reconcile

- 특정 필드가 런타임 시점에 값이 생성되거나 Immutable 필드이거나
- 비교 필드 특성에 따라 비교 로직 변경 필요
- 필드 비교 시 요구 상태와 현재 상태가 계속 달라 무한히 Reconcile 하는 문제 방지

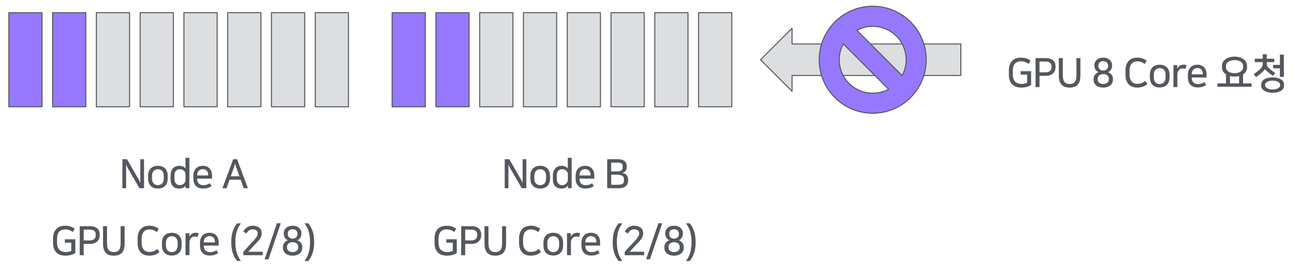
2.5 Scheduler - Why

프로젝트당 모델 종류에 따라 다양한 필요 리소스

- CPU / GPU 사용 여부, GPU 필요 코어, FP32 / FP16에 따른 아키텍처
- 프로젝트별 머신 타입 사용량 제한 스케쥴링

효율적인 리소스 관리를 위한 스케쥴링 정책

- GPU 노드 단편화 문제를 해결하여 가용 리소스 최대화
- 예) 8코어 노드에 2코어 애플리케이션 할당된 상황에서 8코어 애플리케이션 할당 요청



2.5 Scheduler - Detail

DEVIEW 2021

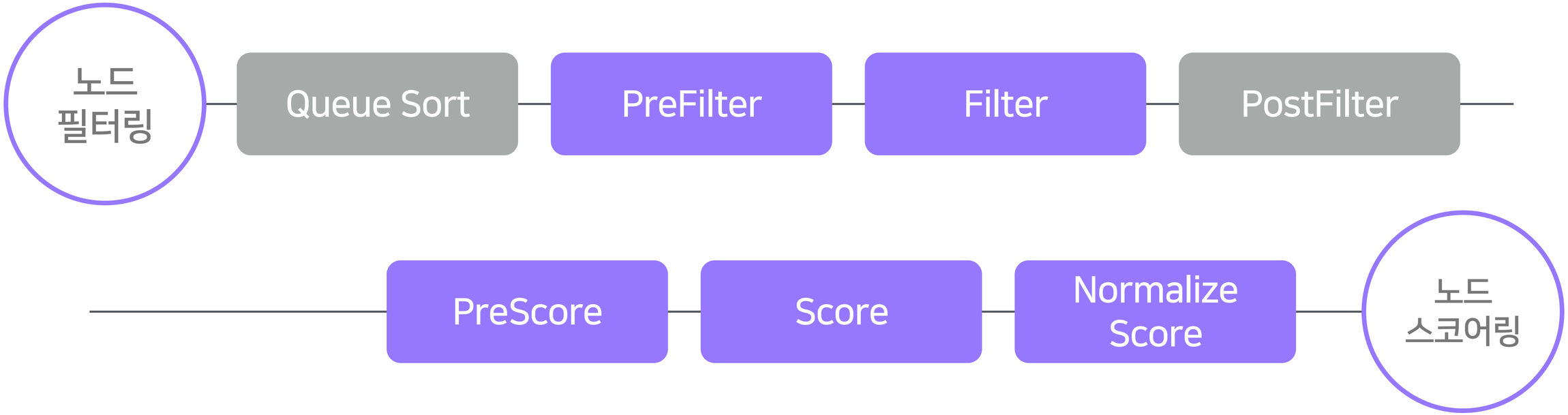
Scheduling Framework

- K8S 1.19 부터 지원하는 커스텀 스케쥴러 프레임워크
- 스케쥴링 노드 필터링 및 스코어링과 같은 플러그인 포인트 제공
- 노드 필터링, 스코어링, 예약, 할당 단계

https://kubernetes.io/docs/concepts/scheduling-eviction/scheduling-framework/

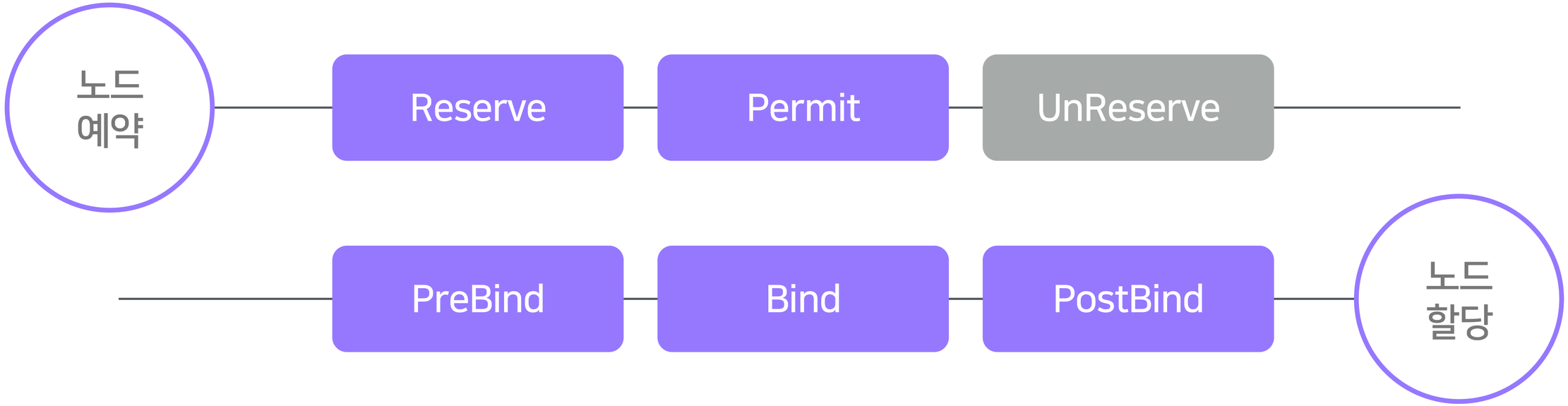
2.5 Scheduler - Detail

- 스케쥴링 프레임워크 워크플로우 (Extension points)



2.5 Scheduler - Detail

- 스케쥴링 프레임워크 워크플로우 (Extension points)

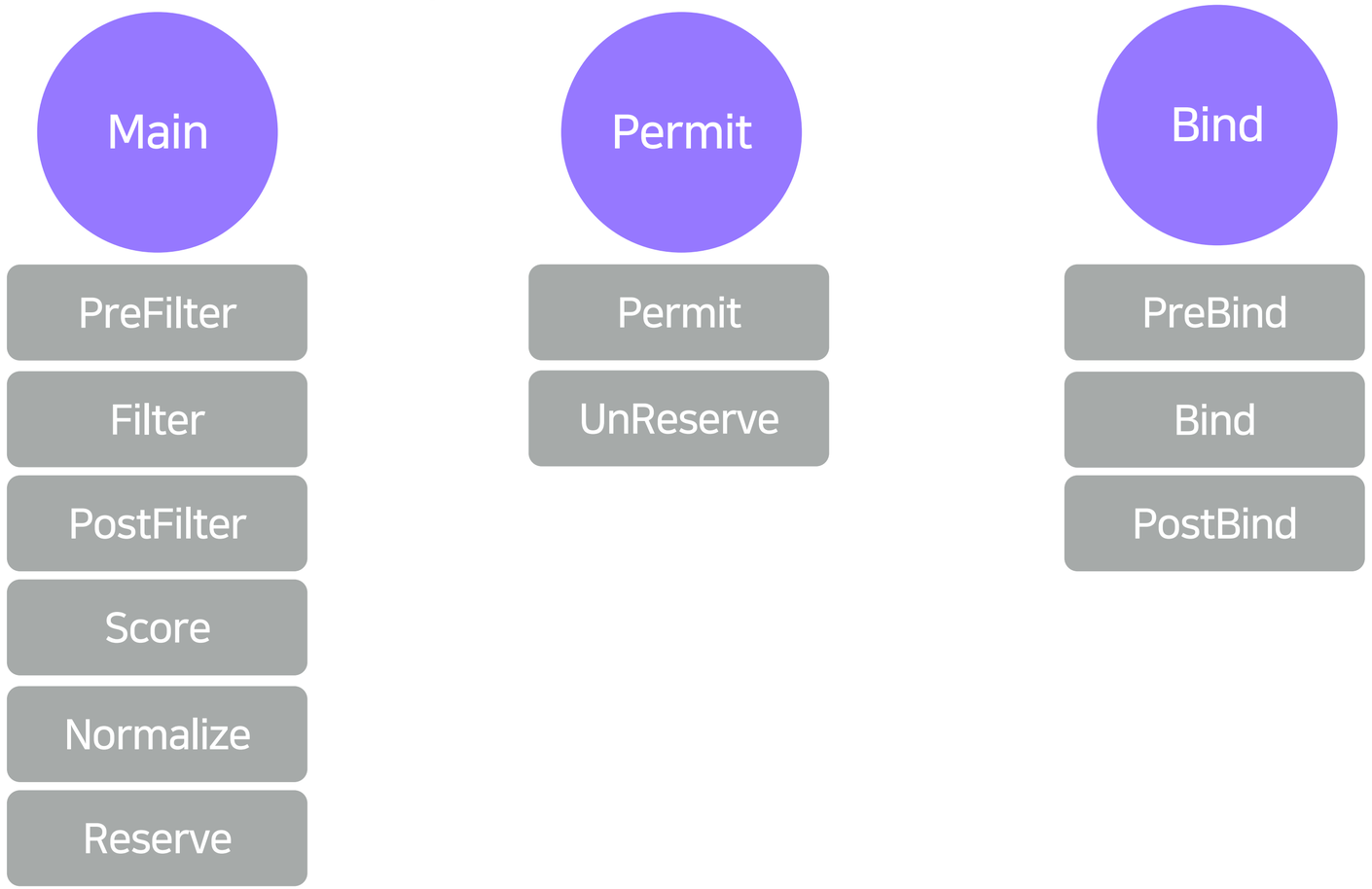


2.5 Scheduler - Detail

DEVIEW 2021

스케쥴링 프레임워크 스레드

- 세개의 스레드로 병렬 실행하며, 동일 스레드 내 실행 순서 및 단일 실행 보장



2.5 Scheduler - Where

DEVIEW 2021

프로젝트 별 노드 스케쥴링

- CR 기반 CLOps 서비스 내 프로젝트별 사용 가능한 노드 할당
- 단일 클러스터에서도 프로젝트(네임스페이스별) 노드 스케쥴링 가능

커스텀 스코어링

- 노드 할당을 위한 점수 부여 로직을 커스텀 적용
- 단편화 방지 및 가용 노드 확보

2.5 Scheduler - TIP

DEVIEW 2021

병렬 스레드 간 경쟁 상태가 없도록 구현

- 스레드 간 Extension Point 특성 파악 필요
- 스케쥴링 로직 내 리소스 경쟁 상태로 데드락 또는 데이터 부정합 발생 가능

단일 스케쥴 사이클 내 정보 공유

- CycleState 구조체를 통해 스케쥴링 라이프사이클 내 데이터 공유 가능
- 동일 데이터 API 호출로 인해 성능 저하 예방

2.5 Scheduler - TIP

Active / StandBy 사용 시, 리더 여부 확인

- 스케쥴러 내 추가적인 Informer 구성 시, 자체 리더 선출 리소스를 사용하여 구현 필요
- 스케쥴링 프레임워크 내 구현부에서 리더 여부를 알 수 없는 구조

노말라이즈 스코어 단계 고려 사항

- 노말라이즈를 위해 스코어에 대한 가중치에 대한 고려 필요
- 기본 스코어링도 함께 작용하기 때문에 의도치 않은 스케쥴링이 될 수 있음

2.6 Horizontal Pod Autoscaler (HPA) - Why

DEVIEW 2021

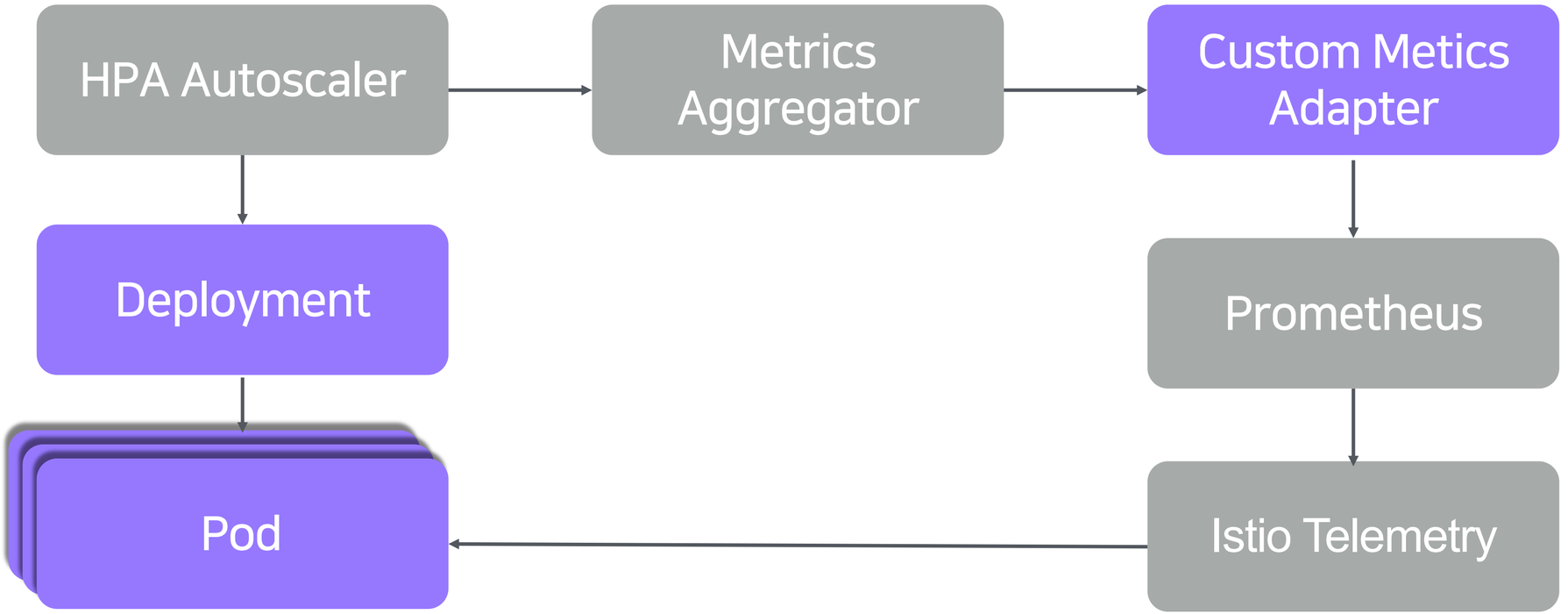
기존 HPA 항목의 한계

- CPU/메모리 기반 HPA 는 모델 서빙을 위한 HPA 메트릭으로 적합하지 않음
- 사용자 정의 (요청수, Latency, GPU 등) 기반 HPA 메트릭 필요

2.6 Horizontal Pod Autoscaler (HPA) - Detail

DEVIEW 2021

- HPA Metrics Aggregator 구조



2.6 Horizontal Pod Autoscaler (HPA) - Where

요청량에 따른 오토스케일링

- (모델러) 요청량 임계값(Threshold) 설정
- (HPA) 임계값을 기준으로 스케일아웃 / 인 진행

```
spec:
    hpa:
        maxReplicas: 10
        minReplicas: 1
        metrics:
        - resource:
          name: hpa-exam
          target:
            type: RequestRate
            averageUtilization: 60
```

2.7 Model Registry - Why

Contains trained ML models

- Allows us to easily access the models to deploy from one location

Model versioning

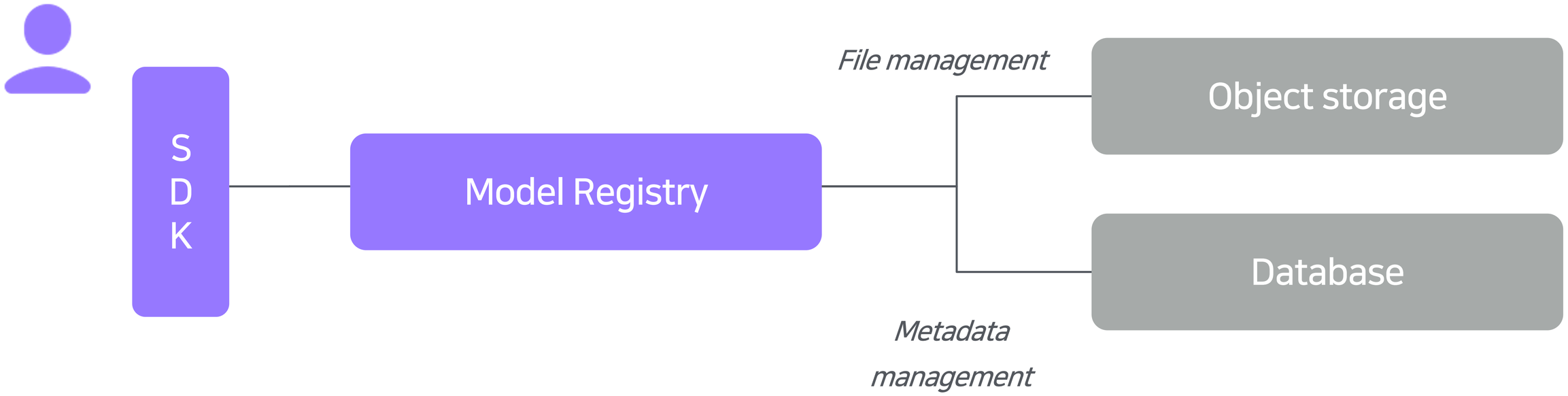
- Easy rollback to previous versions
- Enables *A/B/n* testing between different versions of same model

Model metadata

- Ability to trace which in environment model was trained and with what dataset *(reproducibility)*

2.7 Model Registry - Detail

- Client SDK for interacting with registry
- Store files and metadata in respective backends

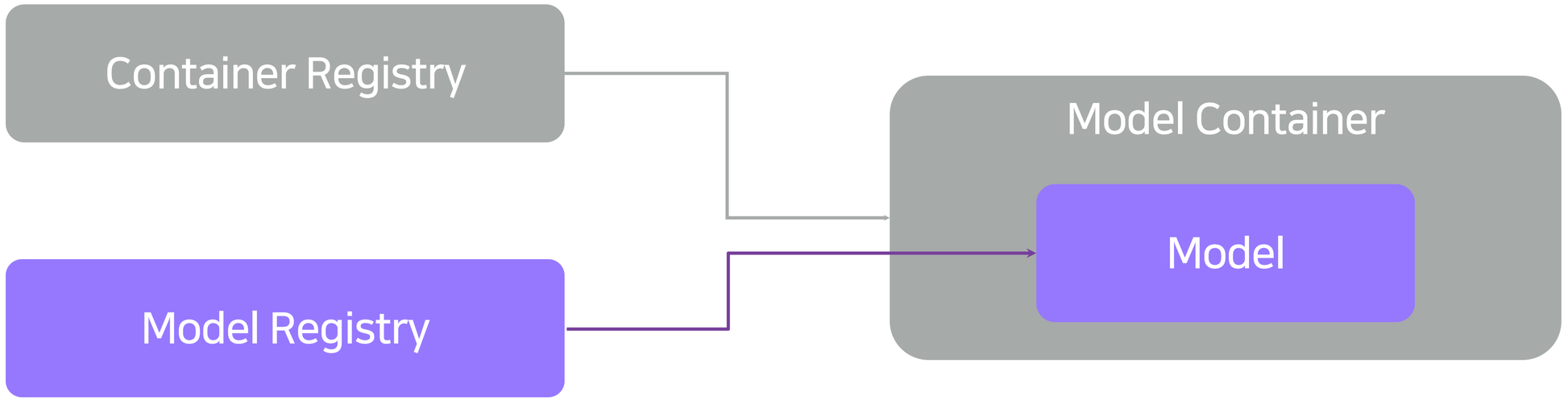


2.7 Model Registry - Detail

DEVIEW 2021

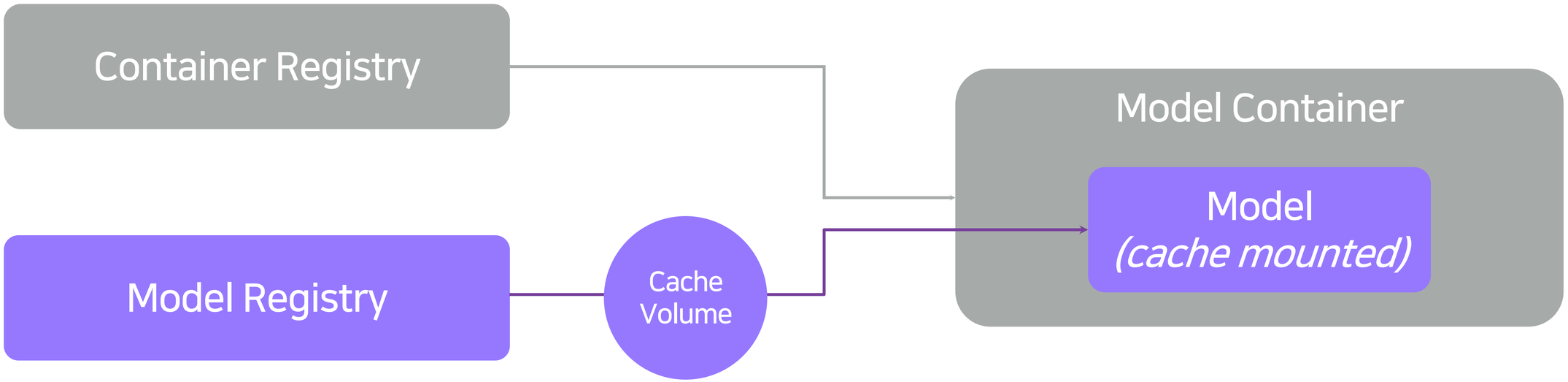
Model downloaded when deploying

- Separate the trained model and its execution environment
- Easier to manage with their own life-cycles



2.7 Model Registry - Detail

- For large models caching is supported



2.7 Model Registry - TIP

Parallel upload/download

- Many models are large in size and uploading/downloading can be time consuming
- Using multiple threads can increase total throughput

- When to cache models
- Network storage is usually more expensive than ethereal *(local) disk storage*
- Consider if caching is actually required when deploying each model
- Highly critical or very large models are good candidates

2.8 Synchronous/Asynchronous - Why

DEVIEW 2021

Synchronous predictions

- Client requests and waits until prediction is done
- Default prediction mode

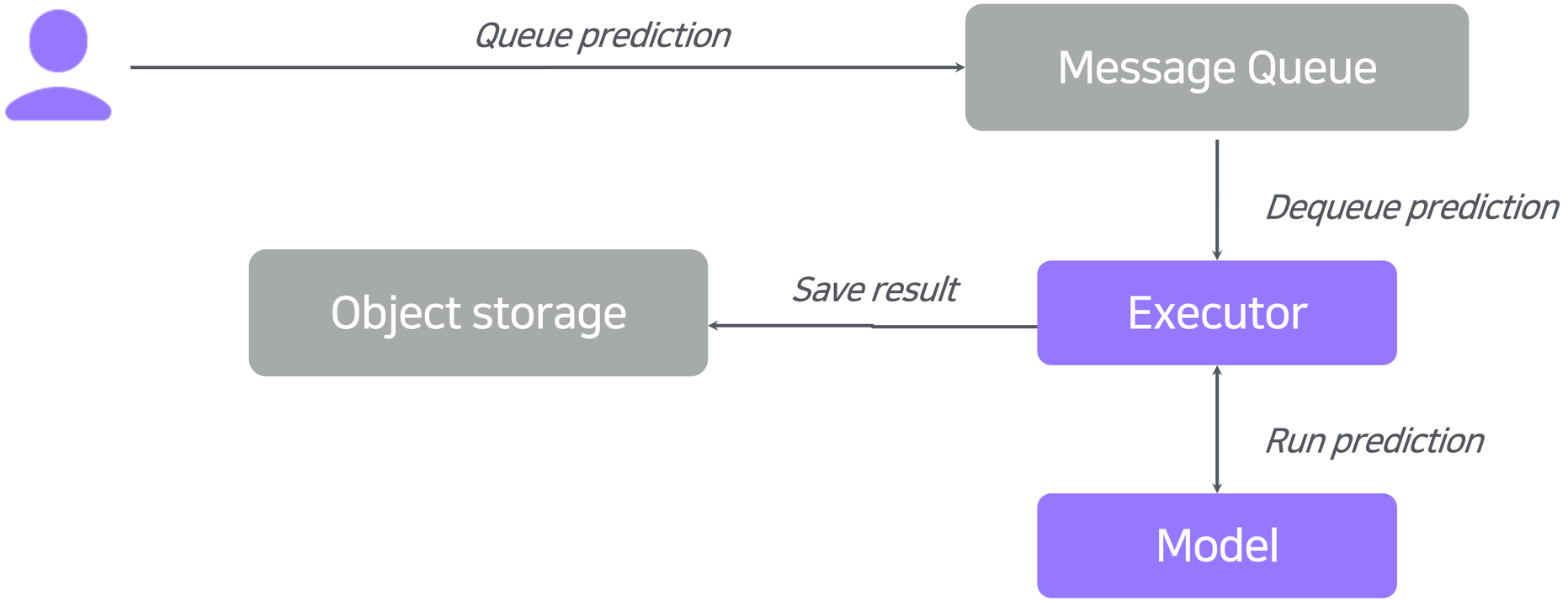
Asynchronous

- Client queues predictions
- Can retrieve result when prediction is done
- Preferred when prediction workloads take long *(e.g. video processing)*

2.8 Synchronous/Asynchronous - Detail

DEVIEW 2021

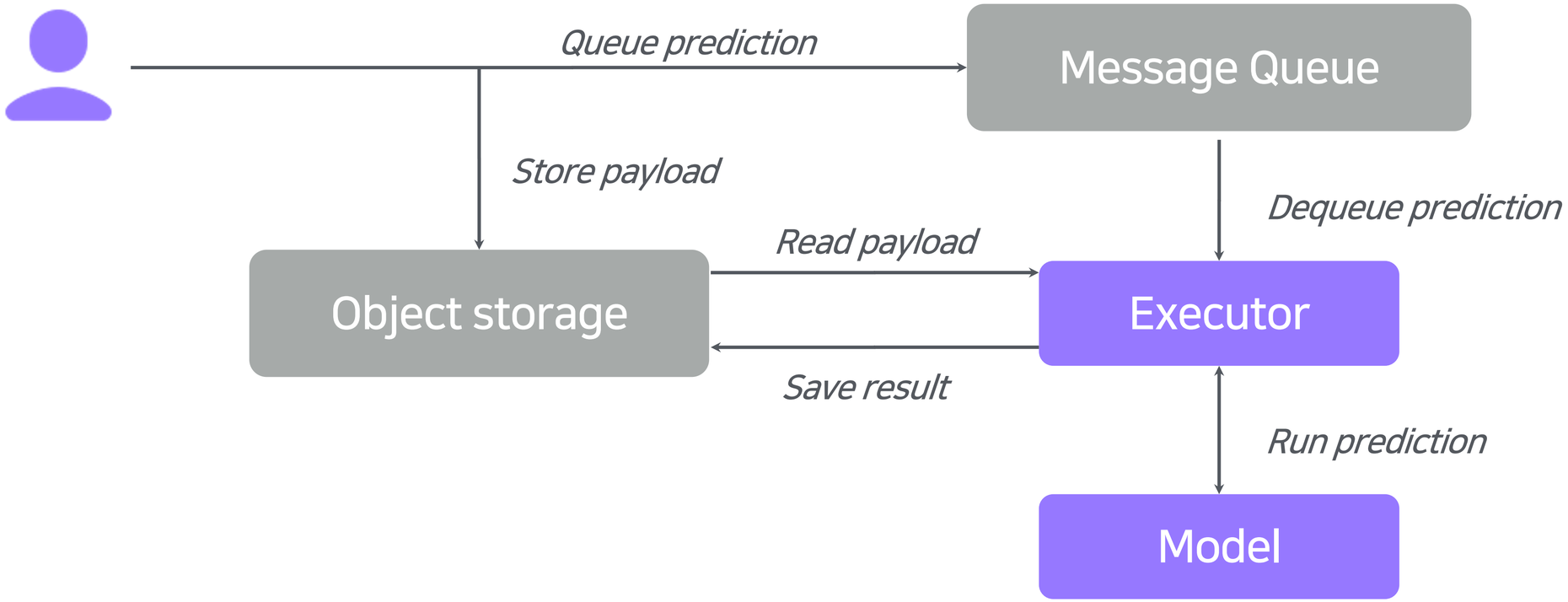
- Use message queue as asynchronous input



2.8 Synchronous/Asynchronous - Detail

DEVIEW 2021

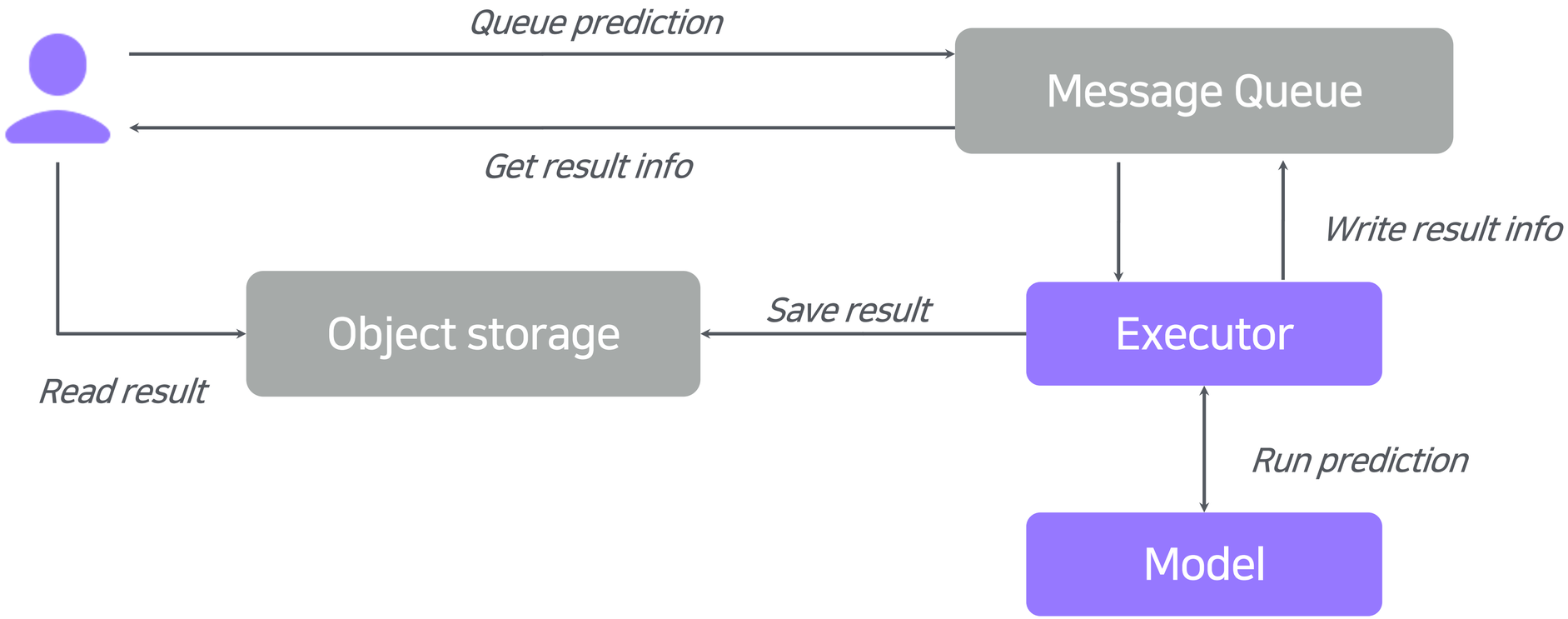
- Store prediction payload if request body is large



2.8 Synchronous/Asynchronous - Detail

DEVIEW 2021

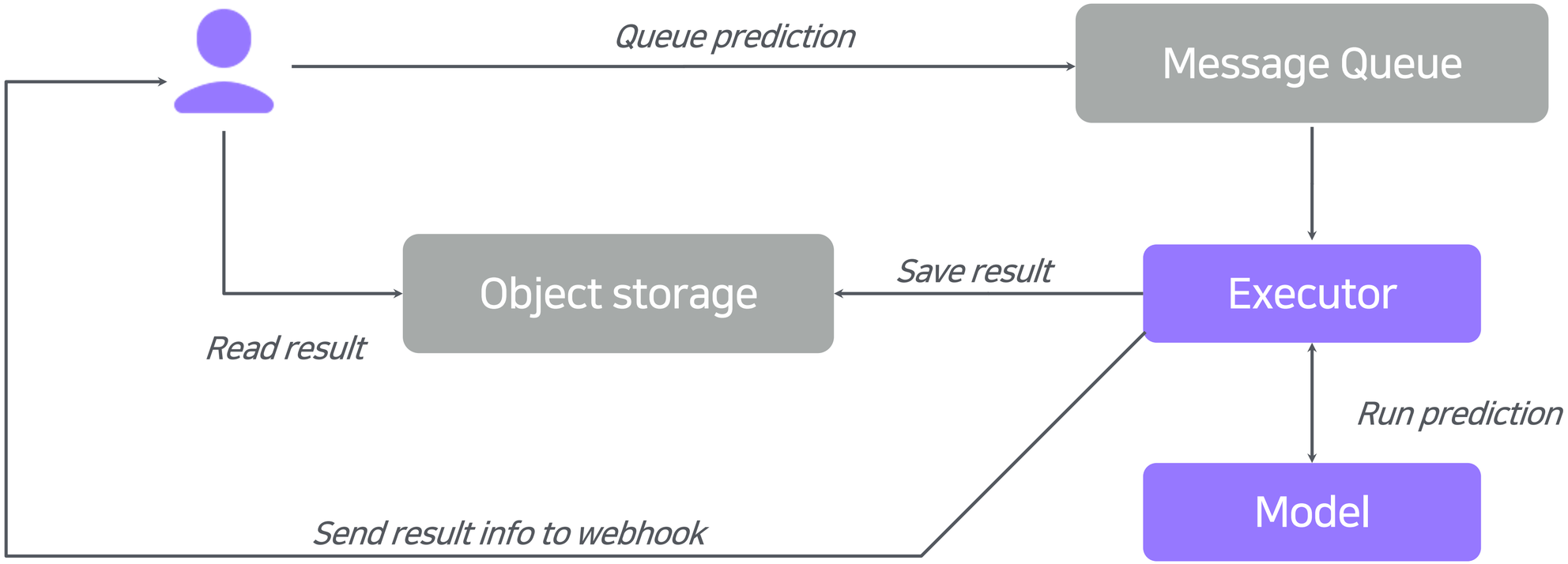
- Get result information via message queue



2.8 Synchronous/Asynchronous - Detail

DEVIEW 2021

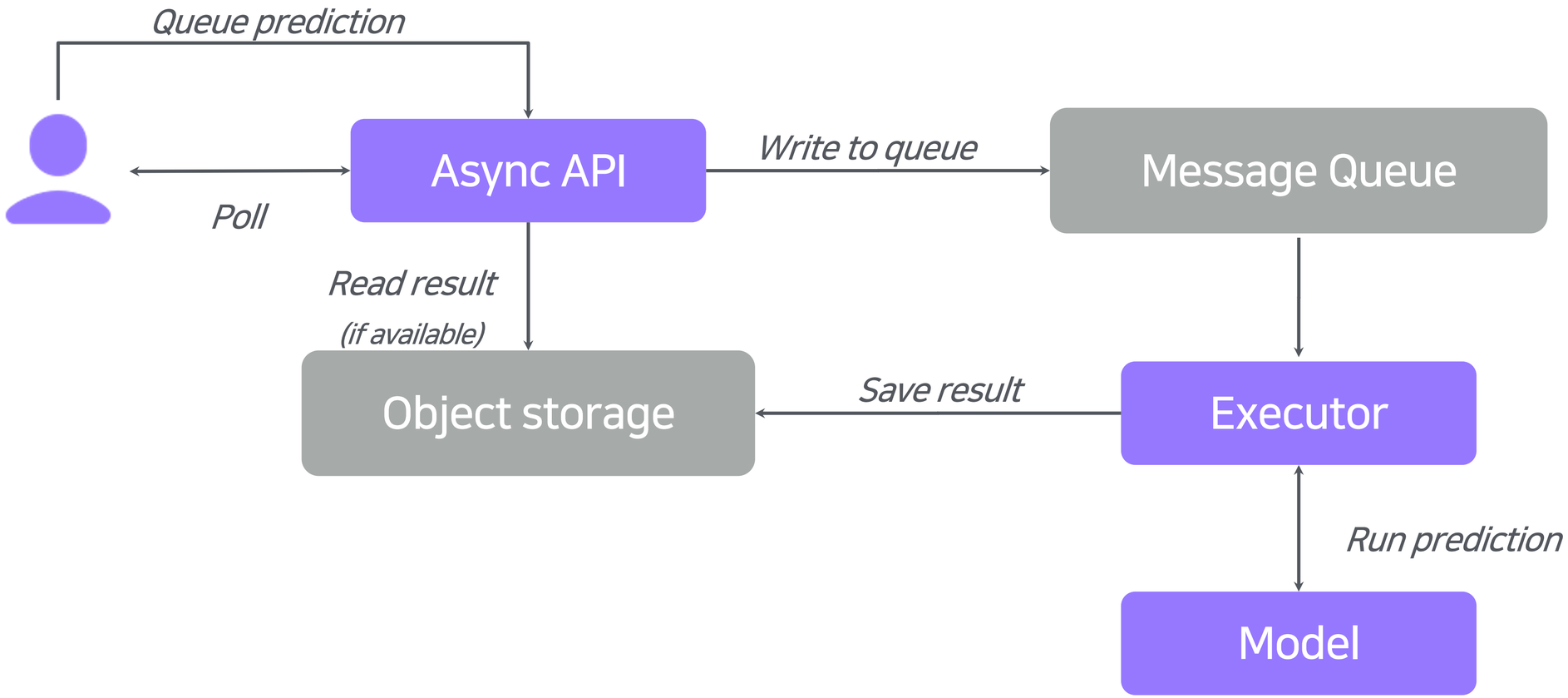
- Get result information via webhook



2.8 Synchronous/Asynchronous - Detail

DEVIEW 2021

- Using Async API server



2.9 Provider / Consumer - Why

DEVIEW 2021

Provider

- Used to represent a model service
- Ability to control request access modes and rate limits for endpoints
- Optionally includes a description and usage guide

Consumer

- Allows us to identify requesting clients
- Linked to organizations or individual users
- Enables auditing and access control per client
- Contains API tokens

2.9 Provider / Consumer - Detail

DEVIEW 2021

Provider access modes

Private
- Only certain authorized clients can access model API
- Provider can choose exactly which consumers have access

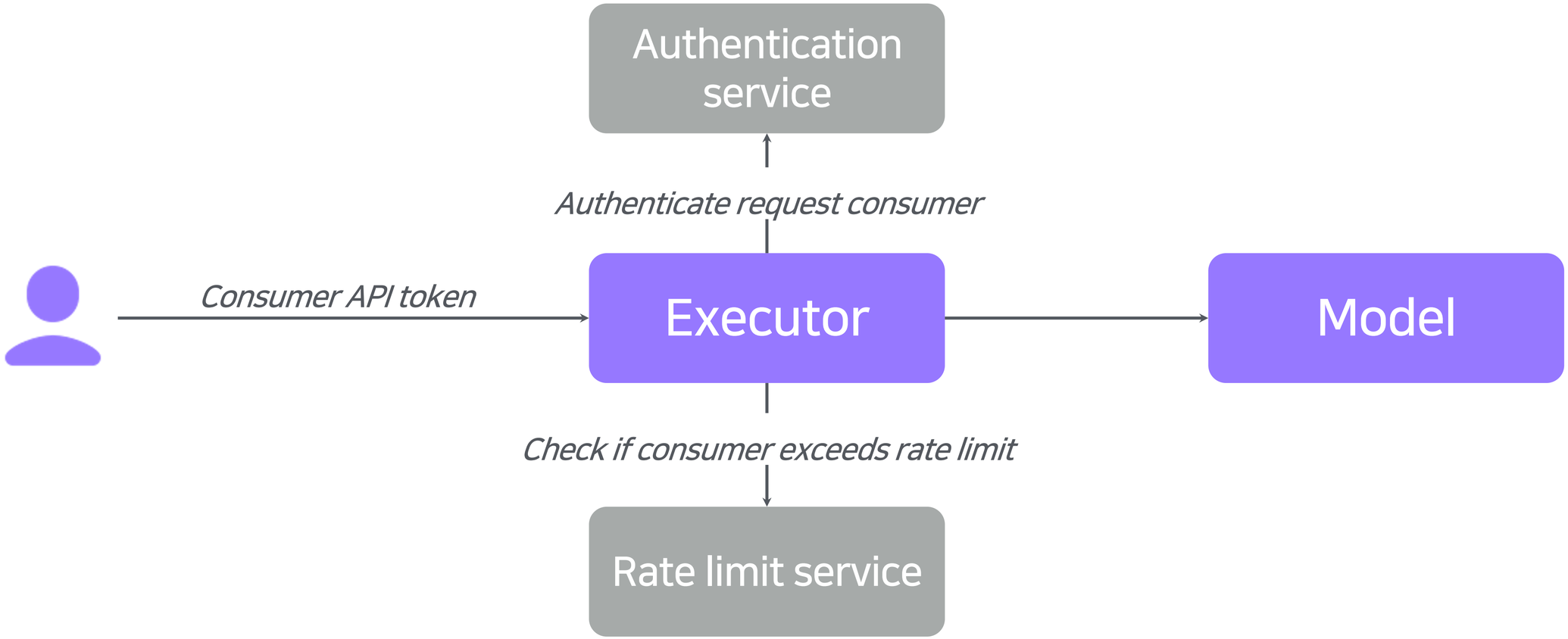
Permissive
- Any request with an API token allowed
- Allows provider owner to audit all requests

Public
- All requests are allowed
- Still authenticates API tokens for auditing if possible

2.9 Provider / Consumer - Detail

DEVIEW 2021

Consumer authentication via API token



2.9 Provider / Consumer - TIP

DEVIEW 2021

Try to utilize service mesh capabilities

- If using a service mesh, try to see if built-in mechanisms fits your use case

Build service catalogs

- With list of providers it is possible to create a view of all service providers
- Gives clear view to model consumers of which services are available

3.Improvements

3.1 What improved?

DEVIEW 2021

Allocating server resources

- *(Before)* PM/VM equipment ordering and installation
- *(Now)* Various machine type pools that can be assigned as needed

Deploying models

- *(Before)* Install environment and implement specific middleware
- *(Now)* Runtime container image and YAML configuration

3.1 What improved?

DEVIEW 2021

Model logging/monitoring management

- *(Before)* Implement logging and monitoring forwarding
- *(Now)* Simply set forwarding information in YAML

Model networking

- *(Before)* API Gateway, discovery based infra with routes in DB
- *(Now)* Networking configured directly through YAML resources

3.1 What improved?

DEVIEW 2021

Model scalability

- *(Before)* LB in front model, manually add machines to scale out
- *(Now)* Conditional in/out scaling for models

Model registry

- *(Before)* Models spread out in different storages
- *(Now)* Upload/download via CLI/SDK, central store with metadata tracking

3.1 What improved?

DEVIEW 2021

Model operation management

- (Before) Manage server access rights, individual operations by admin
- (Now) Management authority for models and load controllable by user and linked to in-house authentication

4.Next Challenges

4.1 Next Challenges

DEVIEW 2021

Pipelining

- Data collection + Model training + Model inference
- MLOps Level 2

Model graph

- Define flow for complex predictions involving multiple models

Model interface SDK

- Provide abstract model interface to improve model compatibility and reusability

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