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Stworzenie platformy do modelowania i uruchamiania zamkniętych pętli  
sterowania w Kubernetes

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## **Sworzenie platformy do modelowania i uruchamiania zamkniętych pętli sterowania w Kubernetes**

**Streszczenie.** Projekt opisany w niniejszej pracy skupia się na zaproponowaniu oraz zaimplementowaniu reużywalnej architektury (zwanej dalej "Platformą"), która pozwala na modelowanie oraz uruchamianie zamkniętych pętli sterowania w Kubernetes. Genezą projektu jest praca jednego z komitetów ETSI o nazwie "ENI - Experiential Networked Intelligence", która skupia się na ułatwieniu pracy operatora sieci telekomunikacyjnych wykorzystując mechanizmy sztucznej inteligencji w zamkniętych pętlach sterowania. ENI w jednym ze swoich dokumentów dokonuje przeglądu zamkniętych pętli sterowania znanych ludzkości z innych dziedzin.

Naturalnym następnym krokiem jest zaproponowanie platformy, na której operator mógłby takowe pętle projektować oraz uruchamiać. W tym celu zdefiniowano zestaw wymagań oraz założeń dla takiego systemu. Jako środowisko uruchomieniowe wybrano Kubernetes z racji, że jest to system dobrze znany w społeczności oraz sam natywnie używa zamkniętych pętli sterowania. Następnie przeprowadzono obszerną analizę jak za pomocą mechanizmów rozszerzania Kubernetes takich jak "Custom Resources" oraz "Operator" pattern można stworzyć framework umożliwiający modelowanie zamkniętych pętli sterowania. Praca opisuje powstałą platformę, jej architekturę, semantykę składni w definiowanych obiektach, zasady działania, integracje z zewnętrznymi systemami oraz instrukcję jej użytkowania. Omówiona została również implementacja platformy, technologie za nią stojące oraz decyzje podjęte podczas jej powstawania. Finalnie przedstawiono również test działania platformy w praktyce wykorzystując do tego emulator systemu 5G jakim jest Open5GS w połączeniu z UERANSIM. Pracę podsumuję lista wniosków oraz potencjalnych dróg rozwoju platformy.

**Słowa kluczowe:** Zamknięte pętle sterowania, Kubernetes, Zarządzanie sieciami telekomunikacyjnymi, Automatyzacja, Go, Open5GS, Mikroserwisy

# Creation of a platform for designing and running closed control loops in Kubernetes

**Abstract.** The project described in this thesis focuses on proposing and implementing a reusable architecture (hereafter referred to as "the Platform") that enables the modeling and execution of closed control loops in Kubernetes. The genesis of the project lies in the work of one of the ETSI committees called "ENI - Experiential Networked Intelligence," which aims to simplify the work of telecommunications network operators by leveraging artificial intelligence mechanisms in closed control loops based on metadata-driven and context-aware policies. In one of its documents, ENI reviews closed control loops known to humanity from other fields. A natural next step is to propose a platform on which operators could design and execute such loops.

To achieve this, a set of requirements and assumptions for such a system was defined. Kubernetes was chosen as the runtime environment due to its widespread adoption in the community and its inherent use of closed control loops. An extensive analysis was conducted on how Kubernetes extension mechanisms, such as "Custom Resources" and the "Operator" pattern, could be used to create a framework enabling the modeling of closed control loops.

This thesis describes the developed platform, its architecture, the semantics of syntax in the defined objects, operational principles, integrations with external systems, and a user guide. It also discusses the platform's implementation, the technologies behind it, and the decisions made during its development. Finally, the thesis presents a practical test of the platform's functionality using the Open5GS 5G system emulator in combination with UERANSIM. The work concludes with a list of findings and potential extensions or improvements to the platform.

**Keywords:** Closed Control Loops, Kubernetes, Managing Telco-Networks, Automation, Go, Open5GS, Microservices

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## 1. Praefatio

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**Rysunek 1.1.** Tradycyjne godło Politechniki Warszawskiej

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- Item 1:
  - item 1.1;
  - item 1.2;
- Item 2;
- Item 3.

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1. Item 1:

a) item 1.1;

b) item 1.2:

i. item 1.2.1;

ii. item 1.2.2;

c) item 1.3;

2. Item 2;

3. Item 3.

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**Tabela 1.1.** Przykładowa tabela.

Kolumna 1	Kolumna 2	Liczba
cell1	cell2	60
cell4	cell5	43
cell7	cell8	20,45
Suma <sup>2</sup>		123,45

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<sup>1</sup> Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

<sup>2</sup> Table footnote.



## 2. De Finibus Bonorum et Malorum

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$$E = mc^2$$
$$y = ax^2 + bx + c$$

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$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix} \cdot \begin{bmatrix} 4 \\ 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 4 \\ 10 \\ 18 \end{bmatrix} \quad (2.1)$$

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### 2.1. Critique of Pure Reason

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in

the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

**Tabela 2.1.** Tabela wielostronicowa.

Lp	Treść	Kwota	Wariant opłaty
1	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	111 111,11 zł	WAR1
2	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	22 222,22 zł	WAR1
3	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	33 333,33 zł	WAR1
4	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	444 444,44 zł	WAR1
5	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	55 555,55 zł	WAR1
6	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	66 666,66 zł	WAR1
7	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	777 777,77 zł	WAR1
8	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	8 888,88 zł	WAR1
9	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	999 999,99 zł	WAR1
10	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	111 111,11 zł	WAR2
11	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	22 222,22 zł	WAR2

12	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	33 333,33 zł	WAR2
13	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	444 444,44 zł	WAR2
14	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	55 555,55 zł	WAR2
15	Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.	66 666,66 zł	WAR2
	<b>Suma:</b>	<b>7 777 777,77 zł</b>	

Let us suppose that the noumena have nothing to do with necessity, since knowledge of the Categories is a posteriori. Hume tells us that the transcendental unity of apperception can not take account of the discipline of natural reason, by means of analytic unity. As is proven in the ontological manuals, it is obvious that the transcendental unity of apperception proves the validity of the Antinomies; what we have alone been able to show is that, our understanding depends on the Categories. It remains a mystery why the Ideal stands in need of reason. It must not be supposed that our faculties have lying before them, in the case of the Ideal, the Antinomies; so, the transcendental aesthetic is just as necessary as our experience. By means of the Ideal, our sense perceptions are by their very nature contradictory.

## 2.2. Caegorical Imperative

### 2.2.1. Deontological Ethics

Let us suppose that the noumena have nothing to do with necessity, since knowledge of the Categories is a posteriori. Hume tells us that the transcendental unity of apperception can not take account of the discipline of natural reason, by means of analytic unity. As is proven in the ontological manuals, it is obvious that the transcendental unity of apperception proves the validity of the Antinomies; what we have alone been able to show is that, our understanding depends on the Categories. It remains a mystery why the Ideal stands in need of reason. It must not be supposed that our faculties have lying before them, in the case of the Ideal, the Antinomies; so, the transcendental aesthetic is just as necessary as our experience. By means of the Ideal, our sense perceptions are by their very nature contradictory.

### 2.2.2. Consequentialism – the Ideal of practical reason

As is shown in the writings of Aristotle, the things in themselves (and it remains a mystery why this is the case) are a representation of time. Our concepts have lying before them

the paralogisms of natural reason, but our a posteriori concepts have lying before them the practical employment of our experience. Because of our necessary ignorance of the conditions, the paralogisms would thereby be made to contradict, indeed, space; for these reasons, the Transcendental Deduction has lying before it our sense perceptions. (Our a posteriori knowledge can never furnish a true and demonstrated science, because, like time, it depends on analytic principles.) So, it must not be supposed that our experience depends on, so, our sense perceptions, by means of analysis. Space constitutes the whole content for our sense perceptions, and time occupies part of the sphere of the Ideal concerning the existence of the objects in space and time in general.

### 2.3. Gödel's ontological proof

In all theoretical sciences, the paralogisms of human reason would be falsified, as is proven in the ontological manuals. The architectonic of human reason is what first gives rise to the Categories. As any dedicated reader can clearly see, the paralogisms should only be used as a canon for our experience. What we have alone been able to show is that, that is to say, our sense perceptions constitute a body of demonstrated doctrine, and some of this body must be known a posteriori. Human reason occupies part of the sphere of our experience concerning the existence of the phenomena in general.

Lorem ipsum dolor sit amet, consectetur adipiscing elit [7], [8], [9], [10].

**Założenie 1.**  $[\phi] \Rightarrow [P(\phi); \neg P(\phi)]$

**Aksjomat 1** (Dualność).  $\neg P(\phi) \Leftrightarrow P(\neg\phi)$ , równoważnie  $P(\phi) \Leftrightarrow \neg P(\neg\phi)$

**Aksjomat 2** (Całkowitość).  $(P(\phi) \wedge \forall x: \phi(x) \Rightarrow \psi(x)) \Rightarrow P(\psi)$

**Aksjomat 3** (Absolutność).  $P(\phi) \Rightarrow \Box P(\phi)$

**Definicja 1.**  $G(x) \Leftrightarrow \forall \phi: (P(\phi) \Rightarrow \phi(x))$

**Definicja 2.**  $\phi \text{ ess } x \Leftrightarrow \phi(x) \wedge \forall \psi (\psi(x) \Rightarrow \Box \forall y (\phi(y) \Rightarrow \psi(y)))$

**Aksjomat 4.**  $P(G)$

**Lemat 1.**  $P(\phi) \Rightarrow \Diamond \exists x: \phi(x)$

*Dowód.* Dowód pomijamy, bo jest trywialny :)

□

**Lemat 2.**  $\Diamond \exists x: G(x)$

*Dowód.* Natychmiastowy wniosek z aksjomatu 4 i lematu 1.

□

**Lemat 3.**  $G(x) \Rightarrow G \text{ ess } x$

*Dowód.* Poprzez podstawienie do definicji 2.

□

**Definicja 3.**  $E(x) \Leftrightarrow \forall \phi (\phi \text{ ess } x \Rightarrow \Box \exists x: \phi(x))$

**Aksjomat 5.**  $P(E)$

**Twierdzenie 1.**  $\Box \exists x: G(x)$

*Dowód.* Na podstawie definicji 1, lematu 3 i aksjomatu 5.

□

### 3. Code listings

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**Listing 1.** *Hello world* w HTML

```
1 <html>
2   <head>
3     <title>Hello world!</title>
4   </head>
5   <body>
6     Hello world!
7   </body>
8 </html>
```

Sed feugiat. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Ut pellentesque augue sed urna. Vestibulum diam eros, fringilla et, consectetur eu, nonummy id, sapien. Nullam at lectus. In sagittis ultrices mauris. Curabitur malesuada erat sit amet massa. Fusce blandit. Aliquam erat volutpat. Aliquam euismod. Aenean vel lectus. Nunc imperdiet justo nec dolor.

**Listing 2.** Generowanie sekwencji Collatza w języku C++

```
147 class Collatz {
148   private:
149     unsigned current_val_;
150     void update_val() {
151         if( current_val_ % 2 == 0 )
152             current_val_ /= 2;
153         else
154             current_val_ = current_val_ * 3 + 1;
155     }
156
157   public:
158     explicit Collatz(unsigned initial_value) :
159         current_val_(initial_value) {}
160     void print_sequence() {
161         unsigned i = 1;
162         while( current_val_ > 1 ) {
```

```
163         std::cout
164             << "val_" << i << "_=" << current_val_
165             << std::endl;
166         update_val(); ++i;
167     }
168 }
169 };
170
171 int main() {
172     // prints Collatz sequence, starting from 194375
173     Collatz seq(194375);
174     seq.print_sequence();
175     return 0;
176 }
```

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetur tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

## 4. Summatio

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## Wykaz symboli i skrótów

**EiTI** – Wydział Elektroniki i Technik Informacyjnych

**PW** – Politechnika Warszawska

**WEIRD** – ang. *Western, Educated, Industrialized, Rich and Democratic*

## Spis rysunków

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## Załącznik 1. Nazwa załącznika 1

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# Politechnika Warszawska

**Rysunek 1.1.** Obrazek w załączniku.

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## Załącznik 2. Nazwa załącznika 2

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**Tabela 2.1.** Tabela w załączniku.

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