Multi-Tenant Kubernetes Platform

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Corso: Cloud Platforms and Infrastructure as Code

OVERVIEW

Questa piattaforma implementa un ambiente Kubernetes multi-tenant con isolamento completo tra team di sviluppo.

L'architettura permette a più team di operare sullo stesso cluster mantenendo separazione delle risorse, isolamento di rete e visibilità limitata al proprio namespace. Ogni team dispone di quote di risorse definite, policy di sicurezza dedicate e monitoring isolato.

Soluzione:

1. **Isolamento Completo**: Ogni team opera nel proprio namespace dedicato con sicurezza RBAC, Network Policies e Pod Security Standards
2. **Resource Governance**: Quote di risorse definite e limiti per prevenire resource exhaustion
3. **Monitoring Isolato**: Dashboard e metriche separate per ogni namespace con observability dedicata
4. **Self-Service**: Team autonomi nei propri namespace per deployment e gestione
5. **Applicazioni Demo**: Frontend React + Backend Node.js + PostgreSQL per scenari realistici
6. **High Availability**: Auto-scaling (HPA) e Pod Disruption Budgets per zero downtime

Stack Tecnologico

Infrastructure:

- **Kind**: Kubernetes in Docker per ambiente di sviluppo locale
- **Calico**: Container Network Interface (CNI) per networking avanzato e Network Policies

Applications:

- **Frontend**: React.js 18 store demo (team-frontend namespace)
- **Backend**: Node.js 18 API con Express.js e metriche custom (team-backend namespace)
- **Database**: PostgreSQL 13 con dati demo e schema completo

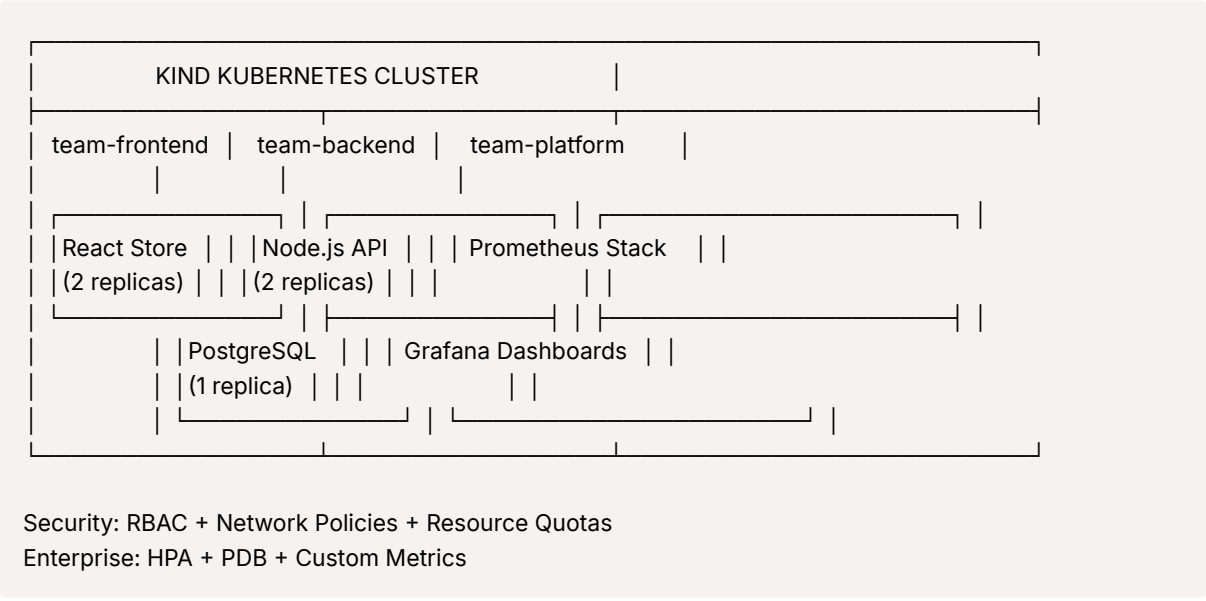
Security & Governance:

- **RBAC**: Role-Based Access Control per isolamento team
- **Network Policies**: Calico policies per isolamento rete tra namespace
- **Resource Quotas**: Limitazione uso risorse (CPU, memory, storage) per namespace
- **Pod Security Standards**: Policy di sicurezza `restricted` a livello pod

Monitoring & Observability:

- **Prometheus**: Raccolta metriche da applicazioni, database e infrastruttura
- **Grafana**: Dashboard dedicati per team e overview platform-wide
- **Custom Metrics**: Metriche applicative Node.js personalizzate
- **ServiceMonitors**: Configurazione automatica target Prometheus
- **Metrics Server**: Raccolta metriche CPU/Memory per HPA auto-scaling

Architettura High-Level



Cluster Nodes:

- **Control Plane**: 1 nodo (API Server, Scheduler, Controller Manager, etcd)
- **Worker Nodes**: 2 nodi (Kubelet, Container Runtime, Calico Node)

INSTALLAZIONE E SETUP

Prerequisiti

Software Richiesto:

```
bash
# Docker Desktop (macOS)
docker --version

brew install kind
kind --version

brew install kubectl
kubectl version --client

brew install helm
```

```
helm version

brew install jq
```

Risorse Hardware:

- **CPU**: Minimo 4 cores (consigliati 8 cores)
- **RAM**: Minimo 8GB (consigliati 16GB)
- **Storage**: Minimo 20GB spazio libero
- **OS**: macOS 12+ (Monterey o superiore)

Procedura di Installazione

Passo 1: Creazione Cluster Kind

```
bash
# 1. Creare cluster Kind con configurazione custom
kind create cluster --name multi-tenant --config kind-config.yaml

# 2. Verificare nodi del cluster
kubectl get nodes
# Atteso: 3 nodi (1 control-plane + 2 workers)
```

File di configurazione Kind:

```
yaml
# kind-config.yaml
kind: Cluster
apiVersion: kind.x-k8s.io/v1alpha4
networking:
  disableDefaultCNI: true# Useremo Calico
  podSubnet: "10.244.0.0/16"
  serviceSubnet: "10.96.0.0/12"
nodes:
- role: control-plane
- role: worker
- role: worker
```

Passo 2: Installazione Calico CNI

```
bash
# 1. Installare Calico per networking avanzato
kubectl apply -f https://raw.githubusercontent.com/projectcalico/calico/v3.26.0/manifests/calico.yaml

# 2. Attendere che Calico sia pronto
kubectl wait --for=condition=ready pod -l k8s-app=calico-node -n kube-system --timeout=300s
```

```
# 3. Verificare che i nodi siano Ready
kubectl get nodes
# Tutti i nodi devono essere "Ready"
```

Passo 3: Deploy Fondamenta Multi-Tenant

```
bash
# 1. Creare namespace per i team
kubectl apply -f kubernetes/01-namespaces/

# 2. Configurare identità e service accounts
kubectl apply -f kubernetes/01-namespaces/service-accounts.yaml

# 3. Implementare sicurezza (RBAC, Network Policies, Quotas)
kubectl apply -f kubernetes/02-security/

# 4. Verificare configurazione sicurezza
kubectl get namespaces | grep team-
kubectl get resourcequota -A
kubectl get networkpolicy -A
```

Passo 4: Deploy Applicazioni

```
bash
# 1. Build immagini Docker
cd applications/frontend/react-store-demo
docker build -t react-store:latest .
cd ../../../

cd applications/backend/users-api
docker build -t users-api:latest .
cd ../../../

# 2. Caricare immagini in Kind
kind load docker-image react-store:latest --name multi-tenant
kind load docker-image users-api:latest --name multi-tenant

# 3. Deploy workloads
kubectl apply -f kubernetes/03-workloads/backend/postgres-deployment.yaml
kubectl apply -f kubernetes/03-workloads/backend/users-api-deployment.yaml
kubectl apply -f kubernetes/03-workloads/backend/users-api-service.yaml
kubectl apply -f kubernetes/03-workloads/frontend/

# 4. Deploy funzionalità enterprise (scaling, HA)
kubectl apply -f kubernetes/04-scaling/
```

Passo 5: Setup Monitoring

```
```

```
bash
# 1. Preparare dashboard Grafana
kubectl create configmap grafana-platform-dashboards \
    --from-file=kubernetes/05-monitoring/grafana/dashboards/ \
    -n team-platform \
    --dry-run=client -o yaml | kubectl apply -f -

kubectl label configmap grafana-platform-dashboards \
    grafana_dashboard=1 -n team-platform --overwrite

# 2. Installare Prometheus Stack
helm repo add prometheus-community https://prometheus-community.github.io/helm-charts
helm repo update

helm install prometheus prometheus-community/kube-prometheus-stack \
    --namespace team-platform \
    --values kubernetes/05-monitoring/prometheus/prometheus-stack-values.yaml \
    --wait --timeout 10m

# 3. Configurare ServiceMonitors per metriche custom
kubectl apply -f kubernetes/05-monitoring/prometheus/backend-servicemonitor.yaml
```

Passo 6: Configurazione Accesso

```
bash
# Setup port-forwards per accesso locale
kubectl port-forward -n team-backend svc/users-api 3001:3000 &
kubectl port-forward -n team-frontend svc/react-store 3000:3000 &
kubectl port-forward svc/prometheus-grafana 3002:80 -n team-platform &
kubectl port-forward svc/prometheus-prometheus 9090:9090 -n team-platform &
```

Verifica Installazione

```
bash
# 1. Verificare tutti i pod sono Running
kubectl get pods -A | grep -v Running

# 2. Testare applicazioni
echo "🧪 Testing services..."
curl -s http://localhost:3001/api/health && echo "✅ Backend OK" || echo "❌ Backend KO"
curl -s http://localhost:3000 >/dev/null && echo "✅ Frontend OK" || echo "❌ Frontend KO"
curl -s http://localhost:9090/-/healthy >/dev/null && echo "✅ Prometheus OK" || echo "❌ Prometheus K
O"
curl -s -u admin:admin123 http://localhost:3002/api/health >/dev/null && echo "✅ Grafana OK" || echo "❌
Grafana KO"

# 3. Verificare metriche custom
curl -s http://localhost:3001/metrics | grep http_requests_total
```

```
# 4. Testare database
curl -s http://localhost:3001/api/products | jq '.metadata.total_products'

# 5. Generare traffico iniziale per dashboard
for i in {1..20}; do
   curl -s http://localhost:3001/api/products >/dev/null
   curl -s http://localhost:3001/api/categories >/dev/null
   sleep 0.5
done

# 6. Controllare isolamento sicurezza
kubectl auth can-i get pods --namespace=team-backend --as=system:serviceaccount:team-frontend:tea
m-frontend-sa
# Risultato atteso: no
```

URLs di Accesso

Applicazioni:

- **Frontend**: http://localhost:3000
- **Backend API**: http://localhost:3001
- **API Health**: http://localhost:3001/api/health
- **API Metrics**: http://localhost:3001/metrics

Monitoring:

- **Grafana**: http://localhost:3002 (admin / admin123)
- **Prometheus**: http://localhost:9090

API Endpoints per Demo:

- `GET /api/products` - Lista prodotti dal database
- `GET /api/categories` - Categorie prodotti con conteggi
- `GET /api/server-info` - Info load balancing (hostname pod)
- `GET /api/db-test` - Test connessione database
- `GET /metrics` - Metriche Prometheus custom

CLEANUP E RIMOZIONE

Rimozione Completa

```
bash
# 1. Fermare tutti i port-forwards
pkill -f 'port-forward'

# 2. Rimuovere monitoring stack Helm
helm uninstall prometheus -n team-platform
```

```
# 3. Eliminare cluster Kind
kind delete cluster --name multi-tenant

# 4. Pulire immagini Docker (opzionale)
docker rmi react-store:latest users-api:latest
docker system prune -f

echo "✅ Cleanup completo eseguito"
```

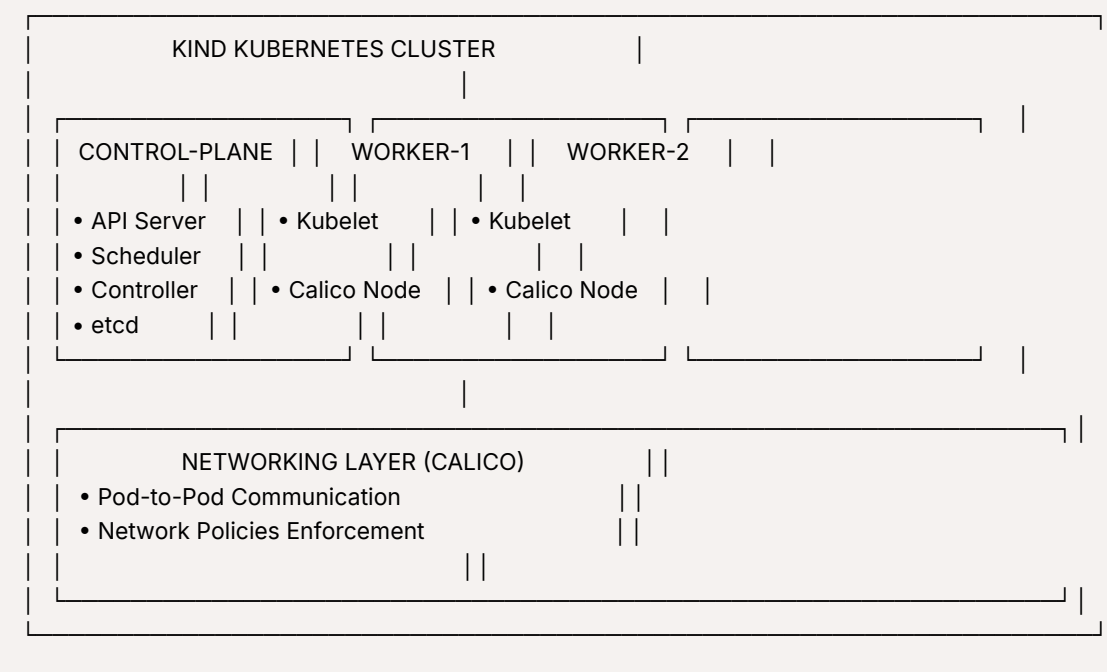
Docker storage cleanup:

```
bash
# Cleanup completo Docker
docker system df# Mostra uso spazio# Remove tutto unused
docker system prune -a -f --volumes

# Remove Kind specific
docker volume ls | grep kind
docker volume rm $(docker volume ls -q | grep kind)
```

ARCHITETTURA DEL SISTEMA

Panoramica Architetturale

L'architettura del sistema è progettata seguendo il **pattern multi-tenant** con **isolamento a più livelli**:



Struttura Namespace

Il cluster è organizzato in **tre namespace principali**:

team-frontend Namespace

```
yaml
Namespace: team-frontend
├── Scopo: Applicazioni frontend e interfacce utente
├── Workloads:
│   ├── Deployment: react-store (2 replicas)
│   └── Service: react-store (ClusterIP)
├── Security:
│   ├── ServiceAccount: team-frontend-sa
│   ├── Role: team-frontend-role
│   ├── ResourceQuota: CPU=4, Memory=8Gi, Pods=50
│   └── NetworkPolicy: isolamento da altri team
└── Monitoring:
    └── Dashboard Grafana dedicato frontend
```

Caratteristiche specifiche:

- **Pod Security Standard**: `restricted`
- **Resource Limits**: Container max 2 CPU, 4Gi RAM
- **Network Access**: Internet HTTPS/HTTP, DNS, stesso namespace
- **RBAC**: Accesso completo solo al proprio namespace

team-backend Namespace

```
yaml
Namespace: team-backend
├── Scopo: API, microservizi, database
├── Workloads:
│   ├── Deployment: users-api (2 replicas)
│   ├── Deployment: postgresql (1 replica)
│   ├── Service: users-api (ClusterIP)
│   └── Service: postgresql (ClusterIP)
├── Security:
│   ├── ServiceAccount: team-backend-sa
│   ├── Role: team-backend-role
│   ├── ResourceQuota: CPU=6, Memory=12Gi, Pods=75
│   └── NetworkPolicy: isolamento + accesso database
└── Monitoring:
    ├── ServiceMonitor: users-api metrics
    └── Dashboard Grafana backend + database
```

Caratteristiche specifiche:

- **Pod Security Standard**: `restricted`
- **Resource Limits**: Container max 4 CPU, 8Gi RAM
- **Network Access**: Solo HTTPS esterno, database interno
- **Custom Metrics**: Node.js app metrics + PostgreSQL stats

team-platform Namespace

```
yaml
Namespace: team-platform
├── Scopo: Infrastruttura, monitoring, gestione piattaforma
├── Workloads:
│   ├── StatefulSet: prometheus-prometheus
│   ├── Deployment: prometheus-grafana
│   ├── DaemonSet: node-exporter
│   └── Deployment: kube-state-metrics
├── Security:
│   ├── ServiceAccount: team-platform-sa
│   ├── ClusterRole: team-platform-cluster-role (admin)
│   ├── ResourceQuota: CPU=8, Memory=16Gi, Pods=100
│   └── NetworkPolicy: accesso cross-namespace per monitoring
└── Monitoring:
    ├── Dashboard: Platform Overview
    ├── Dashboard: Per-Team Dashboards
    └── Alerting Rules
```

Caratteristiche specifiche:

- **Pod Security Standard**: `privileged` (per monitoring tools)
- **Cluster Permissions**: Full admin access per operations
- **Cross-Namespace Access**: Monitoring di tutti i namespace
- **High Resource Allocation**: Per stack monitoring enterprise

Service Accounts

Ogni namespace dispone di **ServiceAccount dedicati** per l'identità e autenticazione delle applicazioni:

team-frontend ServiceAccount

```
yaml
apiVersion: v1
kind: ServiceAccount
metadata:
  name: team-frontend-sa
  namespace: team-frontend
  labels:
    team: frontend
    component: identity
  annotations:
    description: "ServiceAccount per applicazioni frontend e RBAC"
    kubernetes.io/managed-by: "platform-team"
automountServiceAccountToken: true
```

Caratteristiche:

- **Scope**: Solo namespace team-frontend
- **Permissions**: Read/Write su risorse frontend
- **Token**: Auto-mount per pod authentication

- **Usage**: Assegnato ai pod React store

team-backend ServiceAccount

```
yaml
apiVersion: v1
kind: ServiceAccount
metadata:
  name: team-backend-sa
  namespace: team-backend
  labels:
    team: backend
    component: identity
  annotations:
    description: "ServiceAccount per API backend e database"
    kubernetes.io/managed-by: "platform-team"
automountServiceAccountToken: true
```

Caratteristiche:

- **Scope**: Solo namespace team-backend
- **Permissions**: Full access su API e database resources
- **Database Access**: Credentials per PostgreSQL
- **Usage**: Assegnato ai pod Node.js API e PostgreSQL

team-platform ServiceAccount

```
yaml
apiVersion: v1
kind: ServiceAccount
metadata:
  name: team-platform-sa
  namespace: team-platform
  labels:
    team: platform
    component: identity
  annotations:
    description: "ServiceAccount per operazioni infrastruttura"
    privilege-level: "cluster-admin"
    kubernetes.io/managed-by: "platform-team"
automountServiceAccountToken: true
```

Caratteristiche:

- **Scope**: Cluster-wide access
- **Permissions**: Cluster admin per monitoring e operations
- **Cross-namespace**: Accesso a tutti i namespace per monitoring
- **Usage**: Prometheus, Grafana, platform tools

Isolation Matrix

Risorsa	team-frontend	team-backend	team-platform
Pods (proprio NS)	✅ Full Access	✅ Full Access	✅ Full Access
Pods (altri NS)	❌ No Access	❌ No Access	✅ Read Access
Services (proprio NS)	✅ Full Access	✅ Full Access	✅ Full Access
Secrets (proprio NS)	✅ Full Access	✅ Full Access	✅ Full Access
Secrets (altri NS)	❌ No Access	❌ No Access	✅ Read Access
NetworkPolicies	✅ Manage Own	✅ Manage Own	✅ Manage All
ResourceQuotas	❌ View Only	❌ View Only	✅ Full Management
Cluster Resources	❌ No Access	❌ No Access	✅ Full Access

Frontend: React Store Demo

Tecnologie:

- **Framework**: React 18 con Hooks
- **Build Tool**: Create React App
- **Container**: Node.js 18 Alpine

Funzionalità:

- **Product Catalog**: Lista prodotti da database
- **Category Filter**: Filtro per categoria prodotti
- **Load Balancing Test**: Button per testare distribuzione carico
- **Real-time Stats**: Connessione backend per demo

Sicurezza:

- **Non-root user**: UID 1000
- **Read-only filesystem**: Dove possibile
- **Resource limits**: 200m CPU, 1Gi RAM request

Networking:

- **Service Type**: ClusterIP (internal)
- **Port**: 3000 (HTTP)

Backend: Node.js API

Tecnologie:

- **Runtime**: Node.js 18
- **Framework**: Express.js
- **Database Client**: pg (PostgreSQL)
- **Metrics**: Custom Prometheus metrics

API Endpoints:

```
GET /                 # Service info
GET /api/health       # Health check
GET /api/products     # Lista prodotti
GET /api/categories   # Categorie con conteggi
GET /api/db-test      # Test connessione DB
```

```
GET /api/server-info     # Info pod (load balancing)
GET /metrics             # Prometheus metrics
```

Database: PostgreSQL

Configurazione:

- **Version**: PostgreSQL 13 Alpine
- **Security**: Non-root user, resource limits

Schema Database:

```
sql
Table: products
├── id (SERIAL PRIMARY KEY)
├── name (VARCHAR(255))
├── description (TEXT)
├── price (DECIMAL(10,2))
├── category (VARCHAR(100))
├── stock_quantity (INTEGER)
├── created_at (TIMESTAMP)
└── updated_at (TIMESTAMP)

Indexes:
├── idx_products_category (category)
├── idx_products_price (price)
└── idx_products_stock (stock_quantity)
```

Dati di Esempio:

- **Electronics**: iPhone 15 Pro, Samsung Galaxy S24
- **Computers**: MacBook Pro M3, Dell XPS 13
- **Audio**: AirPods Max, Sony WH-1000XM5
- **Gaming**: PlayStation 5, Xbox Series X, Nintendo Switch

SECURITY IMPLEMENTATION

La sicurezza è implementata attraverso **quattro layer principali**:

```
┌─────────────────────────────────────────────────────────────────────────┐
│                    SECURITY LAYERS                                      │
├─────────────────────────────────────────────────────────────────────────┤
│ 🔐 RBAC (Role-Based Access Control)                                     │
│    • Namespace-scoped permissions                                       │
│    • ServiceAccount isolation                                           │
├─────────────────────────────────────────────────────────────────────────┤
│ 🚧 Network Policies (Calico)                                            │
│    • Default deny all traffic                                           │
│    • Whitelist-based communication                                      │
├─────────────────────────────────────────────────────────────────────────┤
│ 💰 Resource Quotas & LimitRanges                                        │
│    • CPU/Memory limits per namespace                                    │
```

```
│    • Pod count restrictions                                    │
│    • Storage allocation limits                                 │
├────────────────────────────────────────────────────────────────┤
│ 🔒 Pod Security Standards                                      │
│    • Non-root containers                                       │
│    • No privileged escalation                                  │
└────────────────────────────────────────────────────────────────┘
```

RBAC (Role-Based Access Control)

Il sistema RBAC implementa il **principio del least privilege** con tre livelli di accesso:

Permission Matrix

Team	Scope	Resources	Verbs
Frontend	`team-frontend` only	pods, services, deployments, configmaps, secrets	get, list, create, update, delete
Backend	`team-backend` only	pods, services, deployments, statefulsets, jobs	get, list, create, update, delete
Platform	Cluster	ALL resources	ALL verbs

Implementazione

Frontend Team:

```
# Role (namespace-scoped) → RoleBinding → ServiceAccount
apiVersion: rbac.authorization.k8s.io/v1
kind: Role
metadata:
  name: team-frontend-role
  namespace: team-frontend
rules:
- apiGroups: ["", "apps", "networking.k8s.io", "autoscaling"]
  resources: ["pods", "services", "deployments", "networkpolicies", "hpa"]
  verbs: ["get", "list", "create", "update", "patch", "delete"]
```

Platform Team:

```
# ClusterRole per accesso cluster-wide
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole
metadata:
  name: team-platform-cluster-role
rules:
- apiGroups: ["*"]
  resources: ["*"]
  verbs: ["*"]
```

Network Policies

Implementano **microsegmentazione** con strategia **"default deny all"** + whitelist esplicite.

Policy Architecture

```
┌──────────────────────────────────────────────────────────────┐
│                    NETWORK ISOLATION                         │
├──────────────────┬──────────────────┬────────────────────────┤
│ team-frontend    │ team-backend     │ team-platform          │
```

```
│              │              │                    │
│ DEFAULT DENY  │ DEFAULT DENY  │ FULL ACCESS          │
│ ↓ WHITELIST:  │ ↓ WHITELIST:  │ (monitoring needs)    │
│ • Own namespace │ • Own namespace │                    │
│ • DNS (k8s)   │ • DNS (k8s)   │                    │
│ • Internet HTTPS │ • Internet HTTPS │                    │
│ • Monitoring  │ • Monitoring  │                    │
└──────────────┴──────────────┴────────────────────┘
```

Key Policies

Default Deny All:

```
# Blocca tutto il traffico per sicurezza
spec:
  podSelector: {}  # Tutti i pod
  policyTypes: [Ingress, Egress]
  # Nessuna regola = blocco totale
```

Intra-Namespace Communication:

```
# Permette comunicazione stesso namespace
ingress:
- from:
  - namespaceSelector:
      matchLabels:
        team: frontend  # Solo stesso team
```

DNS Access:

```
# Necessario per service discovery
egress:
- to:
  - namespaceSelector:
      matchLabels:
        name: kube-system
  ports:
  - protocol: UDP
    port: 53
```

Platform Monitoring:

```
# Eccezione per monitoring cross-namespace
ingress:
- from:
  - namespaceSelector:
      matchLabels:
        team: platform
  ports:
  - protocol: TCP
    port: 8080  # Metrics
```

Resource Quotas & LimitRanges

Garantiscono **fair sharing** e prevengono resource exhaustion.

Quota Allocation

Namespace	CPU Request	CPU Limit	Memory Request	Memory Limit	Pods	Storage
team-frontend	4 cores	8 cores	8Gi	16Gi	50	100Gi
team-backend	6 cores	12 cores	12Gi	24Gi	75	200Gi
team-platform	8 cores	16 cores	16Gi	32Gi	100	500Gi

Implementation

ResourceQuota Example:

```
apiVersion: v1
kind: ResourceQuota
metadata:
  name: team-frontend-quota
  namespace: team-frontend
spec:
  hard:
    requests.cpu: "4"
    limits.cpu: "8"
    requests.memory: 8Gi
    limits.memory: 16Gi
    pods: "50"
    persistentvolumeclaims: "10"
```

LimitRange Example:

```
apiVersion: v1
kind: LimitRange
metadata:
  name: team-frontend-limits
  namespace: team-frontend
spec:
  limits:
  - type: Container
    default:         # Se non specificato
      cpu: 200m
      memory: 256Mi
    defaultRequest:   # Richiesta minima
      cpu: 100m
      memory: 128Mi
    max:             # Limite massimo per container
      cpu: "2"
      memory: 4Gi
```

Pod Security Standards

Enforcing **security baselines** a livello pod per prevenire privilege escalation.

- **Non-root user**: `runAsNonRoot: true`
- **No privilege escalation**: `allowPrivilegeEscalation: false`

- **Drop capabilities**: `capabilities.drop: [ALL]`
- **Read-only filesystem**: `readOnlyRootFilesystem: true`

Controllo di Sicurezza Implementazione Copertura Stato

Controllo di Sicurezza	Implementazione	Copertura	Stato
Isolamento Identità	ServiceAccounts + RBAC	Permessi limitati ai namespace	✅ Attivo
Segmentazione Rete	Calico Network Policies	Default deny + accesso selettivo	✅ Attivo
Governance Risorse	ResourceQuotas + LimitRanges	Limiti CPU/Memory/Storage	✅ Attivo
Sicurezza Container	Pod Security Standards	Non-root + no escalation	✅ Attivo
Gestione Privilegi	Security context restricted	Rimozione capabilities	✅ Attivo
Audit Trail	Kubernetes API audit logs	Tracciamento violazioni RBAC	✅ Disponibile
Accesso Monitoring	Eccezioni team platform	Osservabilità cross-namespace	✅ Attivo

HIGH AVAILABILITY E SCALING

La piattaforma implementa **meccanismi** per garantire alta disponibilità e scaling automatico:

```
┌─────────────────────────────────────────────────────────────┐
│                    ENTERPRISE FEATURES                      │
├─────────────────────────────────────────────────────────────┤
│ 📈 HORIZONTAL POD AUTOSCALER (HPA)                          │
│   • Scaling automatico basato su metriche                   │
│   • CPU e Memory utilization triggers                       │
├─────────────────────────────────────────────────────────────┤
│ 🛡️ POD DISRUPTION BUDGET (PDB)                              │
│   • Disponibilità garantita durante maintenance             │
│   • Zero downtime rolling updates                           │
└─────────────────────────────────────────────────────────────┘
```

Horizontal Pod Autoscaler (HPA)

Per garantire il corretto funzionamento dell'**HPA (Horizontal Pod Autoscaler)**, è fondamentale installare il **Metrics Server**.

Il problema senza Metrics Server si manifesta immediatamente quando si tenta di verificare lo stato dell'HPA:

```
bash
kubectl get hpa -n team-backend
# Output: cpu: <unknown>/60%, memory: <unknown>/70%# L'HPA NON può scalare automaticamente
```

In questa situazione, l'HPA non può prendere alcuna decisione di scaling perché non ha visibilità sull'utilizzo effettivo delle risorse dei pod

Installazione Metrics Server (obbligatoria):

```
bash
# Installa Metrics Server
kubectl apply -f https://github.com/kubernetes-sigs/metrics-server/releases/latest/download/components.
```

```
yaml

# Configurazione per Kind (bypass TLS)
kubectl patch deployment metrics-server -n kube-system --type='json' -p='[
  {
    "op": "add",
    "path": "/spec/template/spec/containers/0/args/-",
    "value": "--kubelet-insecure-tls"
  }
]'

# Verifica funzionamento
kubectl wait --for=condition=ready pod -l k8s-app=metrics-server -n kube-system --timeout=60s
kubectl top nodes
kubectl top pods -n team-backend
```

Con Metrics Server funzionante:

```
bash
kubectl get hpa -n team-backend
# Output: cpu: 45%/60%, memory: 32%/70%# L'HPA può ora scalare automaticamente basandosi su metr
iche reali
```

L'HPA garantisce **scaling automatico** basato su metriche CPU e memoria, adattando la capacità al carico.

Architettura HPA

```
📊 Metrics Server → 📈 HPA Controller → ⚖️ Deployment
    ↓                ↓                ↓
CPU/Memory Usage   Scale Decision    Pod Replicas
Custom Metrics     (Up/Down)         (Min → Max)

🎯 Esempio: CPU >50% = Scale Up | CPU <30% = Scale Down
```

Configurazione HPA

Namespace	Target	Min Replicas	Max Replicas	CPU Threshold	Memory Threshold
team-frontend	react-store	2	5	50%	60%
team-backend	users-api	2	4	60%	70%

Behavior Policies:

- **Scale Up**: Veloce (60s stabilization)
- **Scale Down**: Graduale (300s stabilization)

Esempio Configurazione HPA

```
apiVersion: autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: react-store-hpa
```

```
  namespace: team-frontend
spec:
  scaleTargetRef:
    kind: Deployment
    name: react-store
  minReplicas: 2
  maxReplicas: 5
  metrics:
  - type: Resource
    resource:
      name: cpu
      target:
        type: Utilization
        averageUtilization: 50
```

Pod Disruption Budget (PDB)

I PDB garantiscono **disponibilità continua** durante maintenance e rolling updates.

PDB Strategy

```
Normal State:     [Pod1] [Pod2] [Pod3]
                    ✅     ✅     ✅

During Maintenance: [Pod1] [---] [Pod3]
                    ✅     🔧     ✅

PDB Guarantee: Minimum 1 pod always available
```

PDB Configuration

Service	Min Available	Impact
react-store	1 pod	Zero downtime UX
users-api	1 pod	API sempre disponibile
postgresql	N/A	

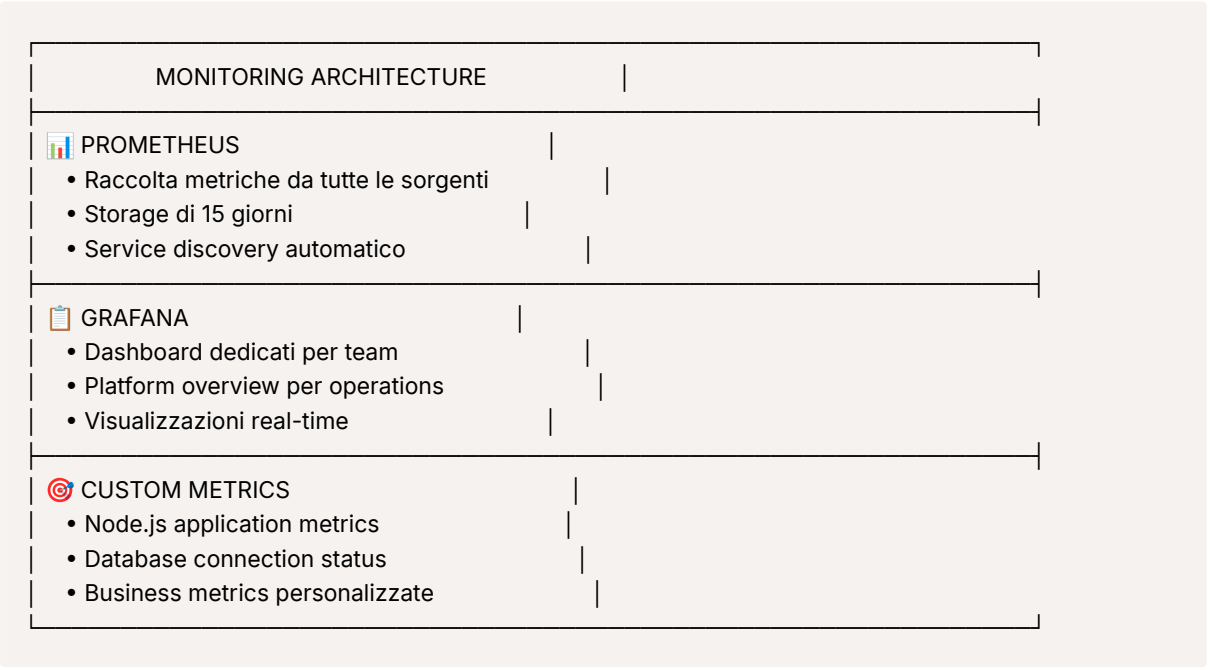
Esempio PDB:

```
apiVersion: policy/v1
kind: PodDisruptionBudget
metadata:
  name: react-store-pdb
  namespace: team-frontend
spec:
  minAvailable: 1
  selector:
    matchLabels:
      app: react-store
```

MONITORING E OBSERVABILITY

Panoramica Stack di Monitoring

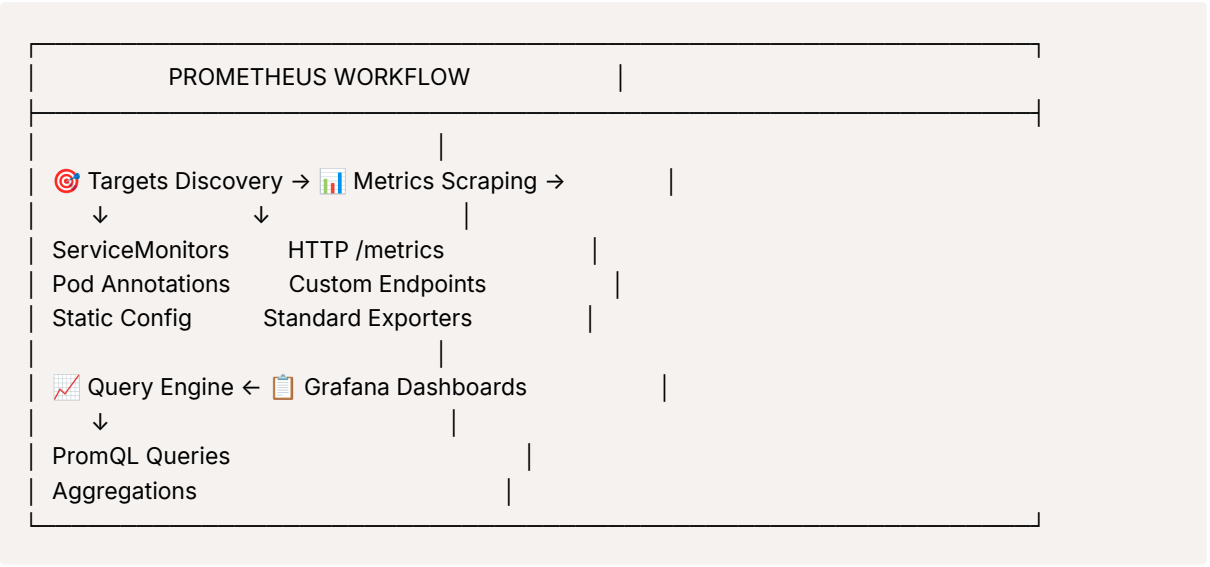
La piattaforma implementa un **sistema di observability completo** per garantire visibilità su performance, utilizzo risorse e health dei servizi:



Prometheus Stack

Prometheus fornisce i mezzi **per la raccolta metriche**.

Architettura Prometheus



Configurazione Stack

Componente	Versione	Namespace	Storage
Prometheus	v2.45+	team-platform	10GB
Grafana	v10.0+	team-platform	Emptydir
Node Exporter	v1.6+	kube-system	N/A
Kube State Metrics	v2.9+	team-platform	N/A

Helm Installation

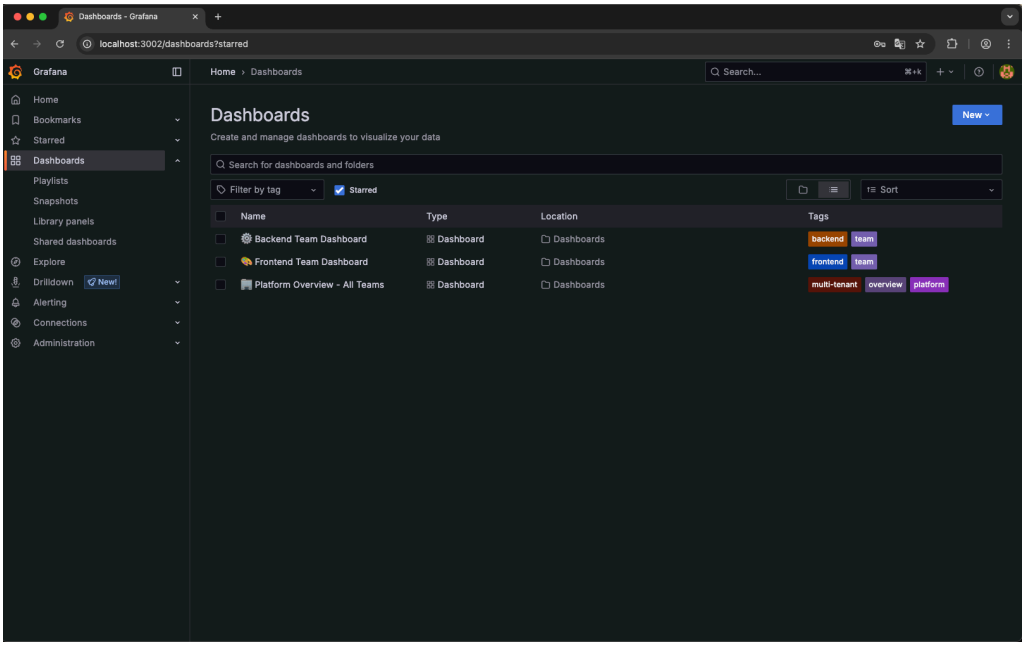
```
# Installazione via Helm con values custom
helm install prometheus prometheus-community/kube-prometheus-stack \
    --namespace team-platform \
    --values prometheus-stack-values.yaml \
    --wait --timeout 10m
```

Configurazione Values Key:

```
prometheus:
  prometheusSpec:
    retention: 15d
    retentionSize: 10GB
    resources:
      requests:
        cpu: 200m
        memory: 512Mi
      limits:
        cpu: 1000m
        memory: 2Gi

grafana:
  adminUser: admin
  adminPassword: admin123
  sidecar:
    dashboards:
      enabled: true
      label: grafana_dashboard
```

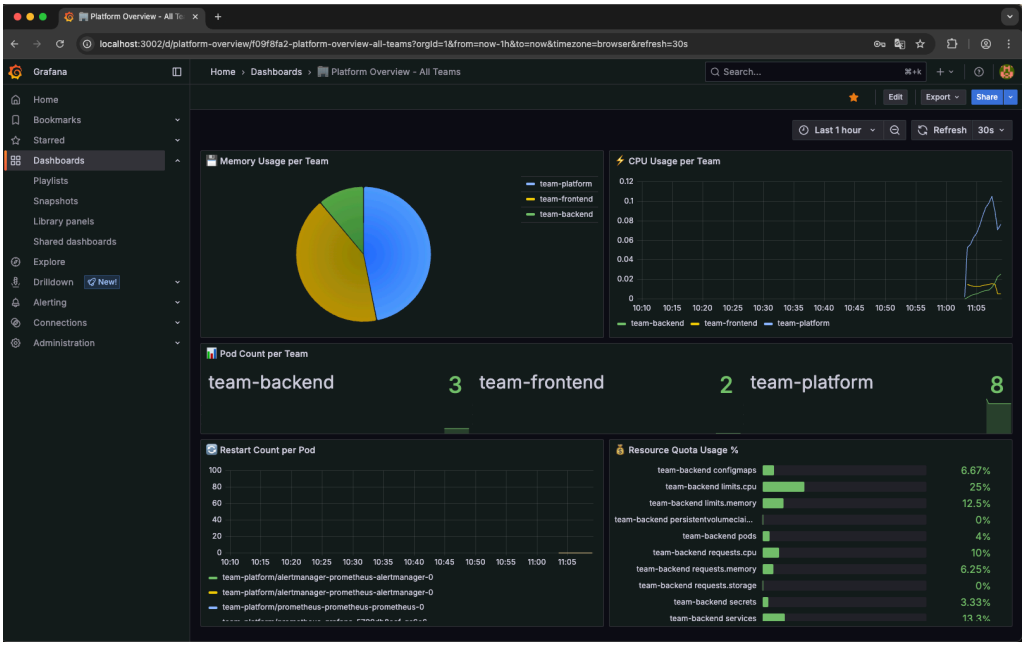
Grafana Dashboards

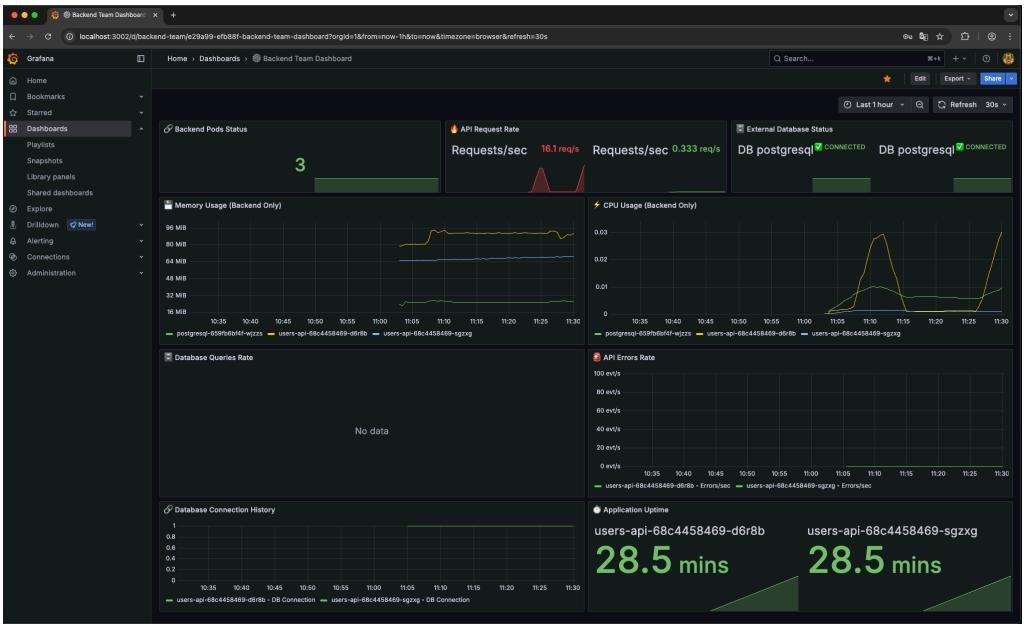
Grafana fornisce **visualizzazioni dedicate** per ogni team e overview platform-wide.



Dashboard Overview

Dashboard	Target Audience	Key Metrics	Update Frequency
Platform Overview	Platform Team, Management	Cross-namespace resources, costs	30s
Frontend Team	Frontend Developers	React performance, UX metrics	30s
Backend Team	Backend Developers	API metrics, DB performance	30s





Dashboard Configuration

```
# ConfigMap per dashboard auto-loading
apiVersion: v1
kind: ConfigMap
metadata:
  name: grafana-platform-dashboards
```

```
  namespace: team-platform
  labels:
    grafana_dashboard: "1"  # Auto-discovery label
data:
  platform-overview.json: |
    {
      "dashboard": {
        "title": "🏢 Platform Overview",
        "panels": [...]
      }
    }
```

Dashboard Deployment:

```
# Auto-discovery tramite sidecar
kubectl create configmap grafana-platform-dashboards \
    --from-file=dashboards/ \
    -n team-platform

kubectl label configmap grafana-platform-dashboards \
    grafana_dashboard=1 -n team-platform
```

Custom Metrics

Le applicazioni espongono **metriche personalizzate** per monitoring approfondito.

Node.js Application Metrics

Il backend Node.js implementa **metriche custom** usando il pattern Prometheus standard:

Metric Name	Type	Description	Labels
`http_requests_total`	Counter	Total HTTP requests	`namespace`, `pod`, `service`
`db_queries_total`	Counter	Database queries executed	`namespace`, `pod`, `database`
`api_errors_total`	Counter	API errors count	`namespace`, `pod`, `service`
`db_connection_status`	Gauge	Database connection health	`namespace`, `pod`, `database`, `host`
`app_uptime_seconds`	Gauge	Application uptime	`namespace`, `pod`, `service`

Metrics Implementation

Metrics Collection nel Codice:

```
// Custom metrics tracking
let metrics = {
  http_requests_total: 0,
  db_queries_total: 0,
  api_errors_total: 0,
  db_connection_status: 1,  // 1=connected, 0=disconnected
  startup_time: Date.now()
};

// Endpoint /metrics per Prometheus
app.get('/metrics', (req, res) => {
  const uptime = Math.floor((Date.now() - metrics.startup_time) / 1000);
```

```
  const prometheusMetrics = `
# HELP http_requests_total Total HTTP requests
# TYPE http_requests_total counter
http_requests_total{namespace="team-backend",pod="${hostname}",service="users-api"} ${metrics.http
_requests_total}

# HELP db_connection_status Database connection status
# TYPE db_connection_status gauge
db_connection_status{namespace="team-backend",pod="${hostname}",database="postgresql"} ${metric
s.db_connection_status}
  `;

  res.set('Content-Type', 'text/plain');
  res.send(prometheusMetrics);
});
```

Service Discovery

Prometheus utilizza **ServiceMonitors** per auto-discovery delle metriche senza configurazione manuale.

ServiceMonitor Architecture

```
┌─────────────────────────────────────────────────────────────┐
│                SERVICE DISCOVERY FLOW                       │
├─────────────────────────────────────────────────────────────┤
│                                                             │
│  📋 ServiceMonitor → 🎯 Service Selector → 📊 Pod Targets   │
│       ↓                    ↓                    ↓          │
│  Label Selector        Kubernetes Service      /metrics     │
│  Prometheus CRD        Port & Path Config      HTTP Scrape  │
│                                                             │
│  🔄 Auto-discovery                                          │
└─────────────────────────────────────────────────────────────┘
```

ServiceMonitor Configuration

Backend API ServiceMonitor:

```
apiVersion: monitoring.coreos.com/v1
kind: ServiceMonitor
metadata:
  name: users-api-metrics
  namespace: team-backend
  labels:
    app: users-api
    team: backend
    release: prometheus  # Required per discovery
spec:
  selector:
    matchLabels:
      app: users-api  # Target service labels
  endpoints:
```

```
  - port: http
    path: /metrics
    interval: 30s
    scrapeTimeout: 10s
```

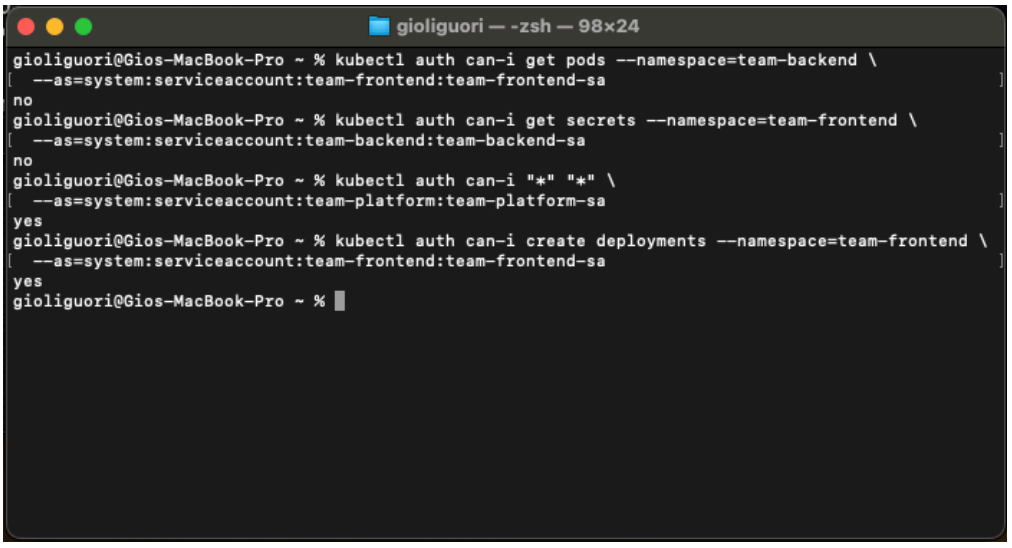
Service con Annotation:

```
apiVersion: v1
kind: Service
metadata:
  name: users-api
  namespace: team-backend
  annotations:
    prometheus.io/scrape: "true"
    prometheus.io/port: "3000"
    prometheus.io/path: "/metrics"
spec:
  ports:
  - port: 3000
    name: http  # Nome importante per ServiceMonitor
  selector:
    app: users-api
```

DEMO

Demo 1: RBAC Isolation

Obiettivo: Dimostrare isolamento completo tra team tramite RBAC



Codice di Riferimento

File: `kubernetes/02-security/rbac.yaml`

```
yaml
apiVersion: rbac.authorization.k8s.io/v1
kind: Role
```

```
metadata:
  name: team-frontend-role
  namespace: team-frontend
rules:
- apiGroups: ["", "apps"]
  resources: ["pods", "services", "deployments"]
  verbs: ["get", "list", "create", "update", "delete"]

---
apiVersion: rbac.authorization.k8s.io/v1
kind: RoleBinding
subjects:
- kind: ServiceAccount
  name: team-frontend-sa
  namespace: team-frontend
roleRef:
  kind: Role
  name: team-frontend-role
```

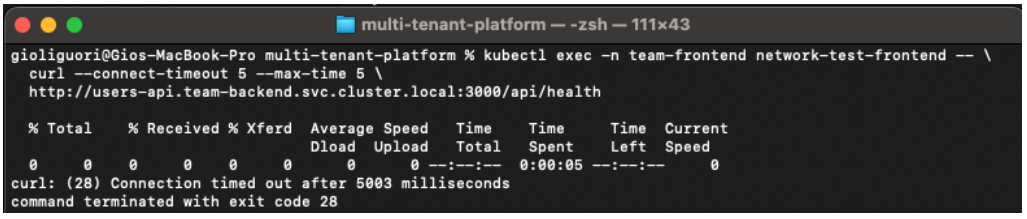
Conclusioni

- **Isolamento perfetto** tra team
- **Platform team** ha accesso cluster-wide
- **Self-service** funziona (team gestiscono proprio namespace)

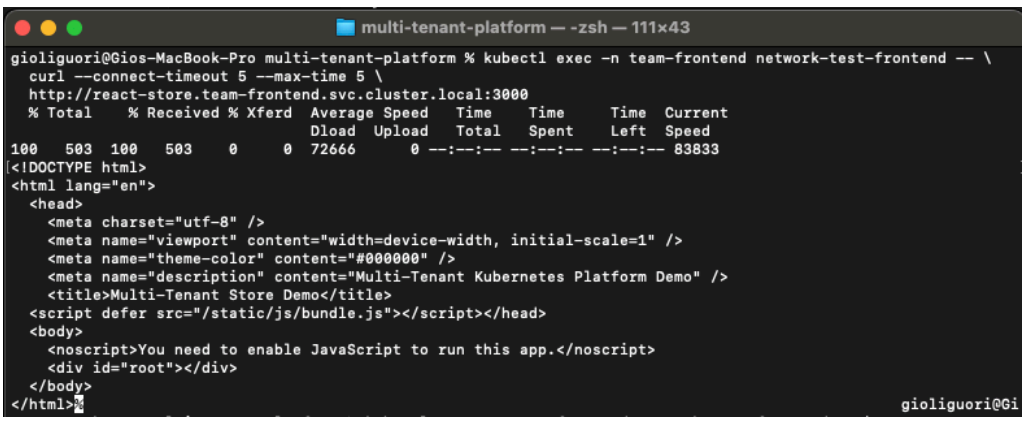
Demo 2: Network Policy Isolation

Obiettivo: Dimostrare isolamento di rete tra namespace

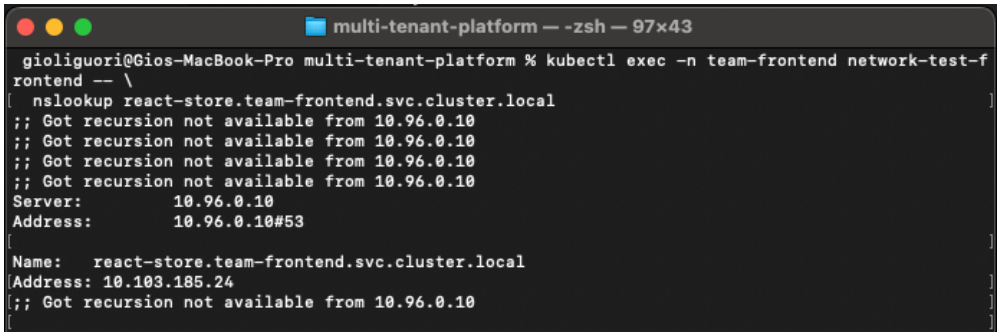
Network Policy blocca accesso cross-namespace



Comunicazione intra-namespace permessa (HTML response ricevuto)



DNS resolution funziona correttamente per servizi autorizzati



Codice di Riferimento File: kubernetes/02-security/network-policies.yaml

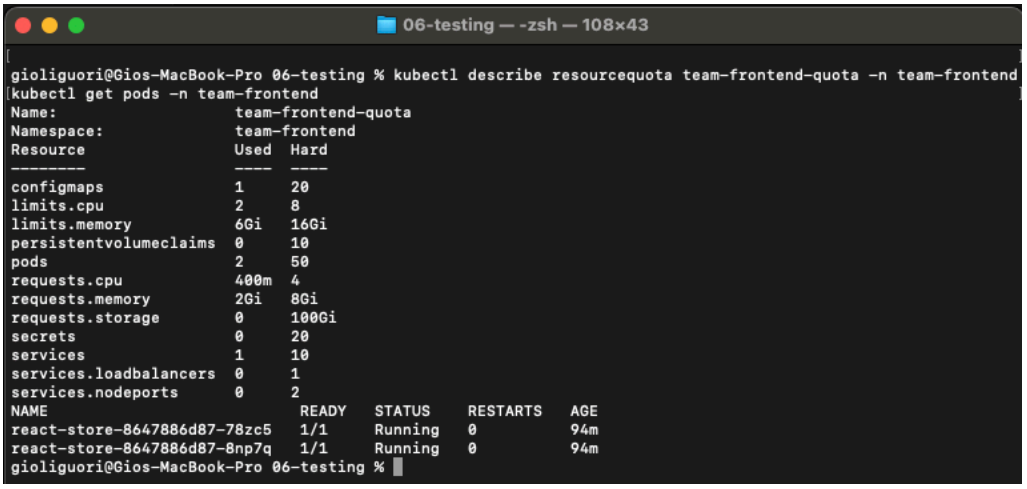
```yaml
# Default Deny All Policy - Security by Design
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: default-deny-all
  namespace: team-frontend
spec:
  podSelector: {}# Tutti i pod del namespace
  policyTypes:
  - Ingress
  - Egress
# Nessuna regola = blocco totale del traffico

---
# Whitelist: Allow Same Namespace Communication
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: allow-same-namespace
  namespace: team-frontend
spec:
  podSelector: {}
  policyTypes:
  - Ingress
  - Egress
  ingress:
  - from:
    - namespaceSelector:
        matchLabels:
          team: frontend# Solo stesso team
  egress:
  - to:
    - namespaceSelector:
        matchLabels:
          team: frontend
```

Conclusioni

- **Network isolation** perfetta: team-frontend ❌ → team-backend
- **Intra-namespace communication** preservata: team-frontend ✅ → team-frontend
- **DNS service discovery** funzionante

Demo 3: Resource Quota Enforcement

Obiettivo: Dimostrare limitazione risorse per namespace

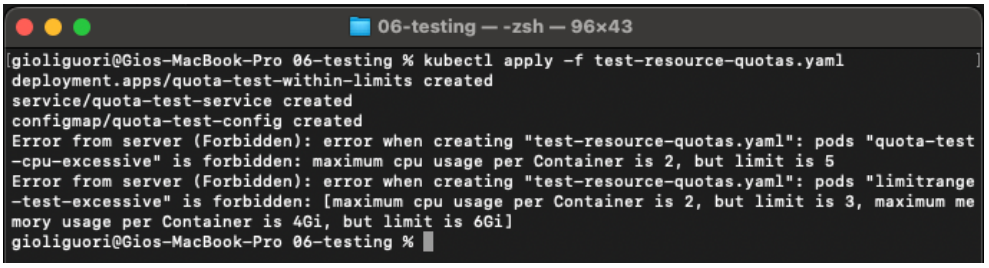


Codice di Riferimento

File: kubernetes/02-security/resource-quotas.yaml

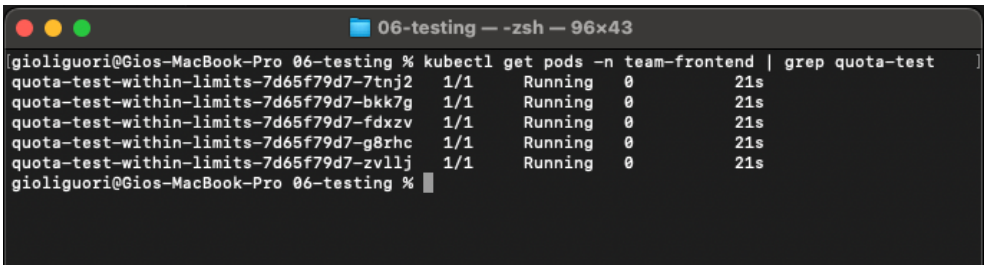
```
yaml
apiVersion: v1
kind: ResourceQuota
metadata:
  name: team-frontend-quota
  namespace: team-frontend
spec:
  hard:
    requests.cpu: "4"
    requests.memory: 8Gi
    limits.cpu: "8"
    limits.memory: 16Gi
    pods: "50"
    services: "10"

---
apiVersion: v1
kind: LimitRange
metadata:
  name: team-frontend-limits
  namespace: team-frontend
spec:
```

```
  limits:
  - max:
      cpu: "2"# Max per container
      memory: 4Gi# Max per container
    type: Container
```



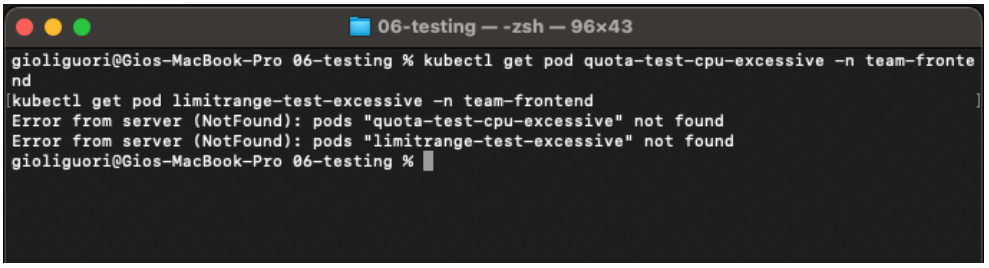
Test 1: Deployment entro limiti

```
yaml
spec:
  replicas: 5 # Entro limite 50 pods
  containers:
  - resources:
      requests:
        cpu: 50m # 5 × 50m = 250m (entro 4 CPU)
        memory: 64M i# 5 × 64Mi = 320Mi (entro 8Gi)
```



Test 2: Pod CPU eccessivo

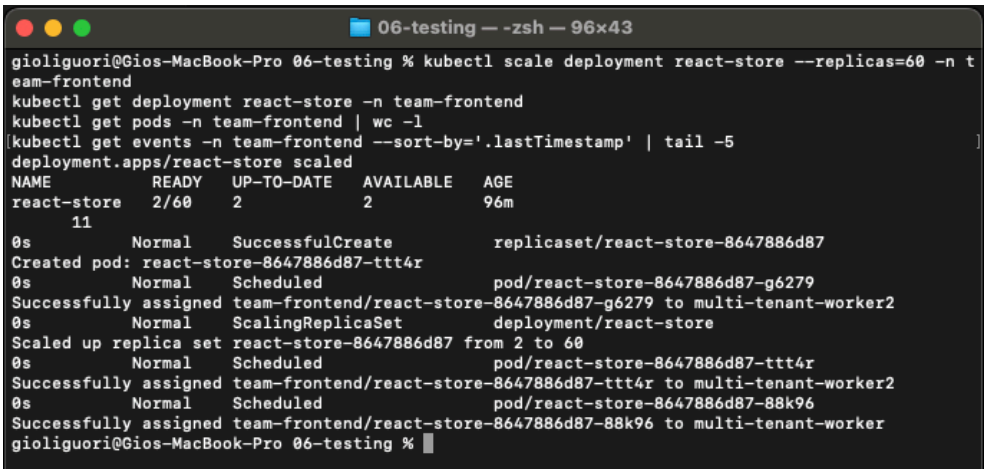
```
yaml
spec:
  containers:
  - resources:
      limits:
        cpu: "5" # VIOLAZIONE: 5 CPU > 2 CPU max LimitRange
```



Test 3: Pod memory eccessivo

```
yaml
spec:
  containers:
  - resources:
      limits:
        memory: 6Gi# VIOLAZIONE: 6Gi > 4Gi max LimitRange
```

Test 4: Scaling oltre quota: Solo 2/60 pod attivi (ResourceQuota enforcement)



Risultati Test:

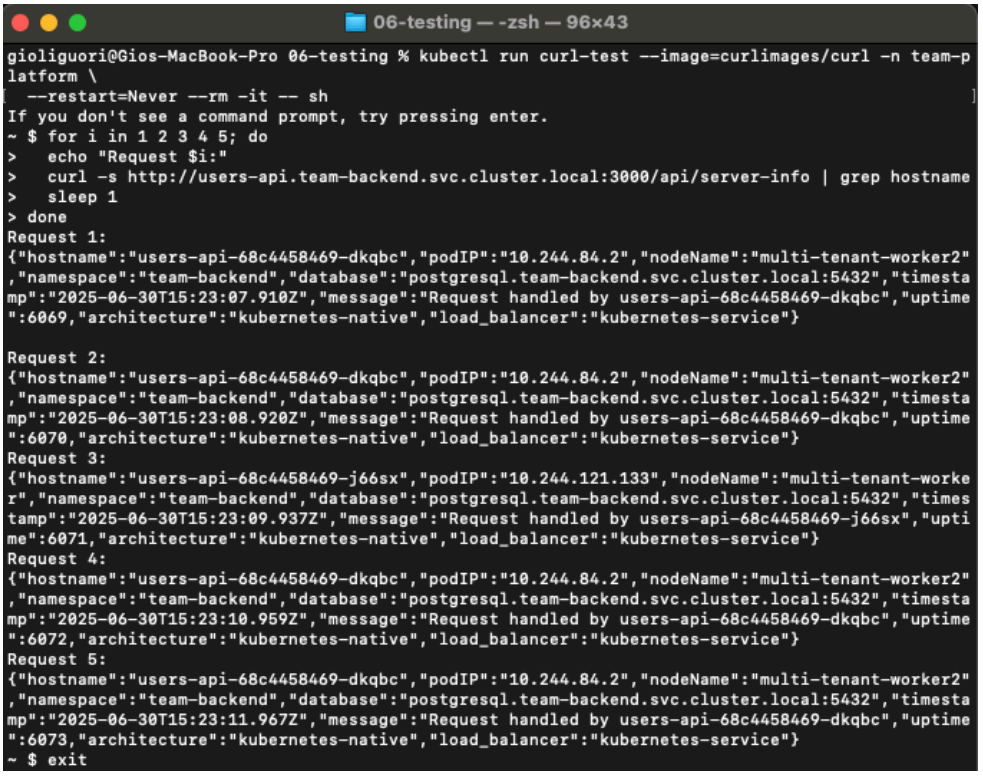
- ✅ **Deployment entro limiti:** 5 pod creati (250m CPU, 320Mi RAM totali)
- ❌ **Pod CPU eccessivo:** Bloccato da LimitRange (5 CPU > 2 CPU max)
- ❌ **Pod memory eccessivo:** Bloccato da LimitRange (6Gi > 4Gi max)

Conclusioni

- **LimitRange**: blocca container con risorse eccessive
- **ResourceQuota**: limita creazione pod oltre limite namespace

Demo 4: Load Balancing tra Pod

Obiettivo: Dimostrare distribuzione carico automatica tra repliche backend all'interno del cluster



Codice di Riferimento

File: kubernetes/03-workloads/backend/users-api-service.yaml

```
yaml
apiVersion: v1
kind: Service
metadata:
  name: users-api
  namespace: team-backend
spec:
  type: ClusterIP
  ports:
  - port: 3000
    targetPort: 3000
    protocol: TCP
    name: http
  selector:
    app: users-api
    team: backend
  sessionAffinity: None # Round-robin load balancing
```

Test interno cluster:

```
bash
# Scale a 3 repliche per demo
kubectl scale deployment users-api --replicas=3 -n team-backend
```

```
# Test load balancing da pod interno
kubectl run curl-test --image=curlimages/curl -n team-platform \
  --restart=Never --rm -it -- sh

for i in 1 2 3 4 5; do
  echo "Request $i:"
  curl -s http://users-api.team-backend.svc.cluster.local:3000/api/server-info | grep hostname
  sleep 1
done
```

Risultati distribuzione:

- **Request 1,2,4,5:** `users-api-68c4458469-dkqbc` (multi-tenant-worker2)
- **Request 3:** `users-api-68c4458469-j66sx` (multi-tenant-worker)

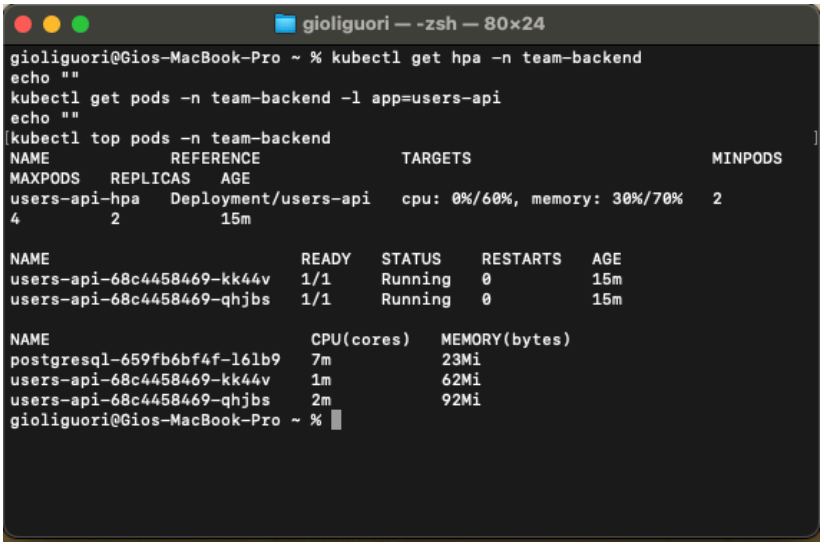
Conclusioni

- **Round-robin distribution** automatica tra pod backend

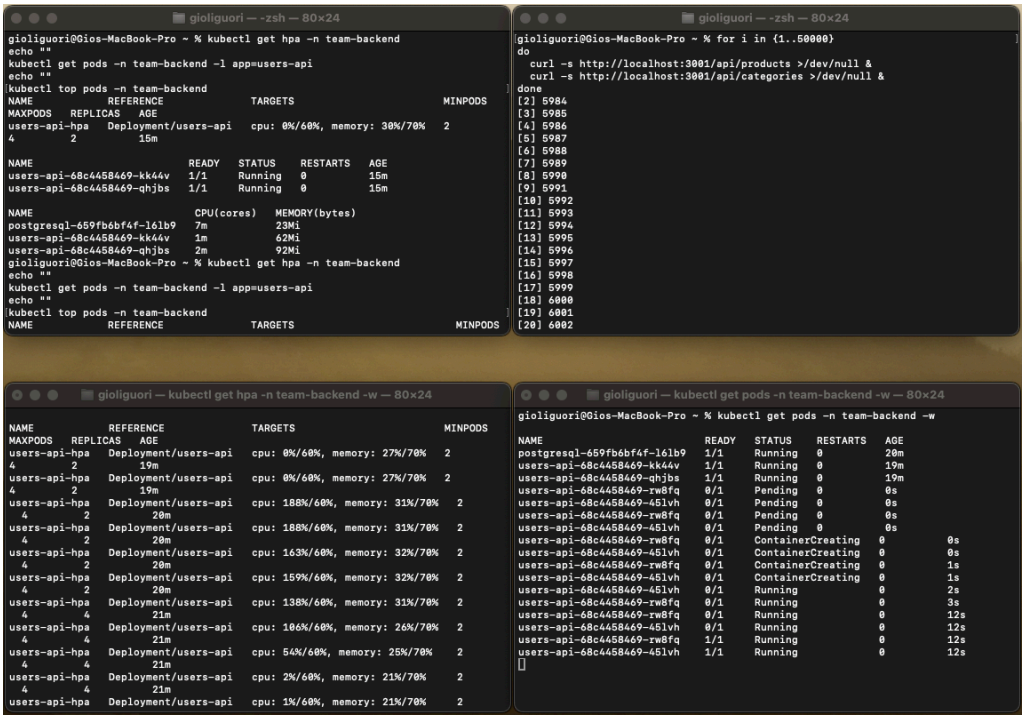
Load balancing funziona solo internamente - il port-forward bypassa il Service connettendosi direttamente a un singolo pod, mentre in produzione si usa Ingress Controller o LoadBalancer per il traffico esterno

Demo 5: HPA Auto-scaling

Obiettivo: Dimostrare scaling automatico basato su metriche CPU per gestione carico enterprise



stato iniziale: HPA configurato, 2 pod attivi, CPU baseline 0%



la CPU ha raggiunto il 188% superando la soglia del 60%. Il sistema di auto-scaling è intervenuto automaticamente, portando i pod da 2 a 4 repliche.

Scale-down automatico: terminato il carico, HPA riduce gradualmente le repliche (4→2) dopo periodo di stabilizzazione

Codice di Riferimento

File: `kubernetes/04-scaling/backend-scaling.yaml`

```
yaml
apiVersion: autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: users-api-hpa
  namespace: team-backend
spec:
  scaleTargetRef:
    apiVersion: apps/v1
    kind: Deployment
    name: users-api
  minReplicas: 2
  maxReplicas: 4
  metrics:
  - type: Resource
```

```
    resource:
      name: cpu
      target:
        type: Utilization
        averageUtilization: 60
  - type: Resource
    resource:
      name: memory
      target:
        type: Utilization
        averageUtilization: 70
  behavior:
    scaleUp:
      stabilizationWindowSeconds: 15
      policies:
      - type: Pods
        value: 2
        periodSeconds: 15
    scaleDown:
      stabilizationWindowSeconds: 30
      policies:
      - type: Pods
        value: 1
        periodSeconds: 15
```

Test auto-scaling:

```
bash
# Verifica HPA status
kubectl get hpa -n team-backend
kubectl describe hpa users-api-hpa -n team-backend

# Load generation intenso
for i in {1..6000}; do
  curl -s http://localhost:3001/api/products >/dev/null &
  curl -s http://localhost:3001/api/categories >/dev/null &
done

# Monitoring real-time
kubectl get hpa -n team-backend -w
kubectl get pods -n team-backend -w
```

Conclusioni

- **Auto-detection** spike CPU (188% > 60% threshold)
- **Automatic scaling** 2→4 pod in <30 secondi
- **Stabilization** con scale-down automatico dopo normalizzazione carico

Pod Disruption Budget

Il PDB garantisce che durante manutenzioni o update rimanga sempre almeno 1 pod attivo.

```
yaml
minAvailable: 1
```

non funziona con port-forward:

Il port-forward si collega direttamente al service. Durante un rolling update, per qualche secondo tutti i pod sono in transizione (vecchio che muore, nuovo che sta partendo) e il service perde la connessione.

CONCLUSIONI

Sviluppi Futuri

L'architettura è stata progettata per essere estendibile. Tra le funzionalità che avrei voluto implementare, ma che non sono riuscito a completare per motivi di tempo, c'è l'integrazione di **ArgoCD** per il GitOps deployment:

L'integrazione con **GitHub Actions** avrebbe permesso di implementare un workflow CI/CD completo:

```
yaml
# .github/workflows/deploy.yml
name: Deploy to Kubernetes
on:
  push:
    branches: [main]
jobs:
  deploy:
    runs-on: ubuntu-latest
    steps:
    - uses: actions/checkout@v3
    - name: Build and Push Docker Image
      run: |
        docker build -t ${{ secrets.REGISTRY }}/app:${{ github.sha }} .
        docker push ${{ secrets.REGISTRY }}/app:${{ github.sha }}
    - name: Update ArgoCD Application
      run: |
        # Trigger ArgoCD sync via webhook o CLI
        argocd app sync backend-apps
```

Altri miglioramenti futuri potrebbero includere:

- **Backup e Disaster Recovery**: Integrazione con Velero per backup automatici

Questo progetto dimostra come Kubernetes, con la giusta architettura e configurazione, possa fornire una piattaforma multi-tenant robusta, sicura e scalabile.