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Real-world AI-based Systems

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Department of Computer Science and Technology

Agenda

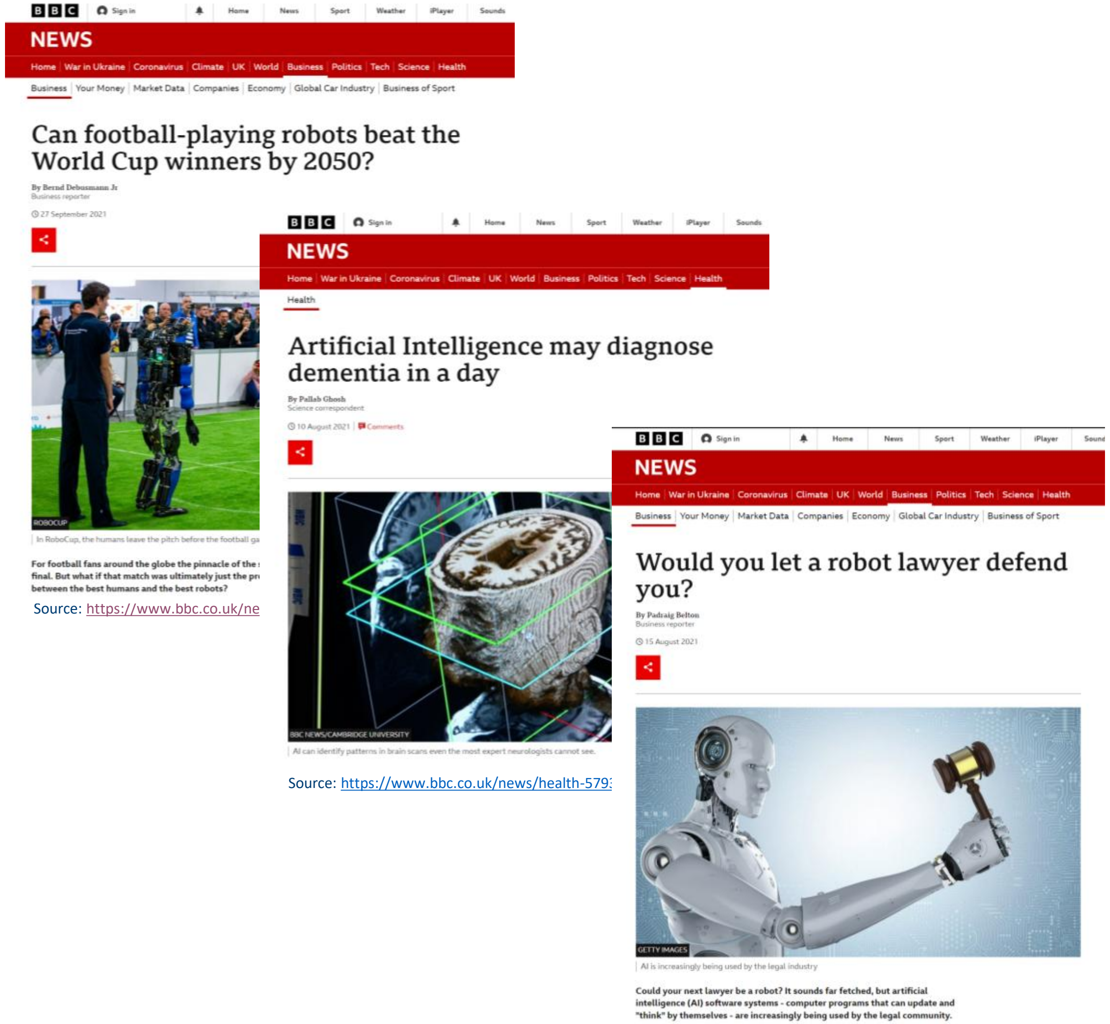
PART I: The great AI question.

PART II: Why the question?

PART III: Possible answers…

PART I: The great AI question.

AI in the news…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27 September 2021

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Source: https://www.bbc.co.uk/ne

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AI can identify patterns in brain scans even the most expert neurologists cannot see.

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Source: https://www.bbc.co.uk/news/business-58158820

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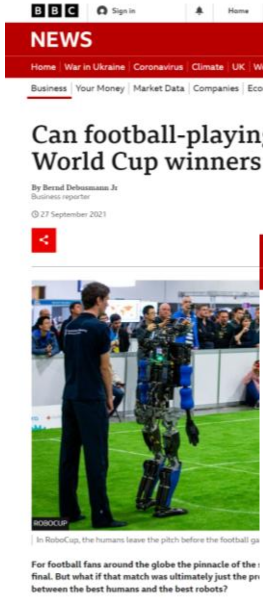
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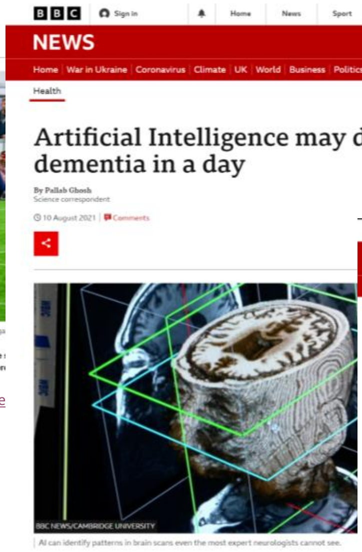
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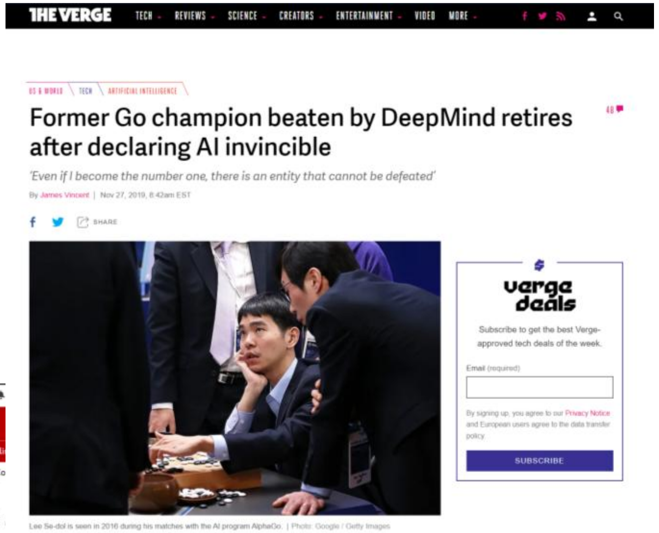
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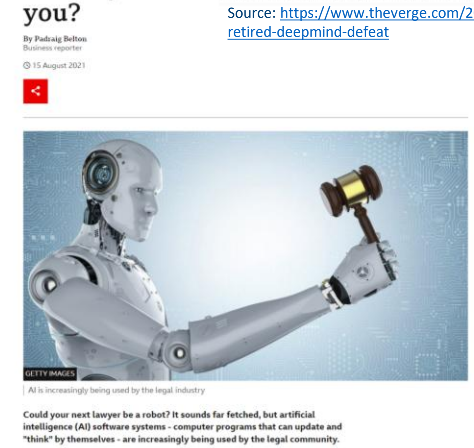
Former Go champion beaten by DeepMind retires after declaring AI invincible

'Even if I become the number one, there is an entity that cannot be defeated'

By James Vincent | Nov 27, 2019, 8:42am EST

Lee Se-dol is seen in 2016 during his matches with the AI program AlphaGo. | Photo: Google / Getty Images

Source: https://www.theverge.com/2019/11/27/20985260/ai-go-alphago-lee-se-dol-retired-deepmind-defeat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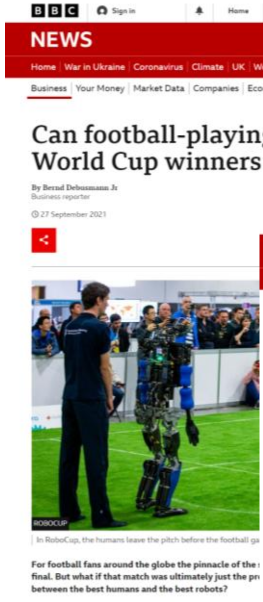

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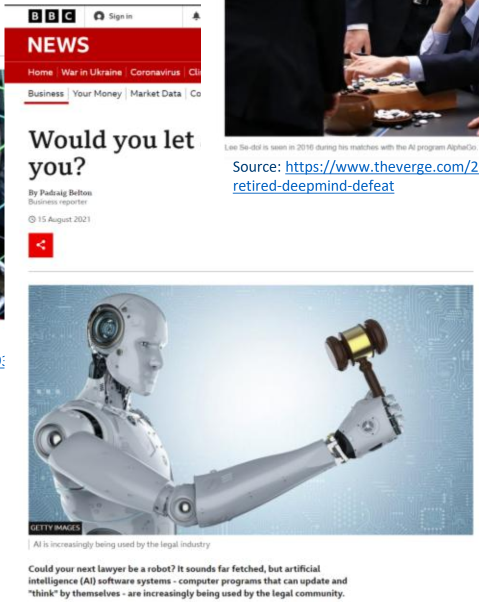

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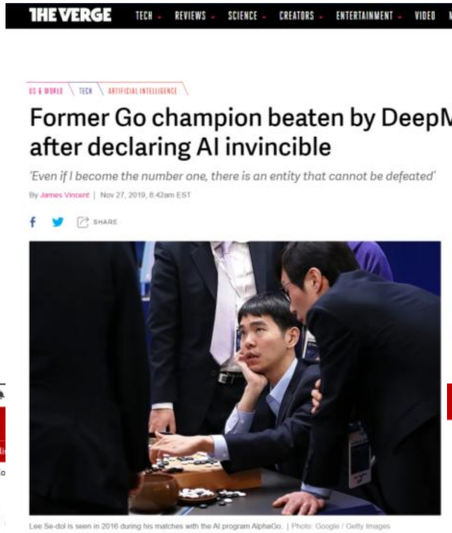

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A FONDO

La inteligencia artificial lo cambiará todo

Escuche el análisis de Juan Carlos Echeverry sobre este tema que se está tomando el mundo.

LA INTELIGENCIA ARTIFICIAL LO CAMBIARÁ TODO

La inteligencia artificial lo cambiará todo

Source: https://caracol.com.co/programa/2019/03/11/6am_hoy_por_hoy/1552309220_833279.html

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Patentan botón para apaga inteligencia artificial en caso rebelión

¿Qué sucedería si las computadoras y los robots se rebelaran contra los seres humanos? Google creó una posible solución a las hipótesis de la ciencia ficción.

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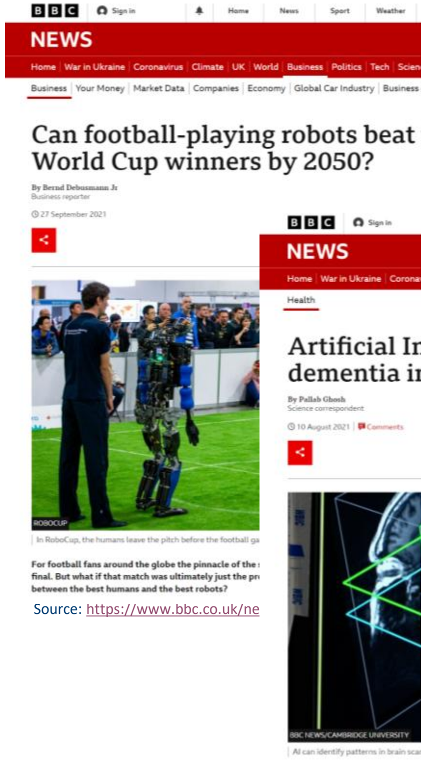
Source: https://caracol.com.co/radio/2016/06/15/tecnologia/1466026084_693727.html

Sounds promising!!!

But…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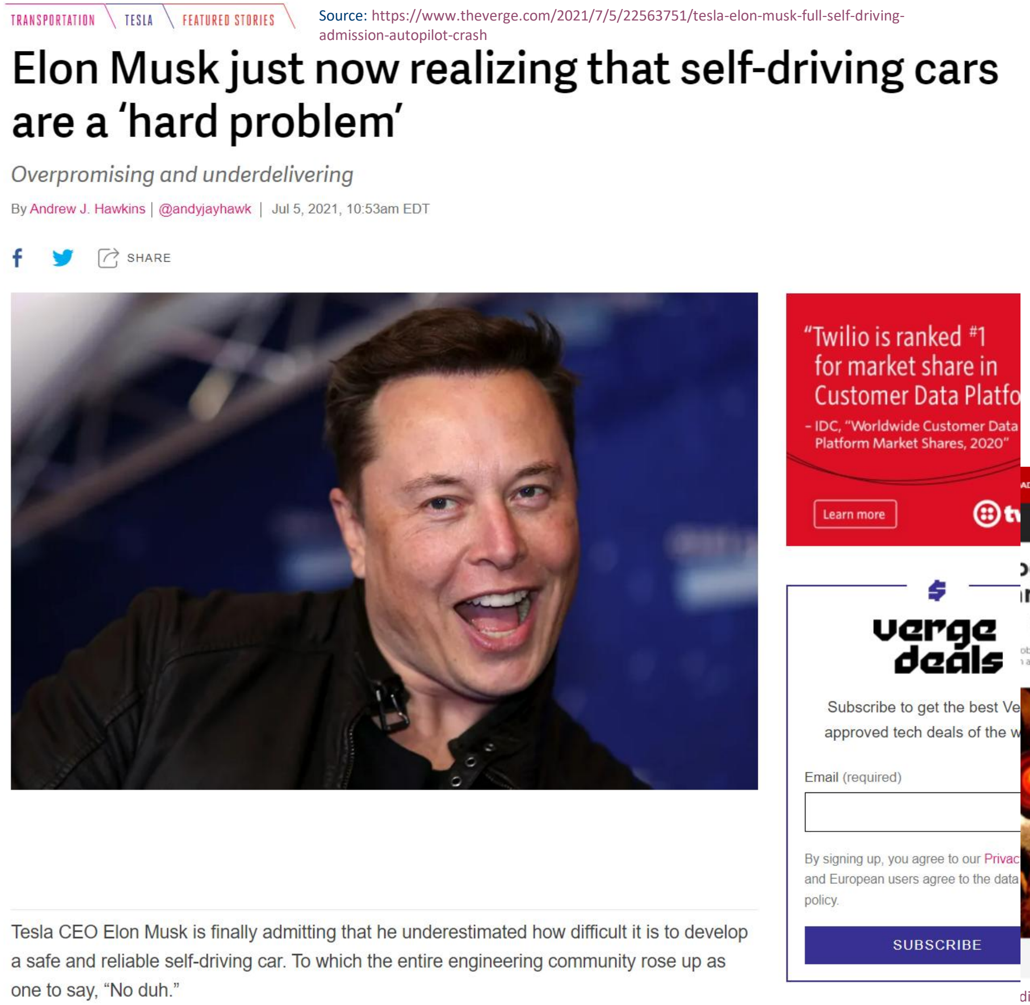

Source: https://www.theverge.com/2021/7/5/22563751/tesla-elon-musk-full-self-driving-admission-autopilot-crash

Elon Musk just now realizing that self-driving cars are a 'hard problem'

Overpromising and underdelivering

By Andrew J. Hawkins | @andyjayhawk | Jul 5, 2021, 10:53am EDT

Tesla CEO Elon Musk is finally admitting that he underestimated how difficult it is to develop a safe and reliable self-driving car. To which the entire engineering community rose up as one to say, "No duh."

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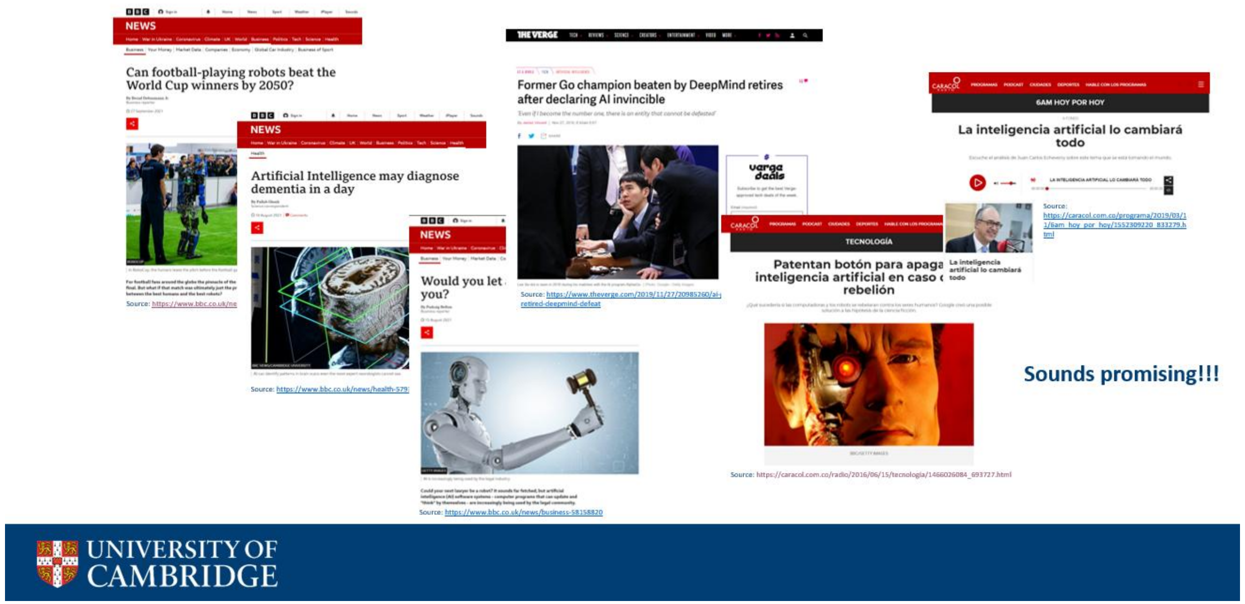
It is far from reality…

The Great AI Fallacy

AI in the news…



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Patentan botón para apaga… inteligencia artificial en caso … rebelión

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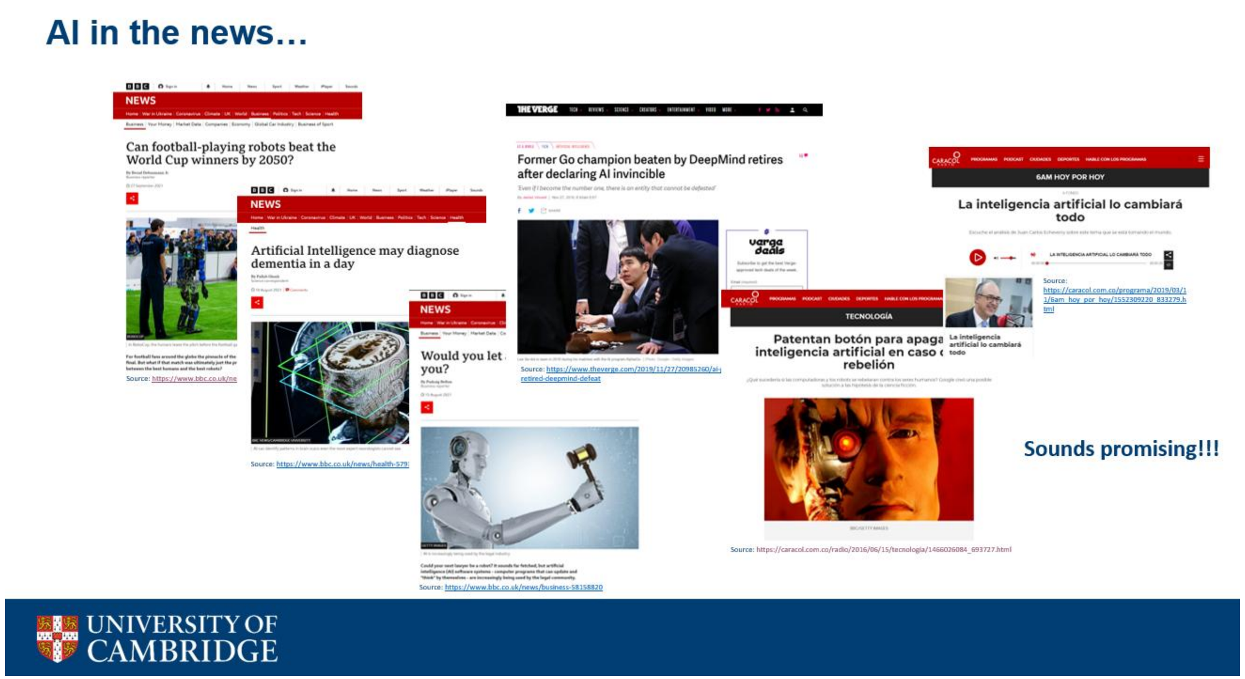
Sounds promising!!!

"The fallacy is associated with an implicit promise that is embedded in many statements about Artificial Intelligence. Artificial Intelligence, as it currently exists, is merely a form of automated decision making. **The implicit promise of Artificial Intelligence** is that it **will be the first wave of automation where the machine adapts to the human**, rather than the human adapting to the machine."[1]

Neil Lawrence
DeepMind Professor
of Machine Learning
at the University
of Cambridge

[1] Lawrence N. "The Great AI Fallacy". Webinar for The Cambridge Network, Apr 2020, Available online: http://inverseprobability.com/talks/notes/the-great-ai-fallacy.html

The Great AI Question



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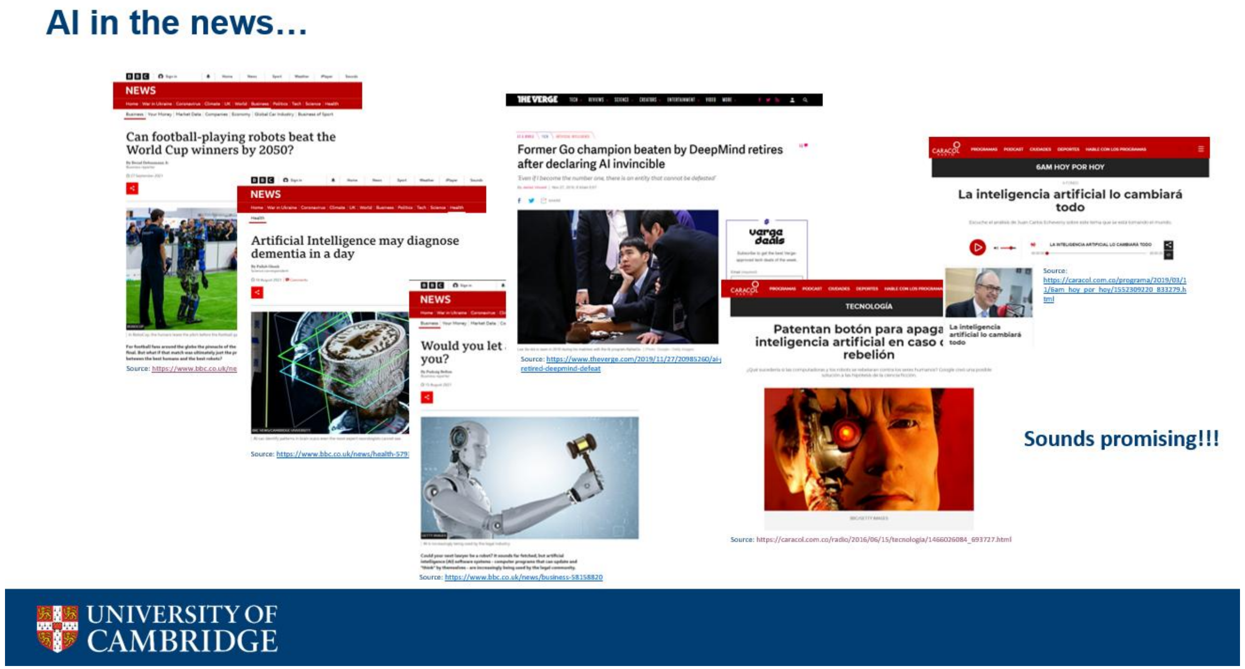

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- **The News focus on impressive headlines.**

- **But they lack scientific rigor:**

    - Problems are not well explained.
    - Assumptions are not considered.
    - Experimental setups are ignored.
    - Limitations are not discussed.

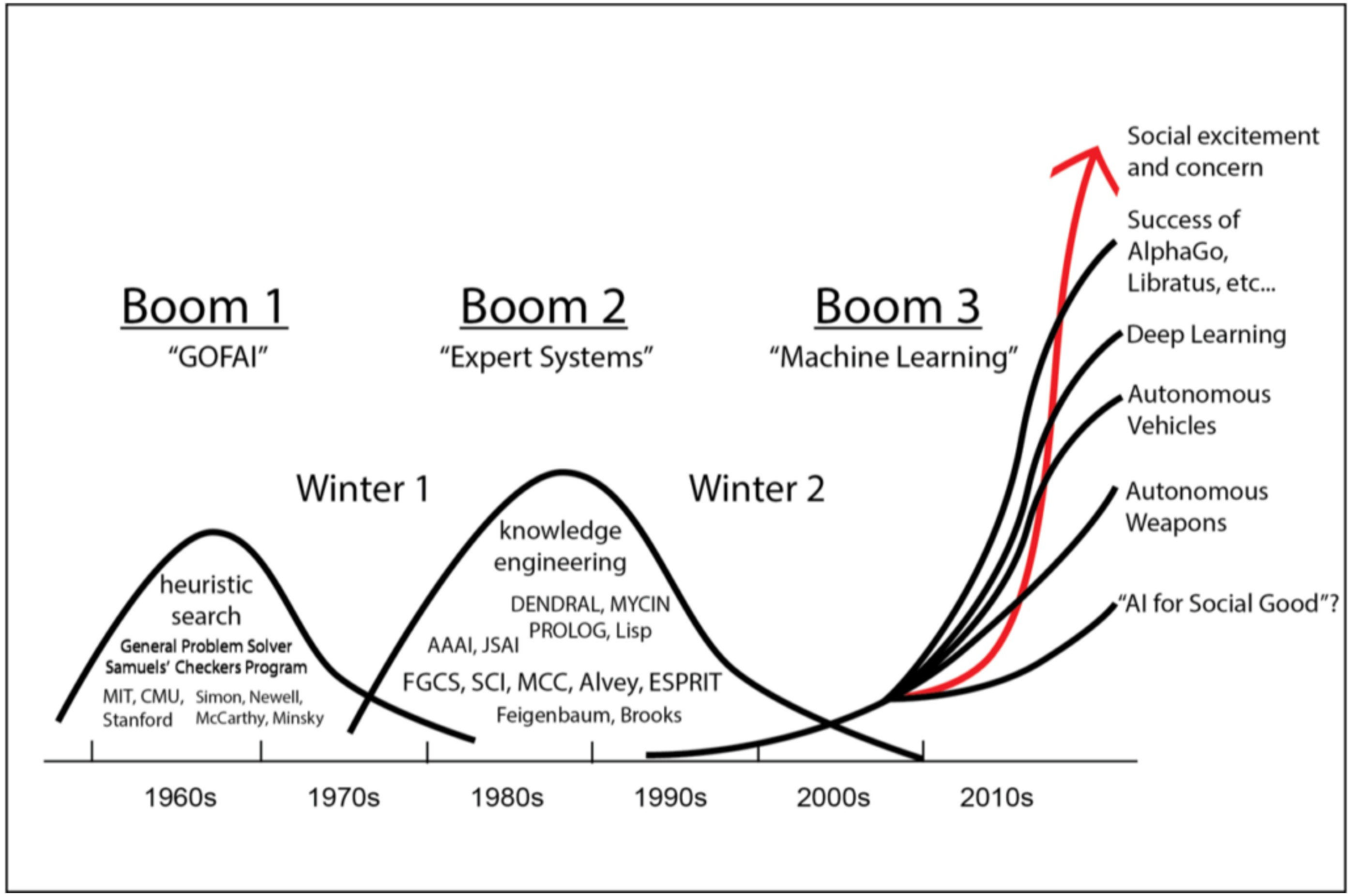
- **Overwhelmed optimism!**

Overwhelmed optimism

- **New technologies usually create this optimism:**
  - There were predictions about Humans conquering other worlds by first decades of 2000s.

- **Then, we have had disappointment periods:**
  - Spatial programs are not as attractive and popular as before.

- **Then, confidence is back again to evaluate actual results:**
  - Global Position System (GPS) is a tool we all use everyday!



Source: https://hackernoon.com/ai-in-medicine-a-beginners-guide-a3b34b1dd5d7

PART II: Why the question?

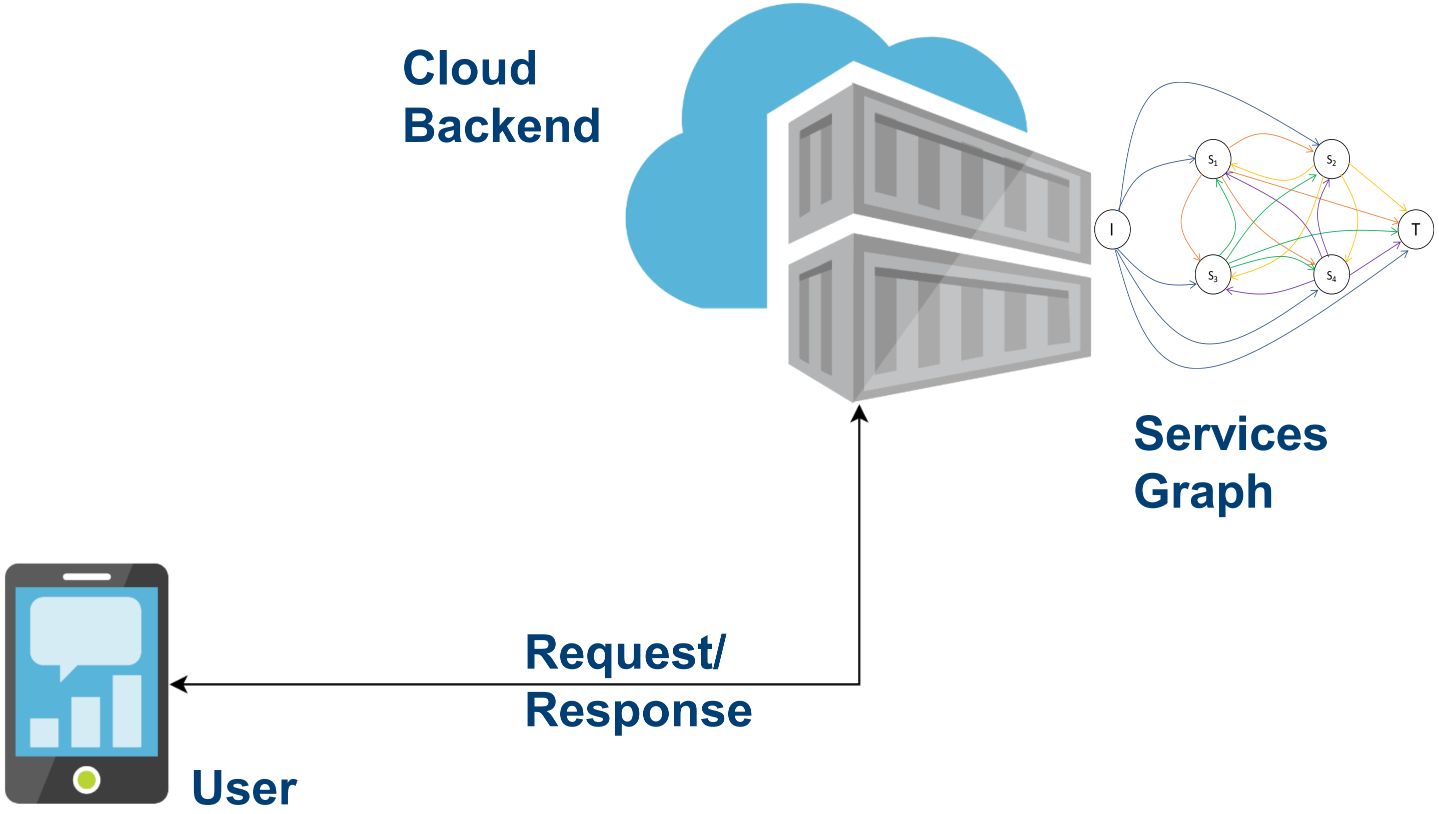
AI Application - Dynamic Service Placement in Edge Computing

- Current applications are **cloud based** and they follow a **Microservices architecture.**

- There is a **physical distance** between users and the cloud, **which generates additional latency**.

- Some applications do not tolerate such latency.

- **Edge computing** is a new paradigm that enables **low-latency applications[1].**



Cloud Backend

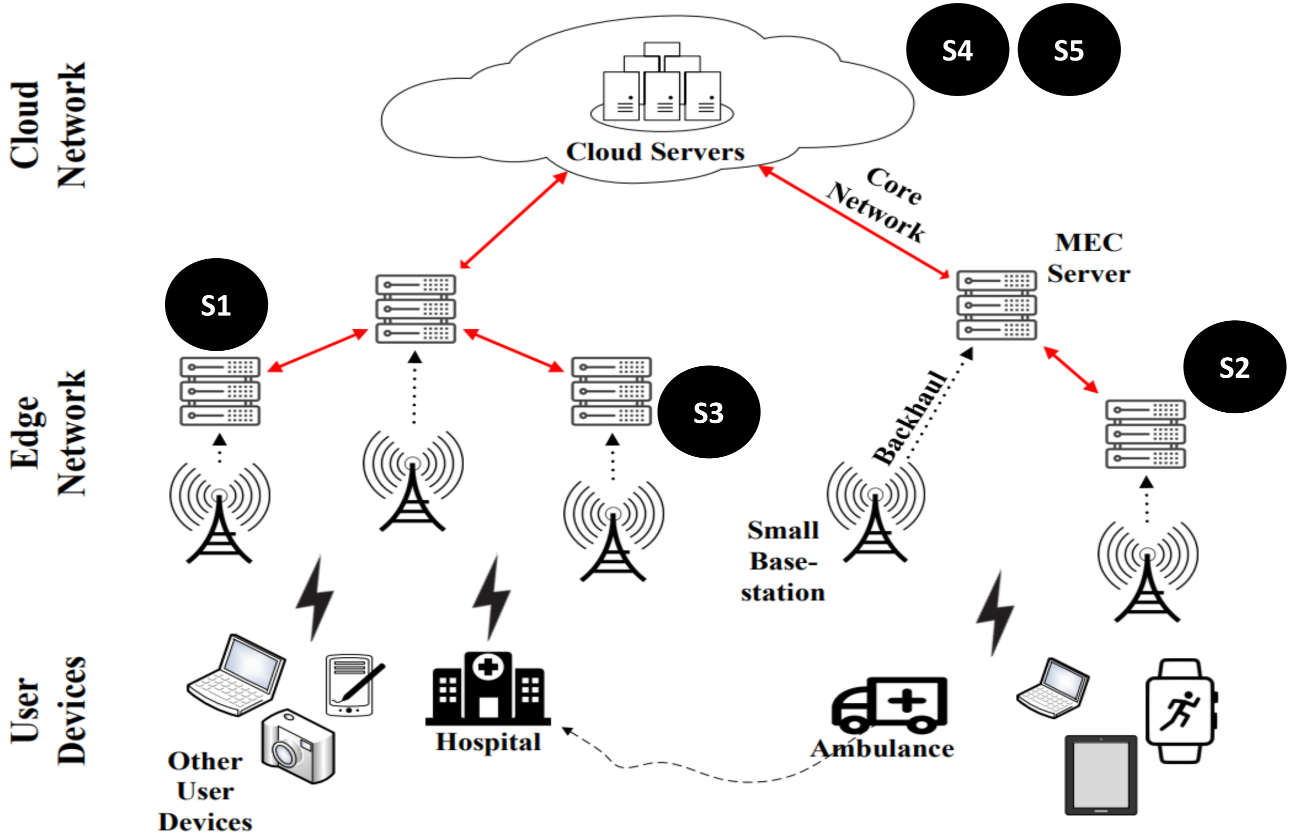
Services Graph

Request/ Response

User

[1] Malazi, H. T., Chaudhry, S. R., Kazmi, A., Palade, A., Cabrera, C., White, G., & Clarke, S. (2022). Dynamic Service Placement in Multi-access Edge Computing: a Systematic Literature Review. *IEEE Access*.

AI Application - Dynamic Service Placement in Edge Computing



- **Edge servers** are closed to end users, and they can **process data locally.**
- Services are executed on edge servers, but they have **limited resources.**
- The problem is to find the **optimal combination** of services and edge servers that **minimizes latency subject to available resources.**
- It is known as **Service Placement Problem[1].**

[1] Malazi, H. T., Chaudhry, S. R., Kazmi, A., Palade, A., Cabrera, C., White, G., & Clarke, S. (2022). Dynamic Service Placement in Multi-access Edge Computing: a Systematic Literature Review. *IEEE Access*.

AI Application - Dynamic Service Placement in Edge Computing

$$\min_{j} \quad wt_j + lat(D_j) \tag{1}$$

$$\min_{i} \sqrt{w_p \sigma(RR^{CPU})^2 + w_m \sigma(RR^{RAM})^2} \tag{2}$$

$$\text{subject to:} \quad \sum_{k=1}^{n} rr_{ik}^{CPU} <= r_i^{CPU} \tag{3}$$

$$\sum_{k=1}^{n} rr_{ik}^{RAM} <= r_i^{RAM} \tag{4}$$

[1] Palade, A., Cabrera, C., White, G., & Clarke, S. (2018, November). Stigmergic service composition and adaptation in mobile environments. In *International Conference on Service-Oriented Computing* (pp. 618-633). Springer, Cham.

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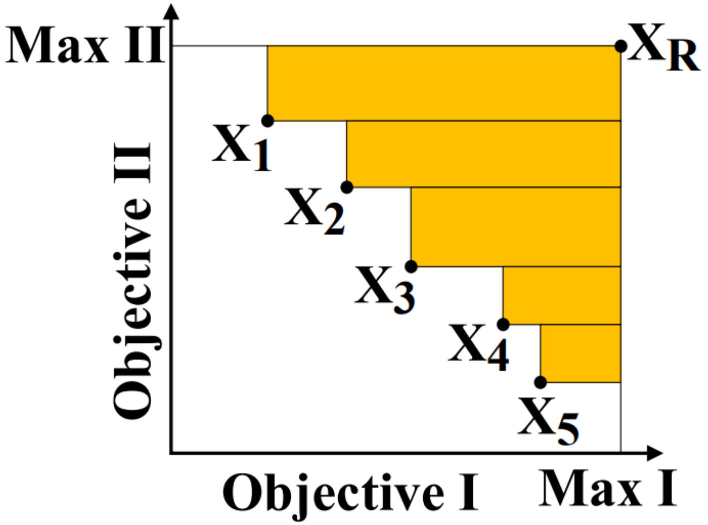
- Pareto-optimal[1]



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- Related work.
  - **Exact algorithms** take too long.
  - **Approximation** and **heuristic** algorithms have problems finding the optimal solution.
  - **Meta-heuristics** are promising solutions for this optimisation problem.
- We explored a **bio-inspired** meta-heuristic [2].
  - Ant colony optimization algorithm.
  - Inspired in how ants find the shortest path to food.
  - **Reinforcement learning.**

[1] Malazi, H. T., Chaudhry, S. R., Kazmi, A., Palade, A., Cabrera, C., White, G., & Clarke, S. (2022). Dynamic Service Placement in Multi-access Edge Computing: a Systematic Literature Review. *IEEE Access*.

[2] Cabrera C., Svorobej, S., Palade, A., Kazmi, A., & Clarke, S. (2022). MAACO: A Dynamic Service Placement Model for Smart Cities. *IEEE Transactions on Services Computing*.

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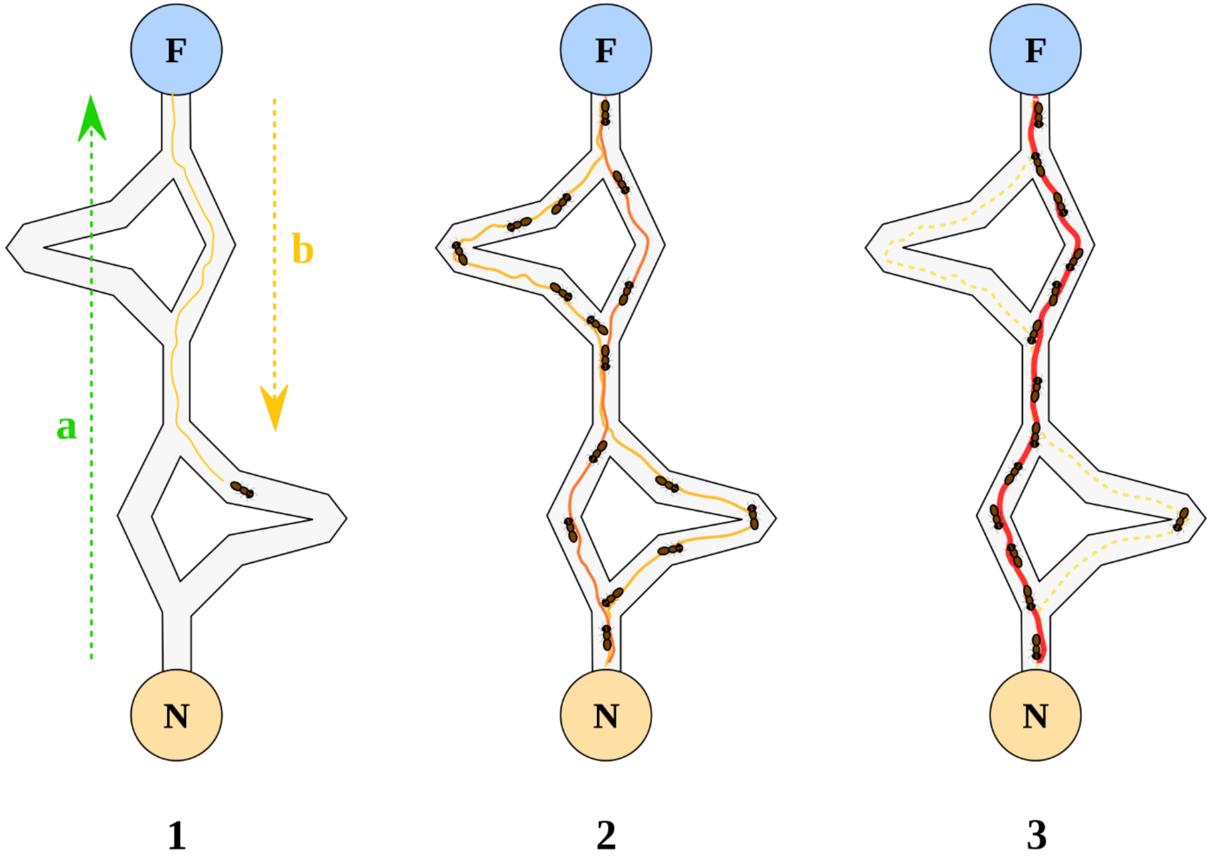
- Ant-Colony Optimisation



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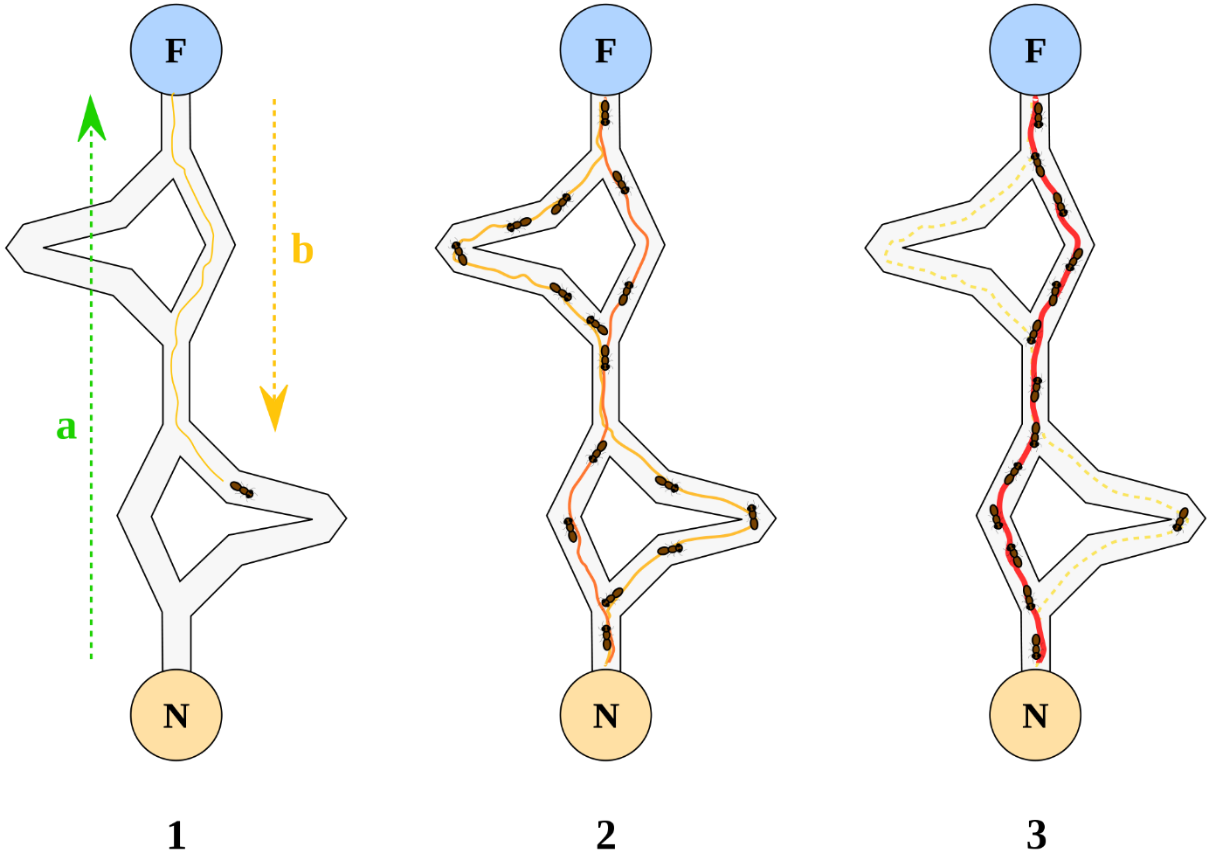

Forward movement:

$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$

Backward movement:

$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

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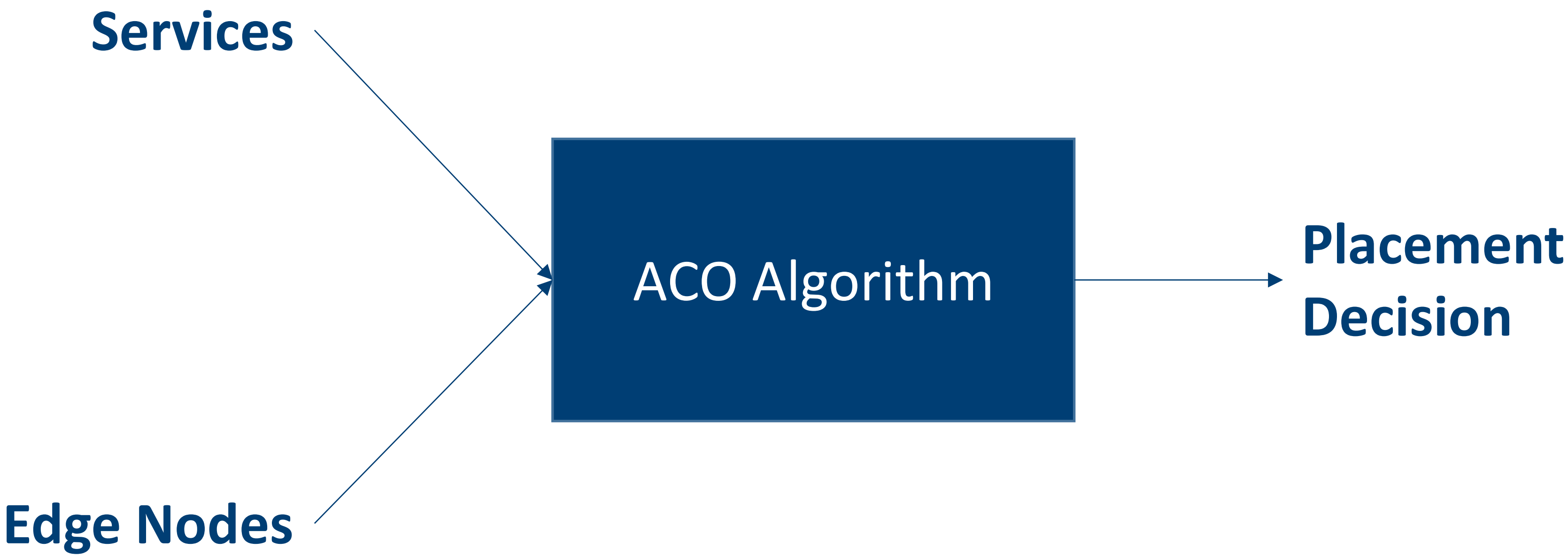


Services

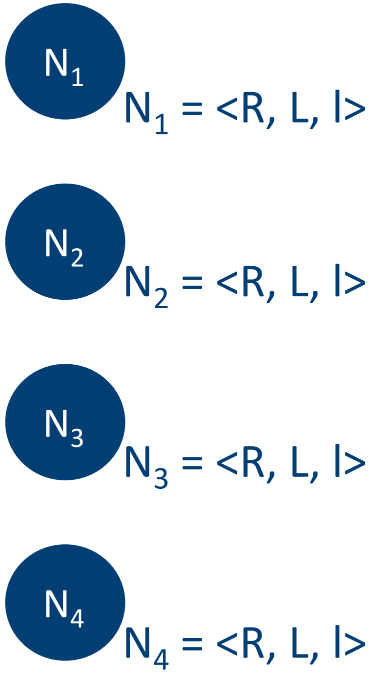
Edge Nodes

ACO Algorithm

Placement Decision

AI Application - Dynamic Service Placement in Edge Computing

App_1=<S, RQ, l, p>
App_2=<S, RQ, l, p>
…
App_n=<S, RQ, l, p>



N_1 = <R, L, l>

N_2 = <R, L, l>

N_3 = <R, L, l>

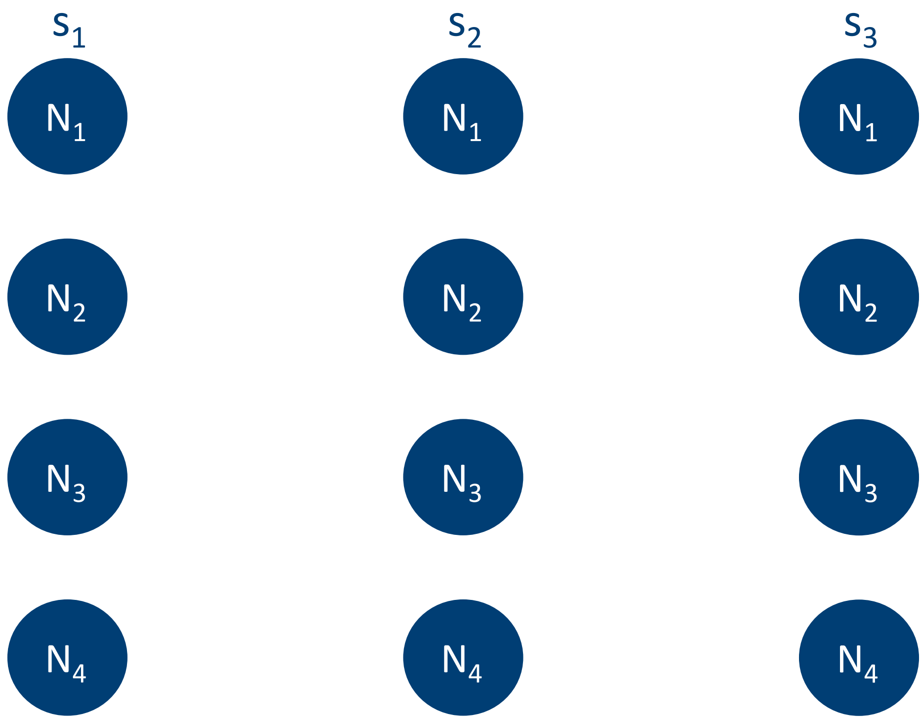
N_4 = <R, L, l>

AI Application - Dynamic Service Placement in Edge Computing

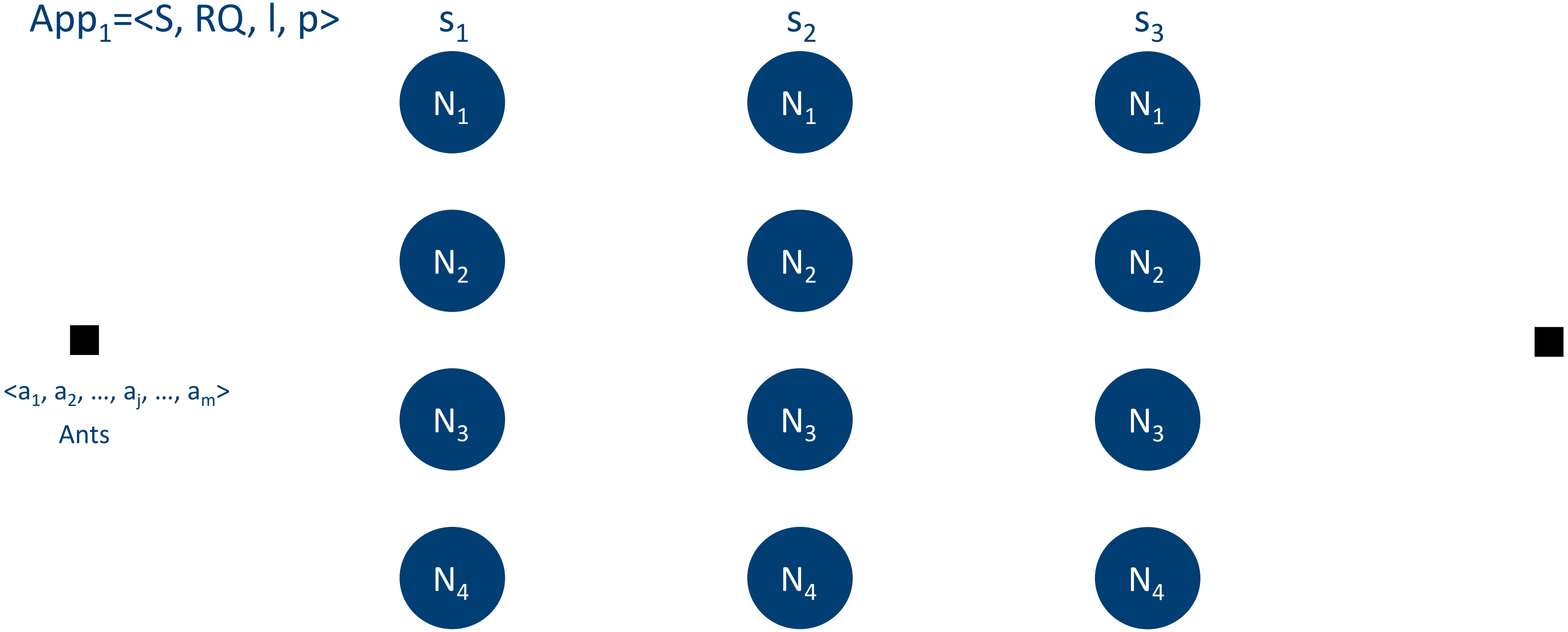
App$_1$=<S, RQ, l, p>

S=<s_1, s_2, s_3>

RQ=<R_{f1}, R_{f2}, Rf_{f3}>



AI Application - Dynamic Service Placement in Edge Computing



App_1=<S, RQ, l, p>

s_1 s_2 s_3

N_1 N_1 N_1

N_2 N_2 N_2

N_3 N_3 N_3

N_4 N_4 N_4

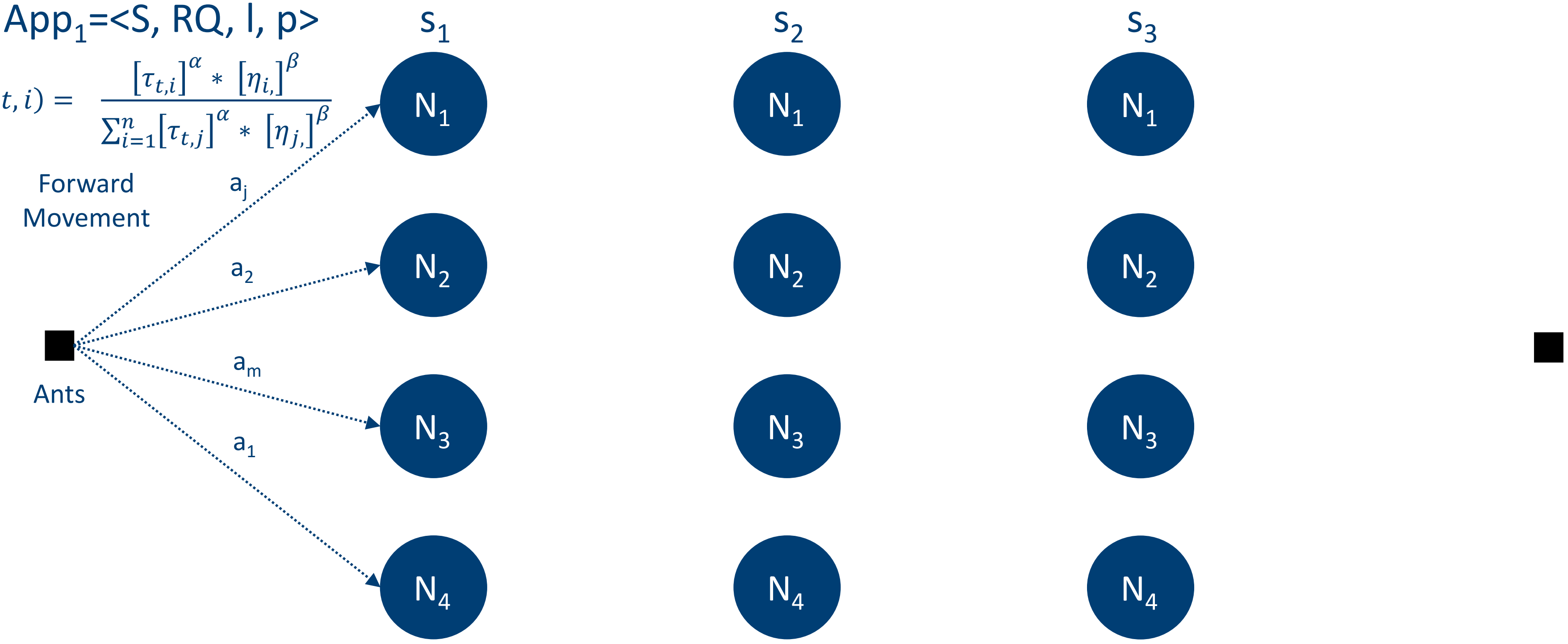
<a_1, a_2, …, a_j, …, a_m>

Ants

AI Application - Dynamic Service Placement in Edge Computing

App$_1$=<S, RQ, l, p>

$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$



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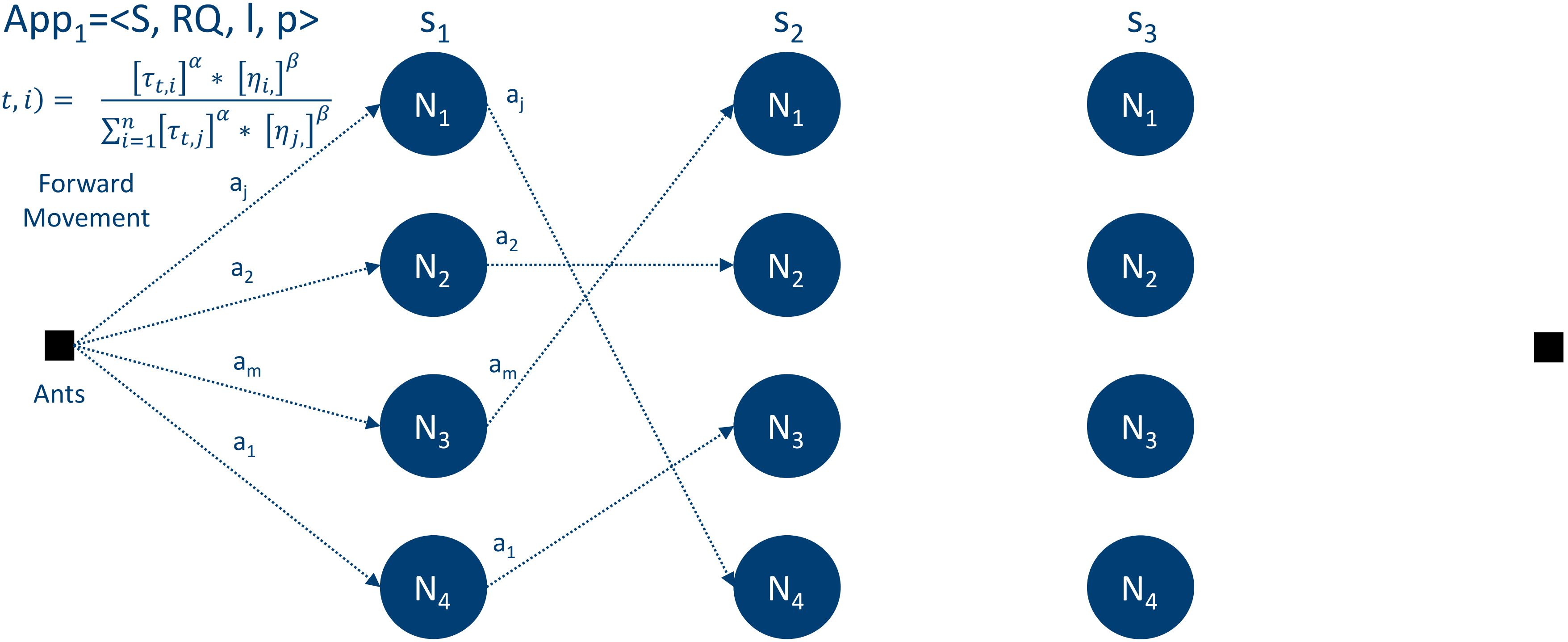

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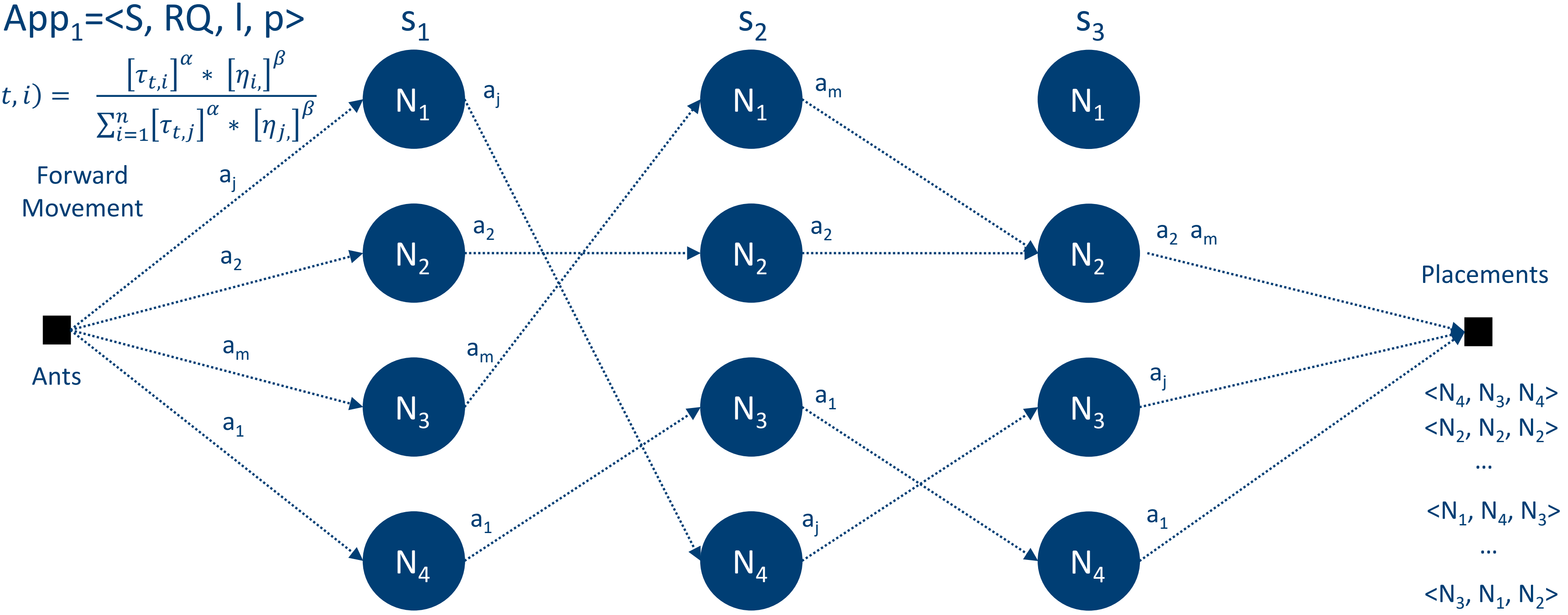

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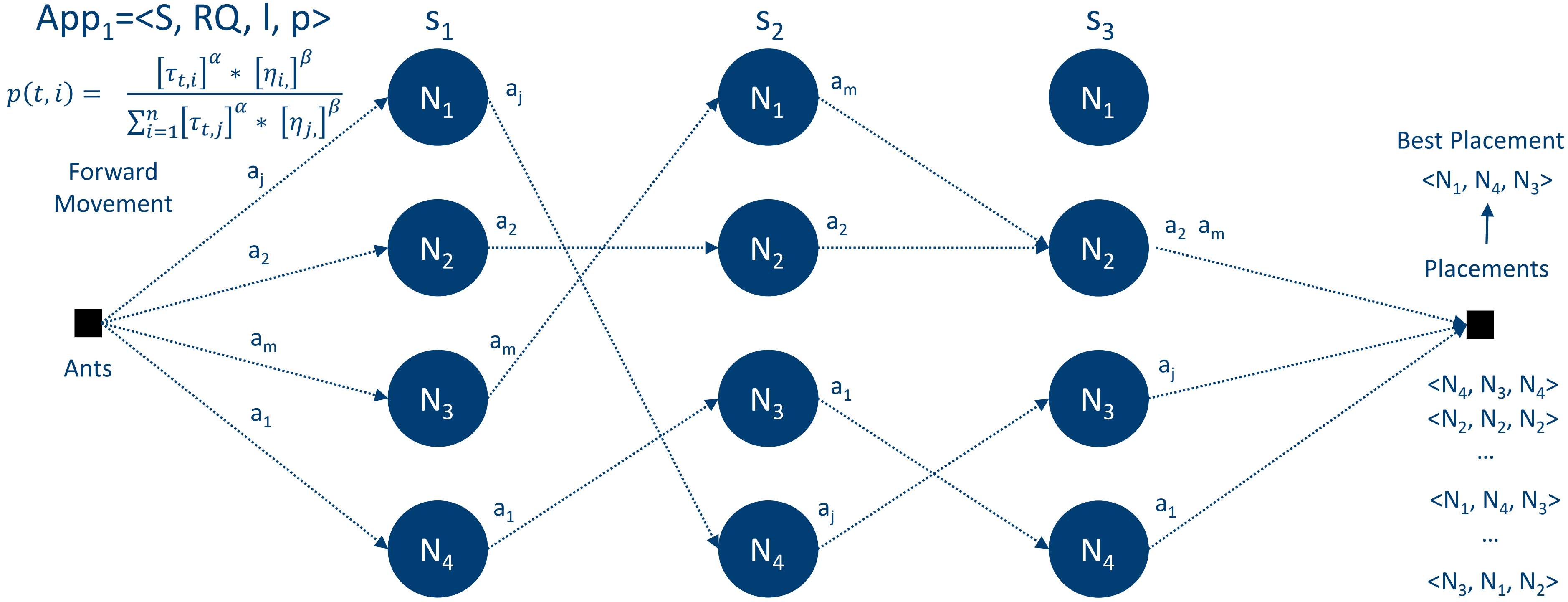

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$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$

Best Placement

<N$_1$, N$_4$, N$_3$>

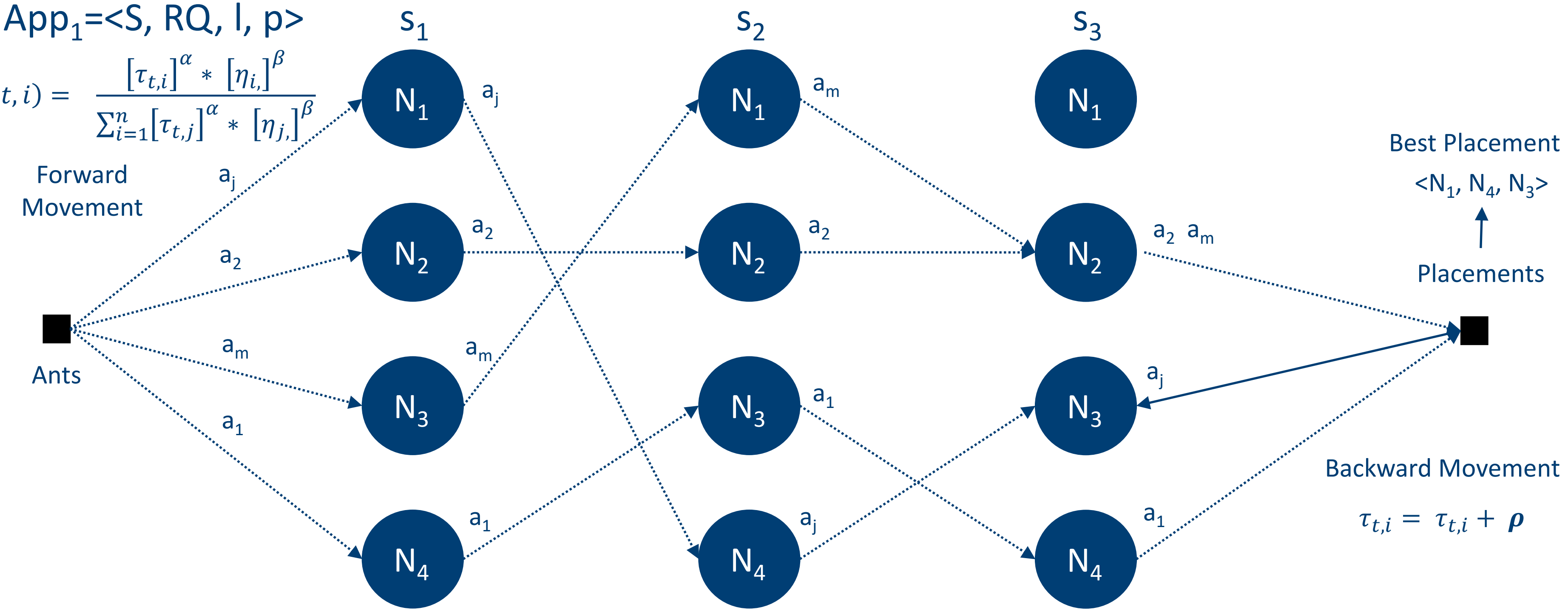
Placements

<N$_4$, N$_3$, N$_4$>
<N$_2$, N$_2$, N$_2$>
…
<N$_1$, N$_4$, N$_3$>
…
<N$_3$, N$_1$, N$_2$>

AI Application - Dynamic Service Placement in Edge Computing

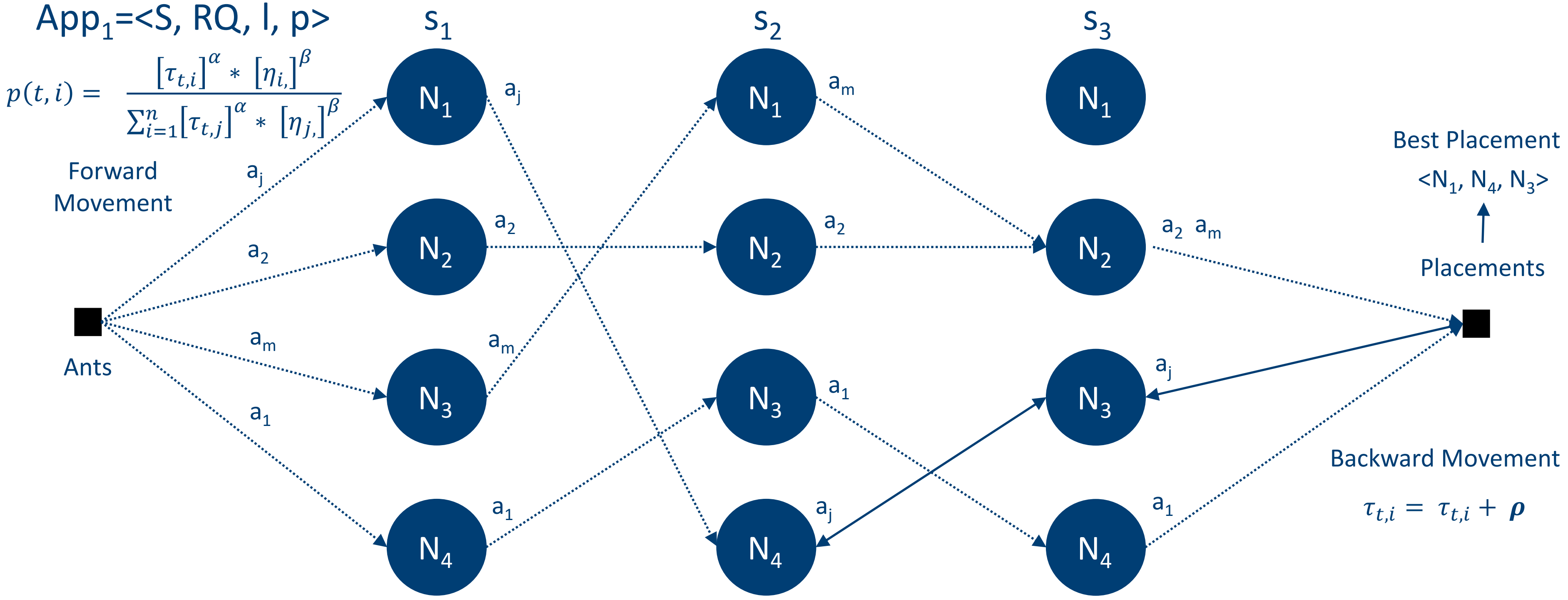
App$_1$=<S, RQ, l, p>

$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$



$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

AI Application - Dynamic Service Placement in Edge Computing



App$_1$=<S, RQ, l, p>

$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$

Forward Movement

Ants

Best Placement

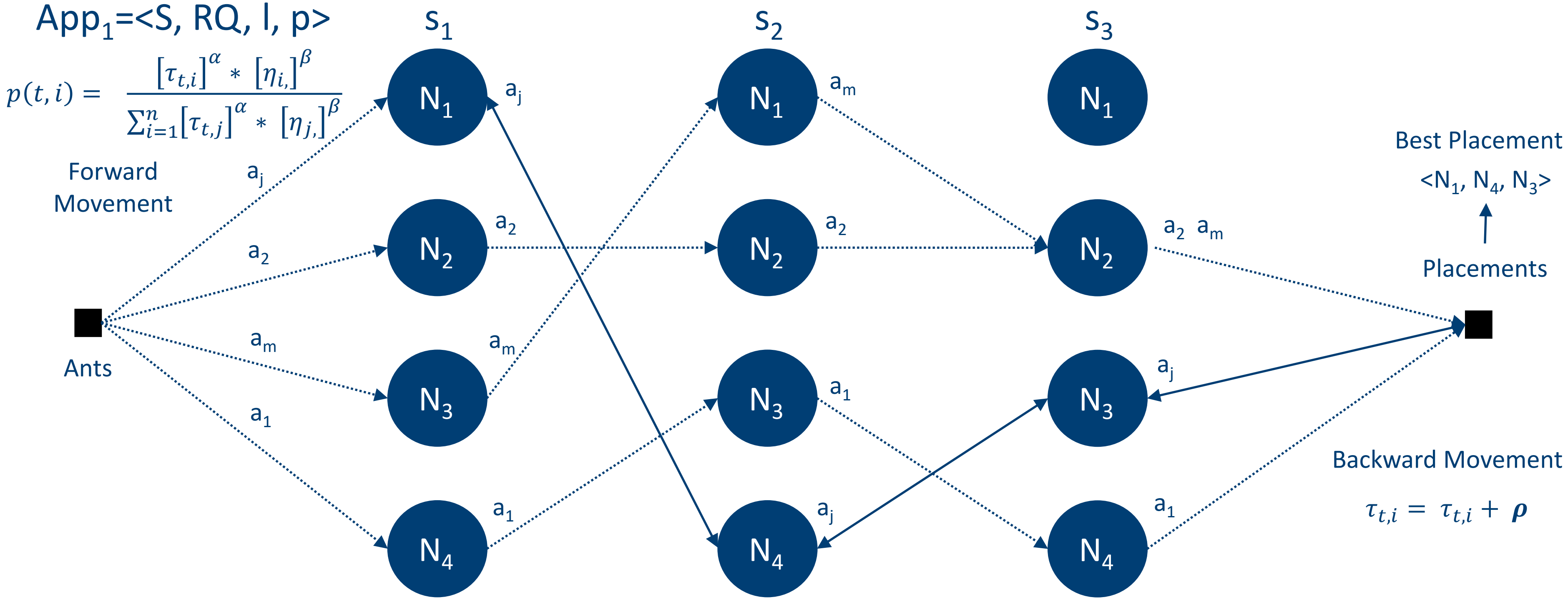
<N$_1$, N$_4$, N$_3$>

Placements

Backward Movement

$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

AI Application - Dynamic Service Placement in Edge Computing



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Forward Movement

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Placements

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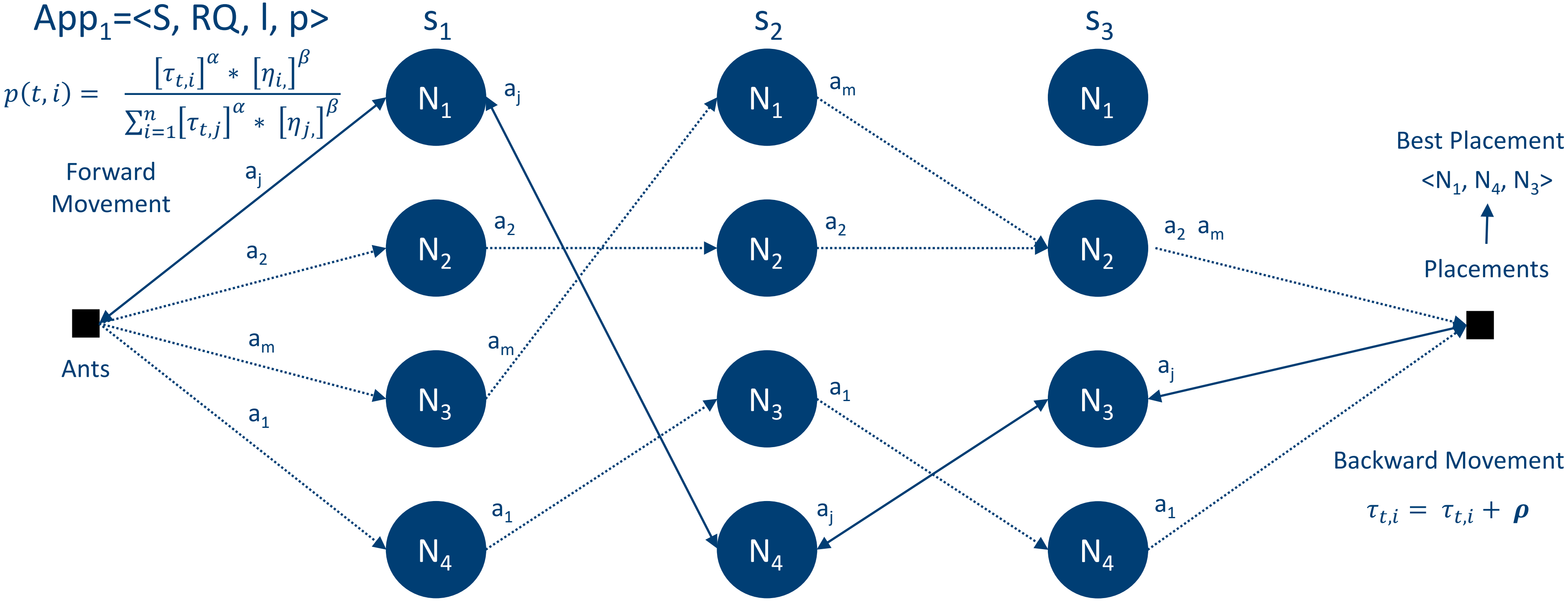
AI Application - Dynamic Service Placement in Edge Computing



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Forward Movement

Ants

Best Placement

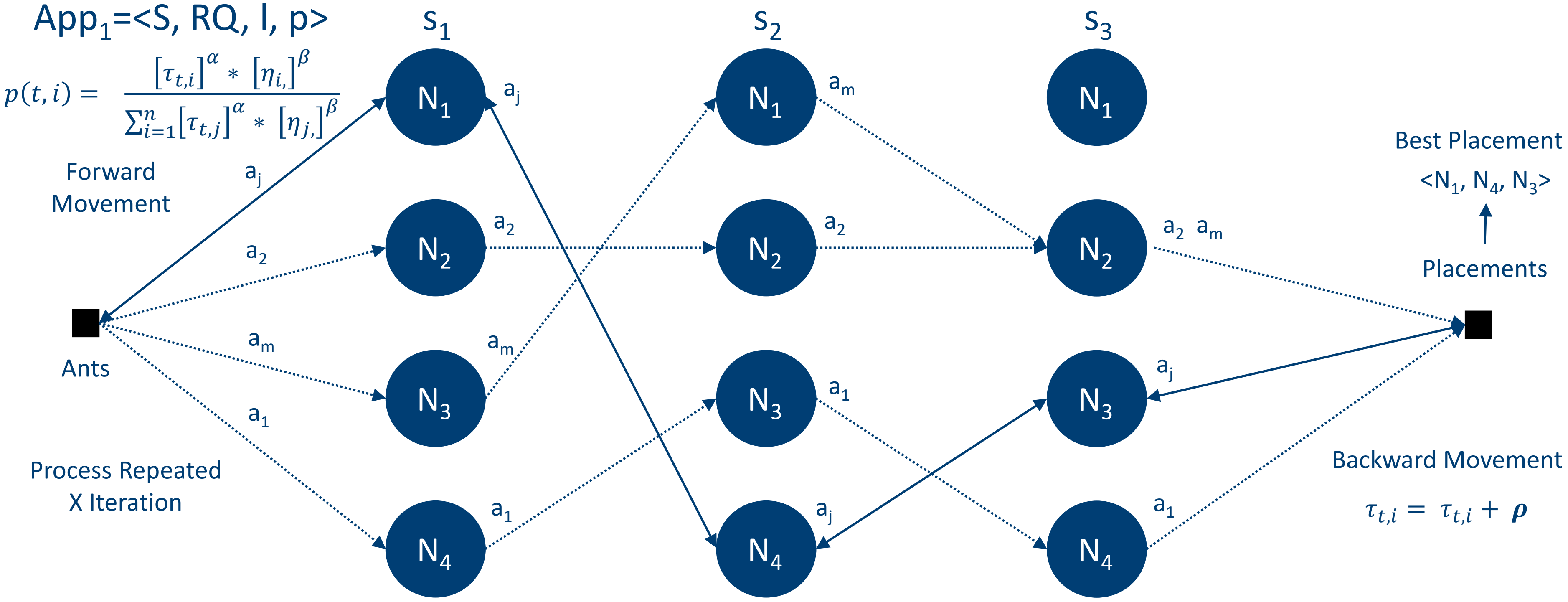
<N$_1$, N$_4$, N$_3$>

Placements

Backward Movement

$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

AI Application - Dynamic Service Placement in Edge Computing



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Forward Movement

Ants

Process Repeated X Iteration

Best Placement

<N_1, N_4, N_3>

Placements

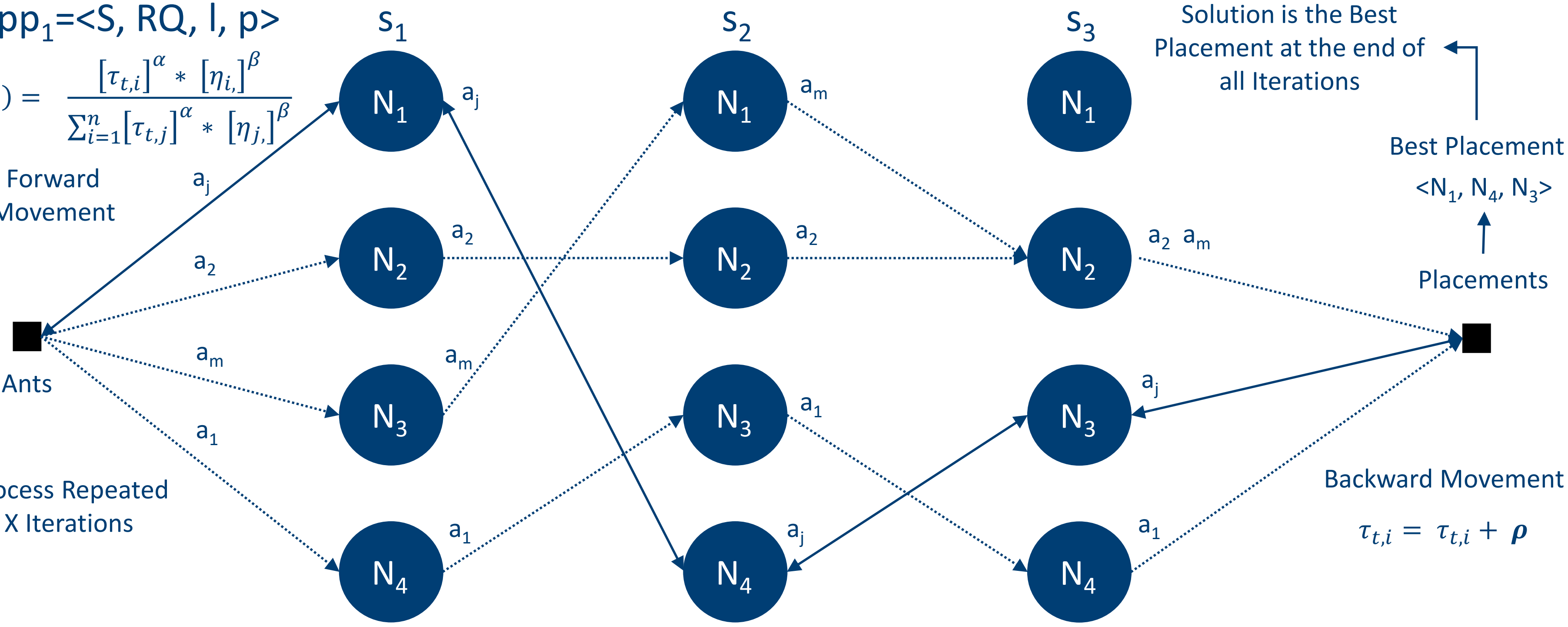
Backward Movement

$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

AI Application - Dynamic Service Placement in Edge Computing

App_1=<S, RQ, l, p>

$$p(t,i) = \frac{[\tau_{t,i}]^{\alpha} * [\eta_{i,}]^{\beta}}{\sum_{i=1}^{n}[\tau_{t,j}]^{\alpha} * [\eta_{j,}]^{\beta}}$$



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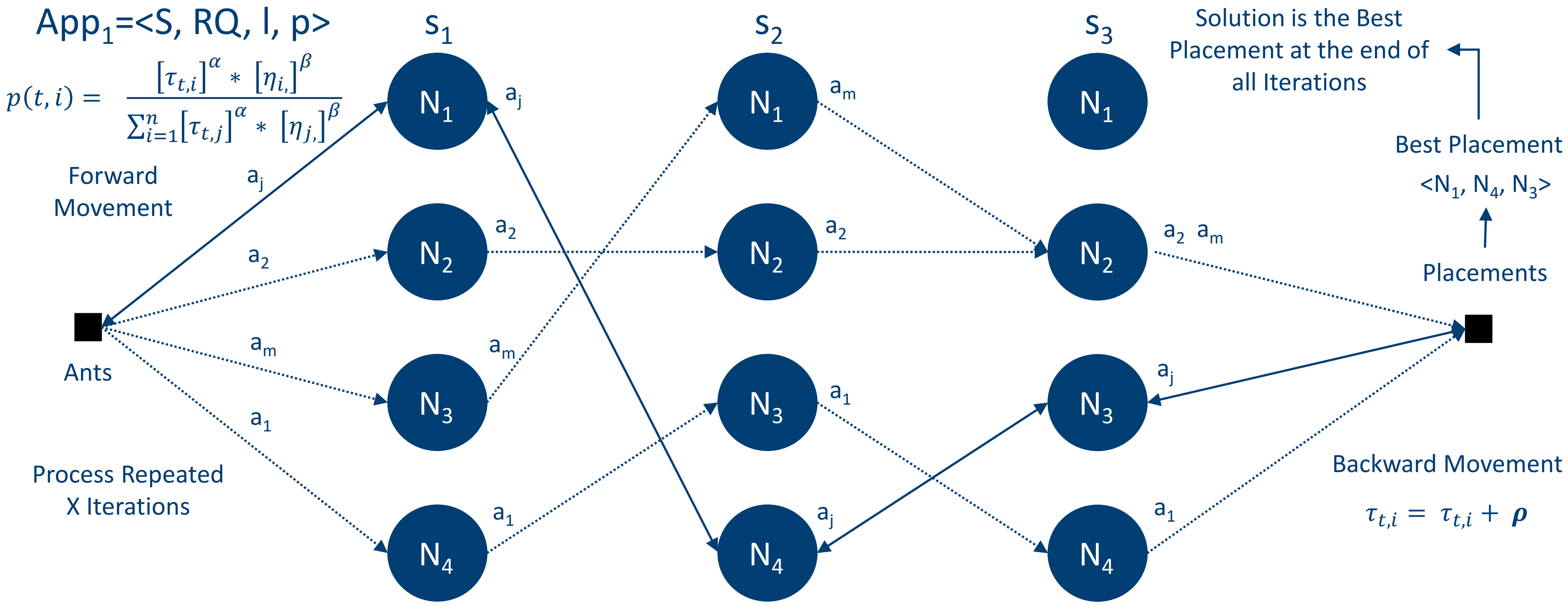
AI Application - Dynamic Service Placement in Edge Computing



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Forward Movement

Ants

Process Repeated X Iterations

Solution is the Best Placement at the end of all Iterations

Best Placement

<N_1, N_4, N_3>

Placements

Backward Movement

$$\tau_{t,i} = \tau_{t,i} + \boldsymbol{\rho}$$

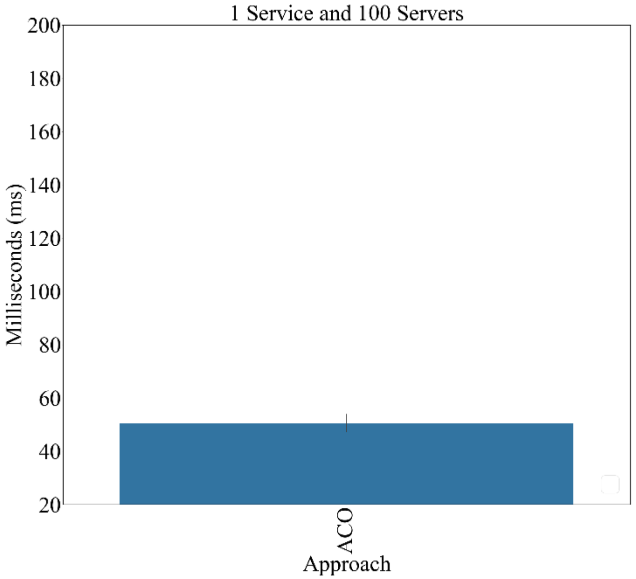
Execution time is affected by:

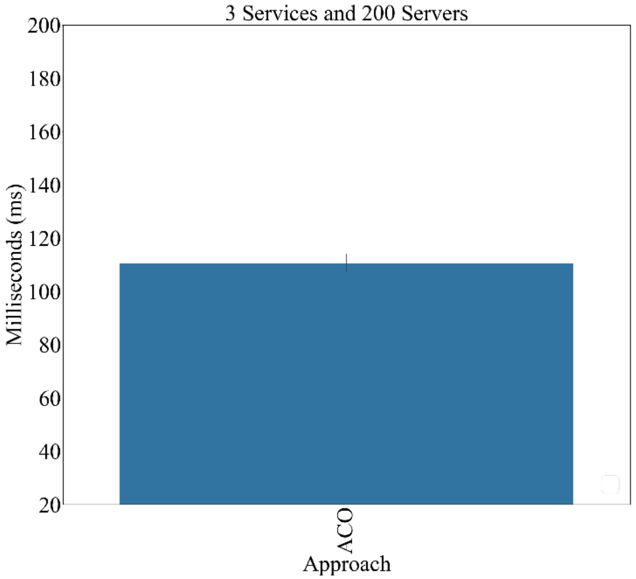
- Number of services.
- Number of edge servers.
- Number of ants.
- Number of iterations

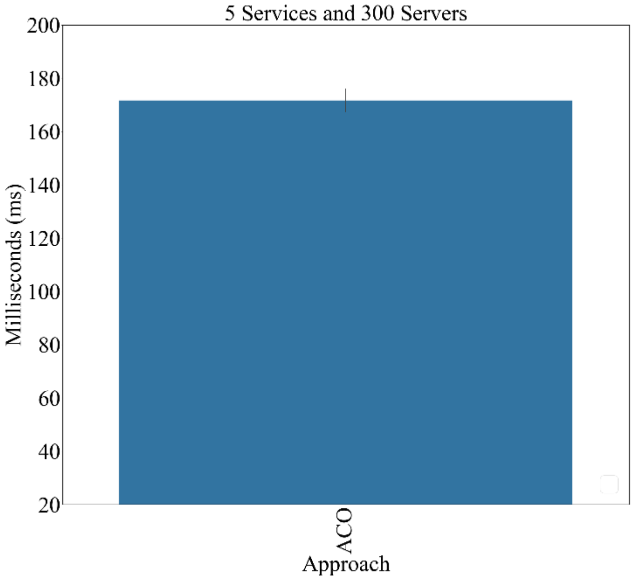
AI Application - Dynamic Service Placement in Edge Computing

Smart-city simulation[1]

Number of ants: 10
Number of iterations: 100


1 Service and 100 Servers


3 Services and 200 Servers


5 Services and 300 Servers

[1] Richerzhagen, B., Stingl, D., Ruckert, J., & Steinmetz, R. (2015, August). Simonstrator: Simulation and prototyping platform for distributed mobile applications. In *The 8th EAI International Conference on Simulation Tools and Techniques (ACM SIMUTOOLS 2015)* (pp. 99-108).

AI Application - Dynamic Service Placement in Edge Computing

Smart-city simulation[1]

Number of ants: 10
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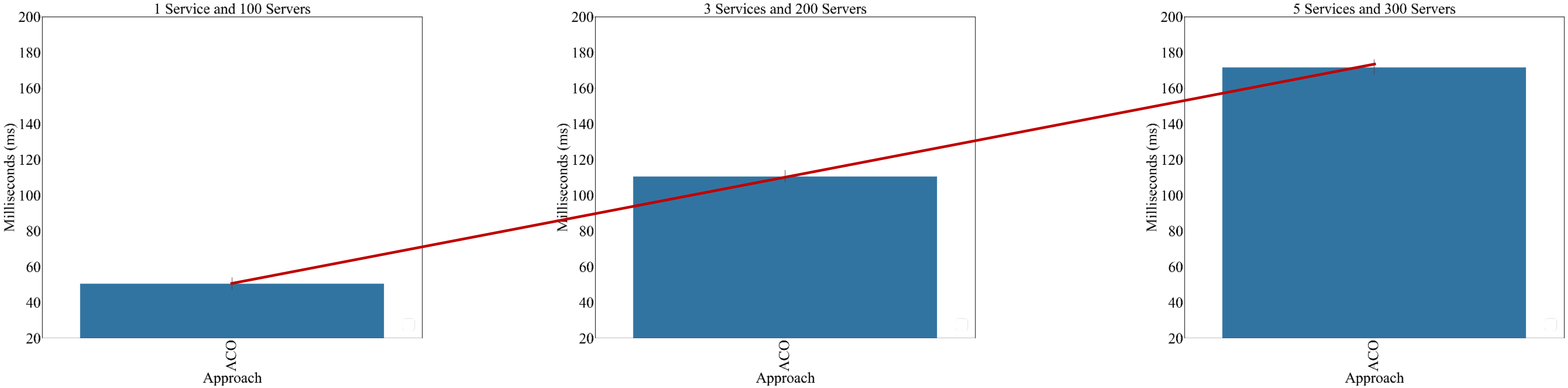
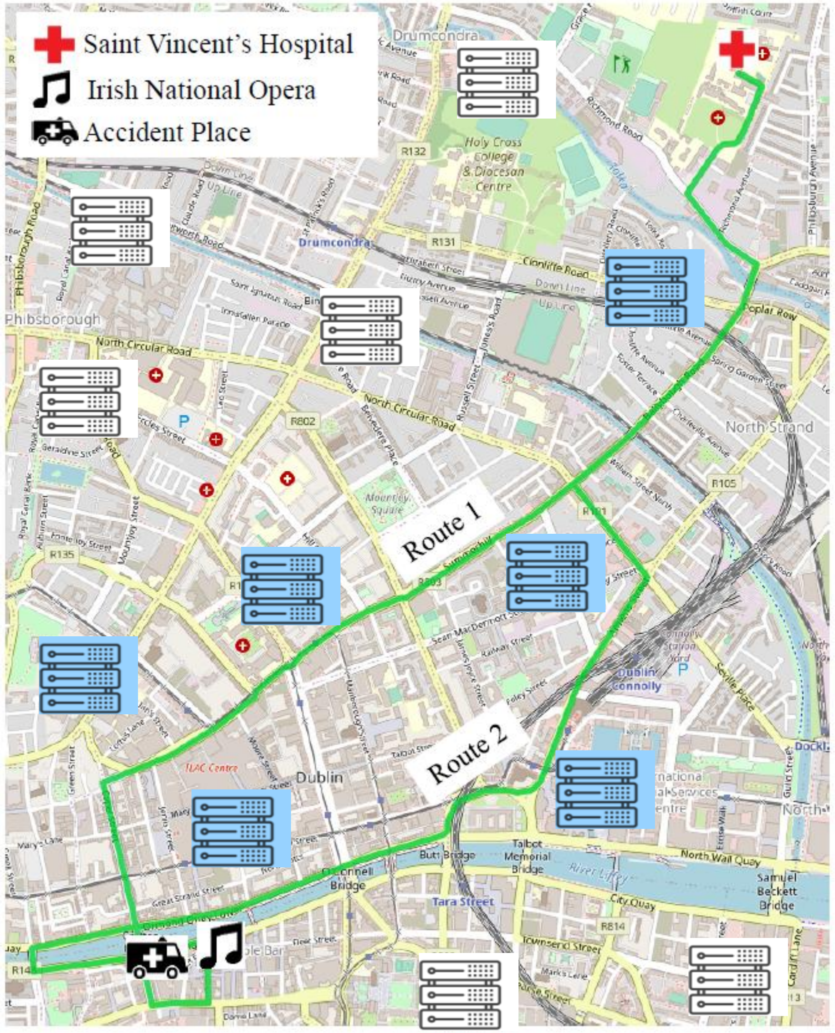


This execution time does not suit low-latency requirements, but that is how ACO is designed!!!

[1] Richerzhagen, B., Stingl, D., Ruckert, J., & Steinmetz, R. (2015, August). Simonstrator: Simulation and prototyping platform for distributed mobile applications. In *The 8th EAI International Conference on Simulation Tools and Techniques (ACM SIMUTOOLS 2015)* (pp. 99-108).

AI Application - Dynamic Service Placement in Edge Computing

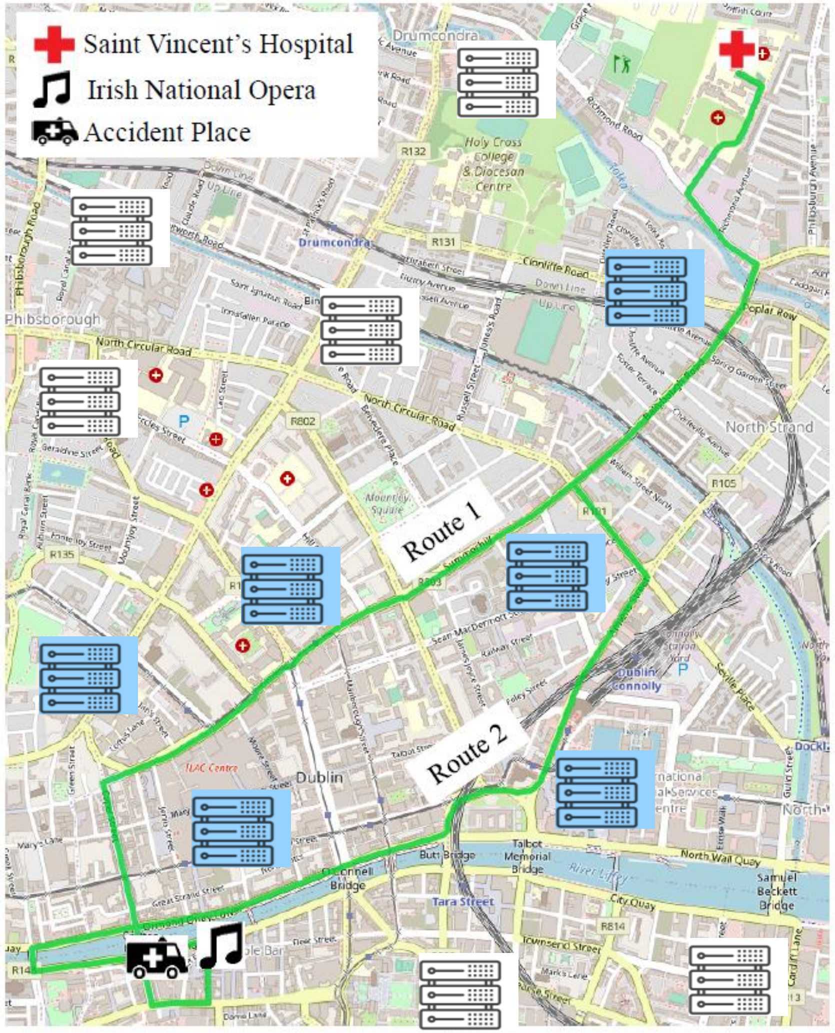


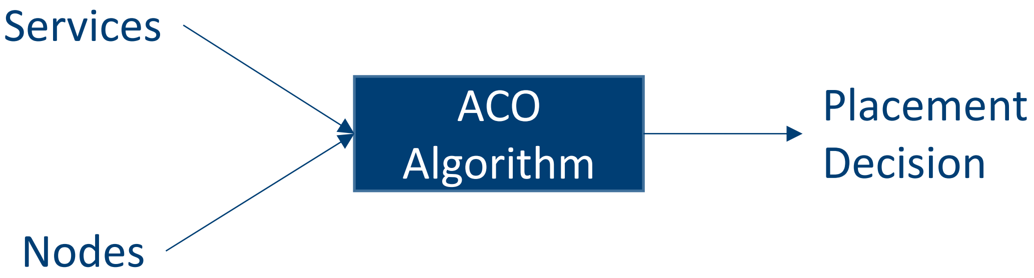
- Variables we cannot reduce:
  - Number of services.
  - Number of iterations.
  - Number of ants.

- **We can reduce the number of servers:**

  - We can pre-select them if we can predict user locations.

AI Application - Dynamic Service Placement in Edge Computing





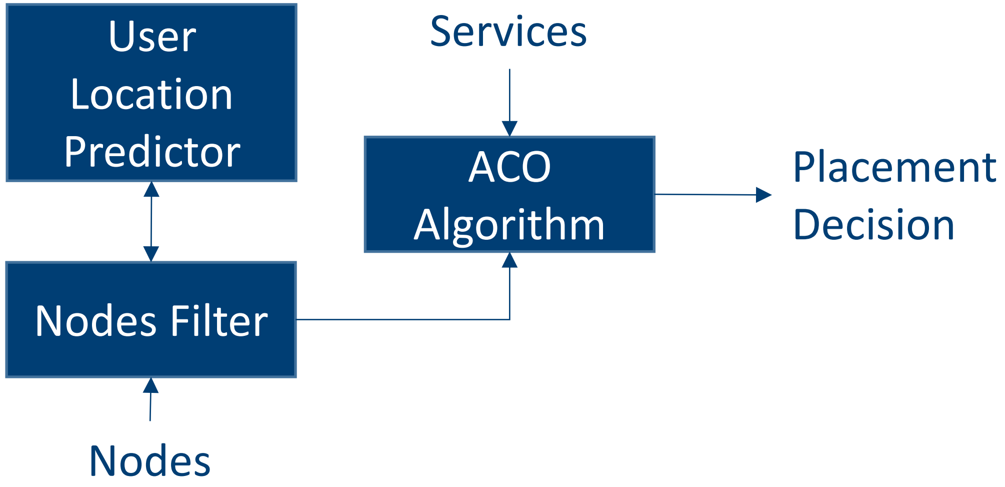
Services

Nodes

ACO Algorithm

Placement Decision

Re-design of the solution:



User Location Predictor

Nodes Filter

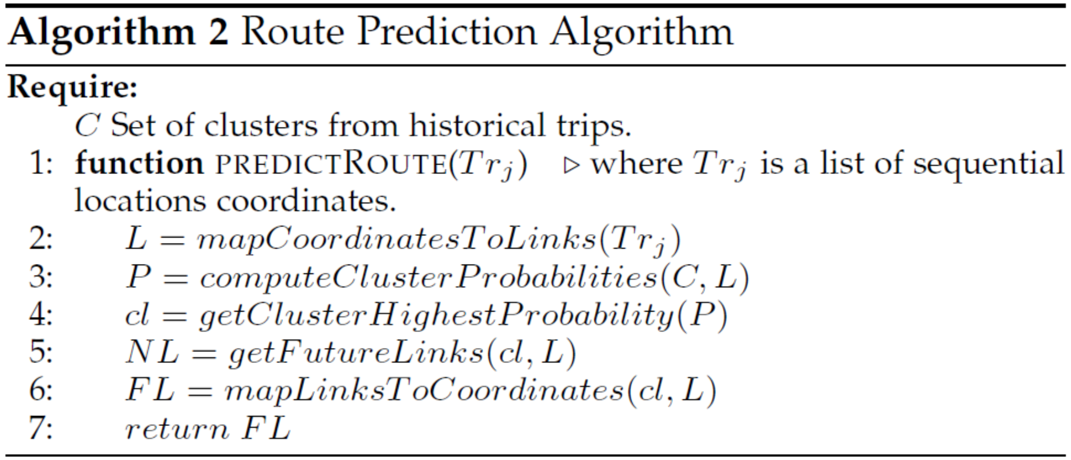
Nodes

Services

ACO Algorithm

Placement Decision

AI Application - Dynamic Service Placement in Edge Computing



Algorithm 2 Route Prediction Algorithm

```
Require:
    $C$ Set of clusters from historical trips.
function PREDICTROUTE($Tr_j$)    ▷ where $Tr_j$ is a list of sequential locations coordinates.
    $L = mapCoordinatesToLinks(Tr_j)$
    $P = computeClusterProbabilities(C, L)$
    $cl = getClusterHighestProbability(P)$
    $NL = getFutureLinks(cl, L)$
    $FL = mapLinksToCoordinates(cl, L)$
    $return\ FL$
```

- The goal is to select the **edge servers** that are **close to** the current and future **user's location.**

- Two approaches were explored: **Bayesian Classifier[1]** and **Hidden Markov Model[2]**.

[1] J. P. Epperlein, J. Monteil, M. Liu, Y. Gu, S. Zhuk, and R. Shorten, "Bayesian classifier for route prediction with markov chains," in 2018 21st International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2018, pp. 677–682.

[2] Y. Lassoued, J. Monteil, Y. Gu, G. Russo, R. Shorten, and M. Mevissen, "A hidden markov model for route and destination prediction," n 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2017.

AI Application - Dynamic Service Placement in Edge Computing

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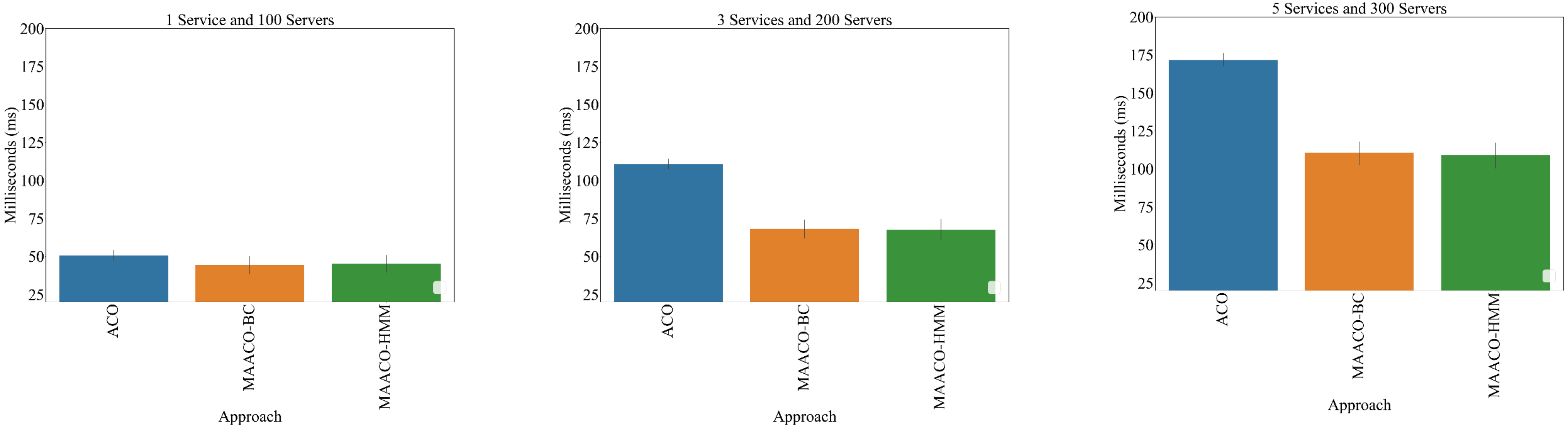

[1] Richerzhagen, B., Stingl, D., Ruckert, J., & Steinmetz, R. (2015, August). Simonstrator: Simulation and prototyping platform for distributed mobile applications. In *The 8th EAI International Conference on Simulation Tools and Techniques (ACM SIMUTOOLS 2015)* (pp. 99-108).

AI Application - Dynamic Service Placement in Edge Computing

Bayesian Classifier [1]

Set of clusters of historical trips C.

Transition matrix for each cluster cl_k. $\mathrm{m} \times m$ dimensions where m is the total number of unique links in historical trips.

The output of the training maps:

$$(L, cl_k) \rightarrow P(L, cl_k)$$

Prediction of a trip belonging to cl_k:

$$p(l_0, \dots, l_t | cl_k) = p(l_0, \dots, l_{t-1} | cl_k)$$

Initial probability:

$$p(l_0 = i | cl_k) = \frac{|L_m | l_0 = i \wedge L_m \in cl_k|}{|L_m | L_m \in cl_k|}$$

Hidden Markov Model [2]

Set of clusters of historical trips C.

Frequency matrix $F_{m \times n}$, where m is the total number of unique links in historical trips and n is the number of clusters.

Prob. of being on link l, if current trip belongs to cl:

$$p(l | C = cl) = \frac{F_{l,cl}}{\sum_{i=1}^{m} F_{i,cl}}$$

Prob. of being in cl knowing current link l :

$$p(C = cl | l) = \frac{F_{l,cl}}{\sum_{j=1}^{n} F_{l,j}}$$

Initial probability:

$$p(cl_k | l_0, \dots, l_t) = p(l_t | cl_k) p(cl_k | l_0, \dots, l_{t-1})$$

[1] J. P. Epperlein, J. Monteil, M. Liu, Y. Gu, S. Zhuk, and R. Shorten, “Bayesian classifier for route prediction with markov chains,” in 2018 21st International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2018, pp. 677–682.

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AI Application - Dynamic Service Placement in Edge Computing

Bayesian Classifier [1]

- Transition matrix depends on the number of links, which are the number of streets in a city.
- A lot of data (i.e., trips) are needed to train the model.
- Training time is now an issue!
- We assumed a limited number of streets in our work.

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AI Application - Dynamic Service Placement in Edge Computing

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AGAIN, NEW DESIGN DECISIONS ARE NEEDED TO DEPLOY THESE ML ALGORITHMS IN THE REAL-WORLD!

[1] J. P. Epperlein, J. Monteil, M. Liu, Y. Gu, S. Zhuk, and R. Shorten, “Bayesian classifier for route prediction with markov chains,” in 2018 21st International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2018, pp. 677–682.

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AI Deployment in the Real-world

- Real-world does not support assumptions.

- Real world environments are usually large, heterogeneous, complex and dynamic.

How to support engineers and developers in the process of deploying AI-based systems in real-world environments?

How to enable the reasoning about AI-based systems in real world environments?

How to automate the repetitive design process?

PART III: Possible answers...

AutoAI Programme

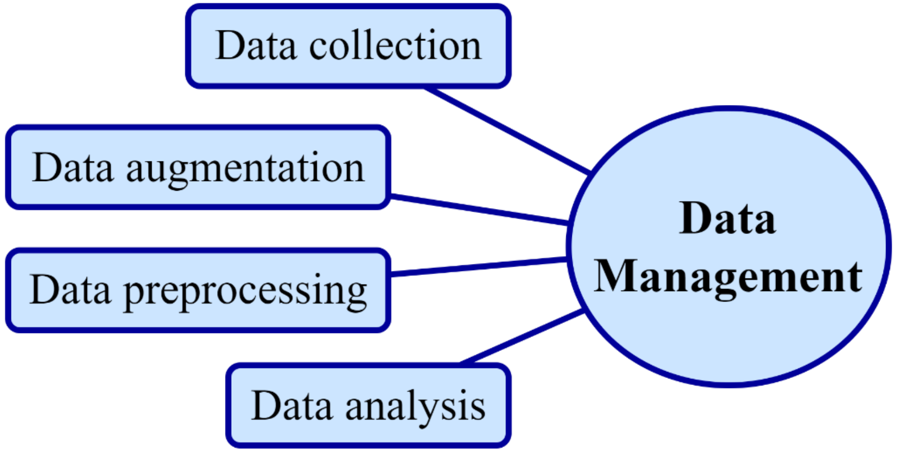
The AutoAI Programme scales our ability to deploy safe and reliable AI solutions, driving innovation in machine learning-enabled techniques for deploying, maintaining, and understanding AI systems. By investigating how to decompose AI systems into their component parts, how to manage data in system development, and how to monitor performance in deployment, **AutoAI will develop a new AI design and engineering paradigm.**

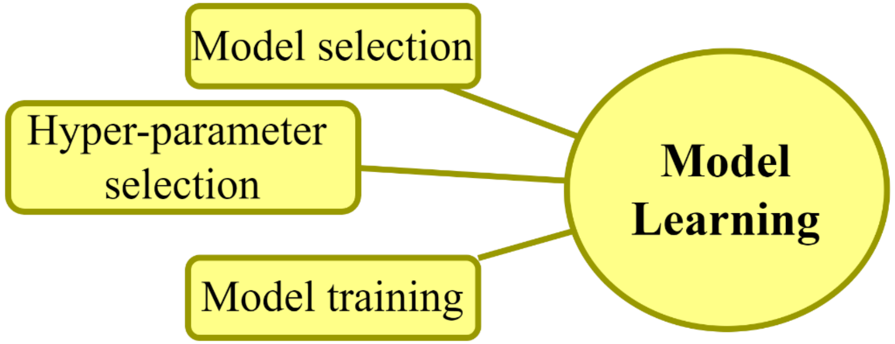
AutoAI Programme

$$model + data \xrightarrow{compute} prediction$$

- There has been **a lot** of focus on and research **efforts** in learning **models** (i.e., new algorithms) and **compute** (i.e., more powerful machines).
- **But, the data has not gotten enough attention!**
  - **The lack of focus on data causes several challenges when deploying ML…**

ML Challenges in Real World[1]





[1] Paleyes, A., Urma, R. G., & Lawrence, N. D. (2020). Challenges in deploying machine learning: a survey of case studies. *arXiv preprint arXiv:2011.09926*.

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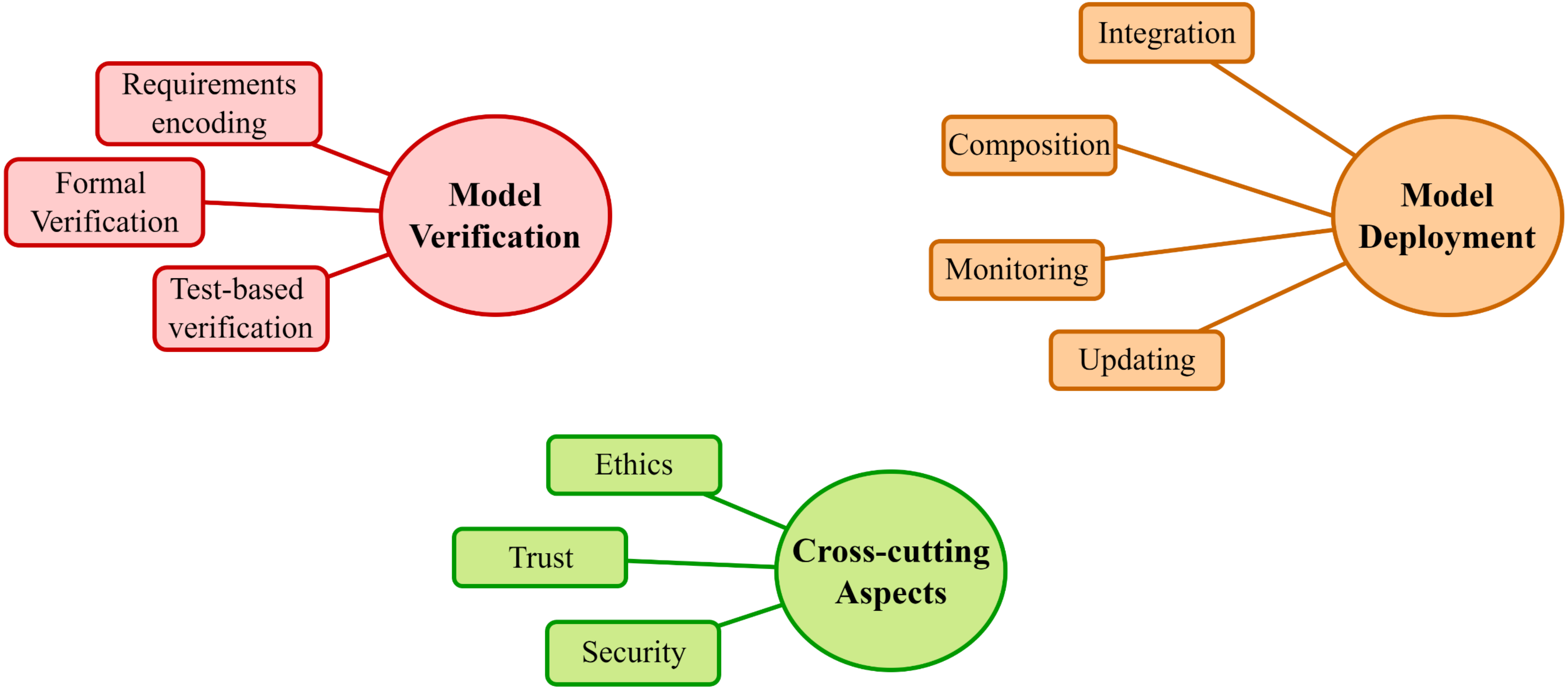


Model Verification

- Requirements encoding
- Formal Verification
- Test-based verification

Model Deployment

- Integration
- Composition
- Monitoring
- Updating

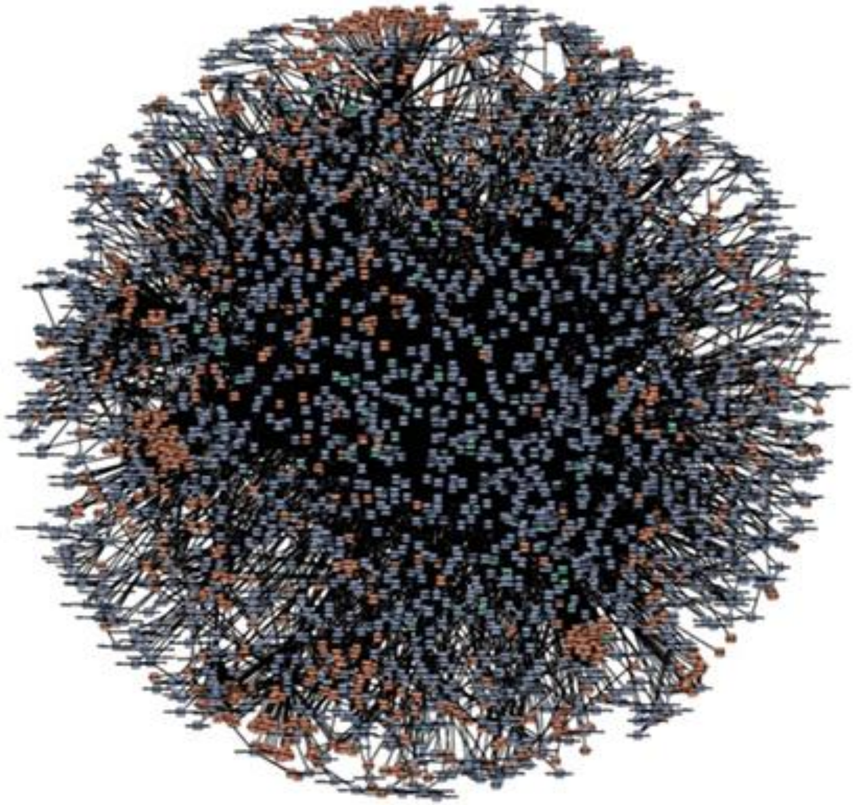
Cross-cutting Aspects

- Ethics
- Trust
- Security

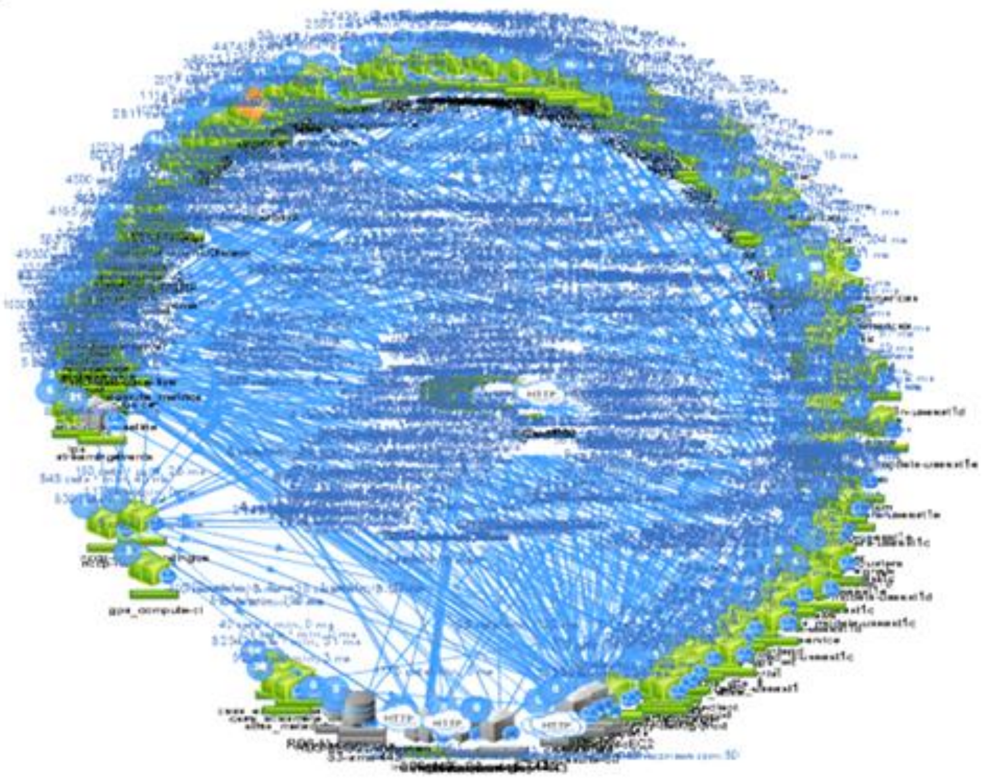
[1] Paleyes, A., Urma, R. G., & Lawrence, N. D. (2020). Challenges in deploying machine learning: a survey of case studies. *arXiv preprint arXiv:2011.09926*.

Systems Design

Microservices Architecture



amazon.com

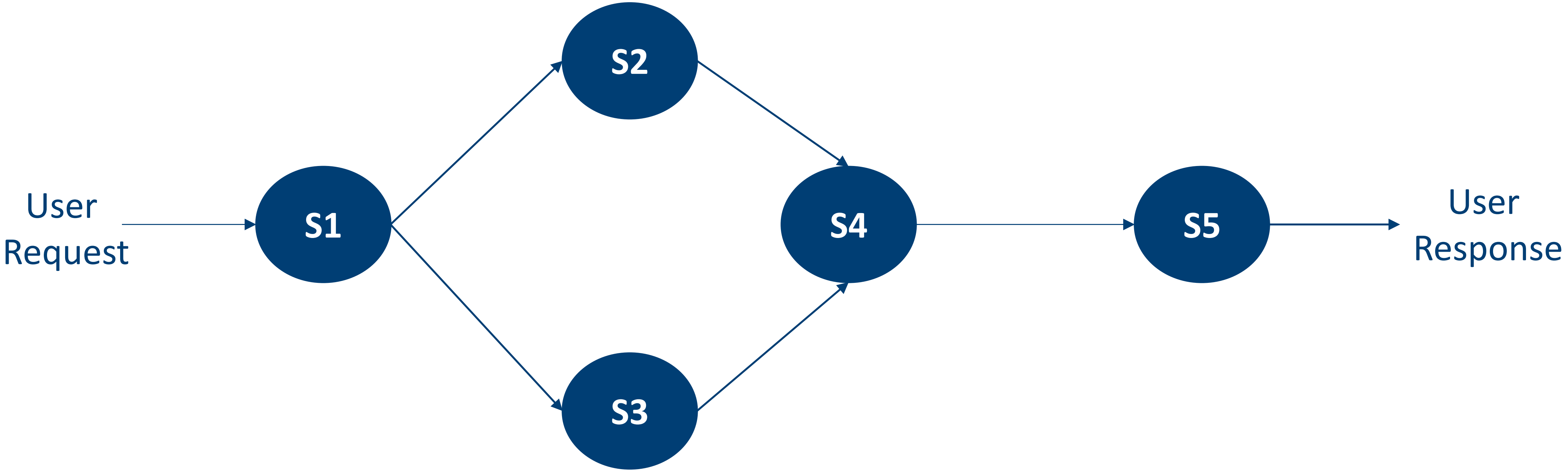


NETFLIX

Source: https://www.divante.com/blog/10-companies-that-implemented-the-microservice-architecture-and-paved-the-way-for-others

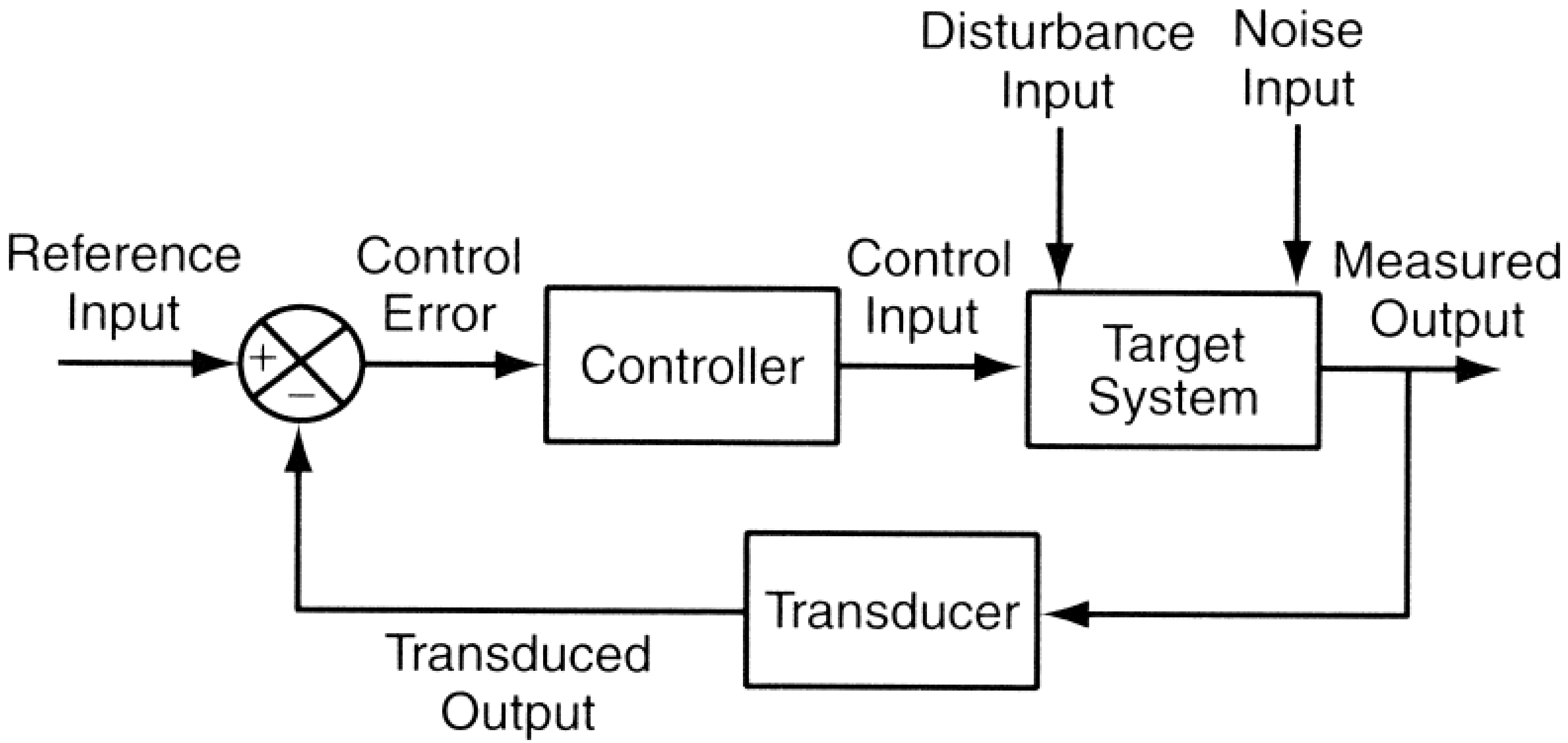
Systems Design

Microservices Architecture



Systems Design

Control System



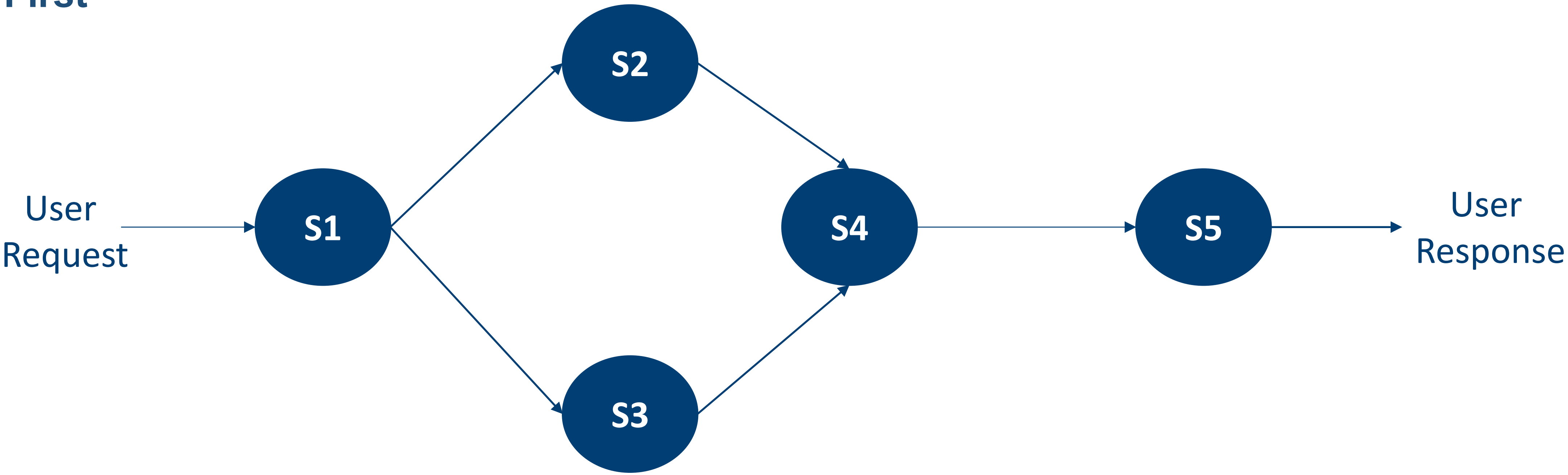
Source: https://www.eecs.umich.edu/courses/eecs373.w05/lecture/control.html

Ongoing Work – Data-Oriented Architectures

- Architecture principles:
  - **Data First.**
  - **Decentralised Architecture.**
  - **Open Architecture.**

Ongoing Work – Data-Oriented Architectures

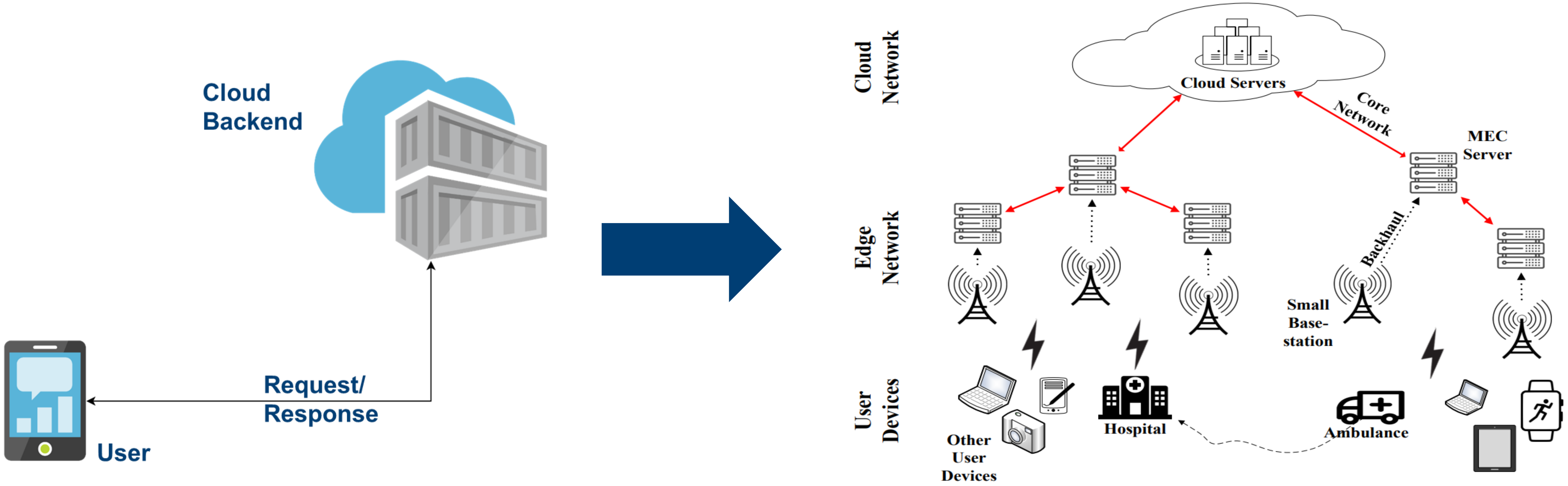
- Data First



Data is primary and the operations on data are secondary.

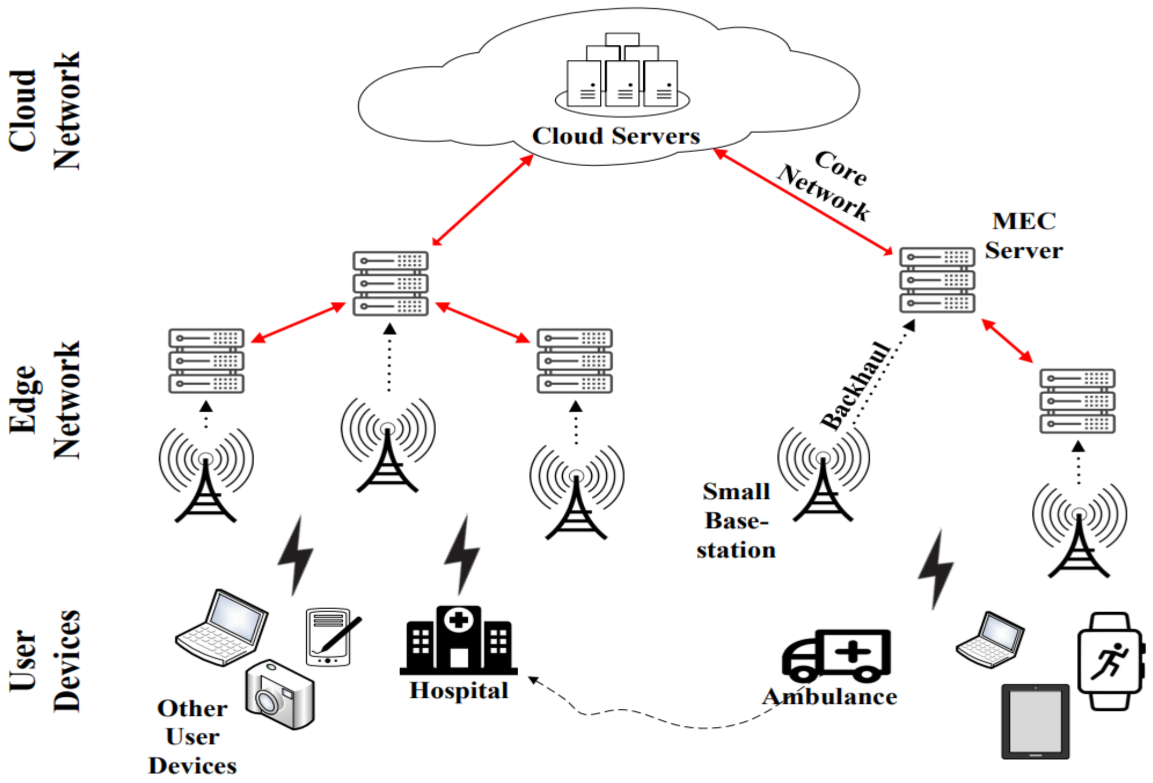
Ongoing Work – Data-Oriented Architectures

- Decentralised architecture.



Ongoing Work – Data-Oriented Architectures

- Open architecture.



Ongoing Work – Data-Oriented Architectures

- **Initial Exploration – SOA vs FBP[1,2]**

We explored programming paradigms that can enable DOAs and compare them against classic SOA.

- **Flow Based Programming:**

Dataflow programming paradigm that defines software applications as a set of processes which exchange data via connections that are external to those processes.

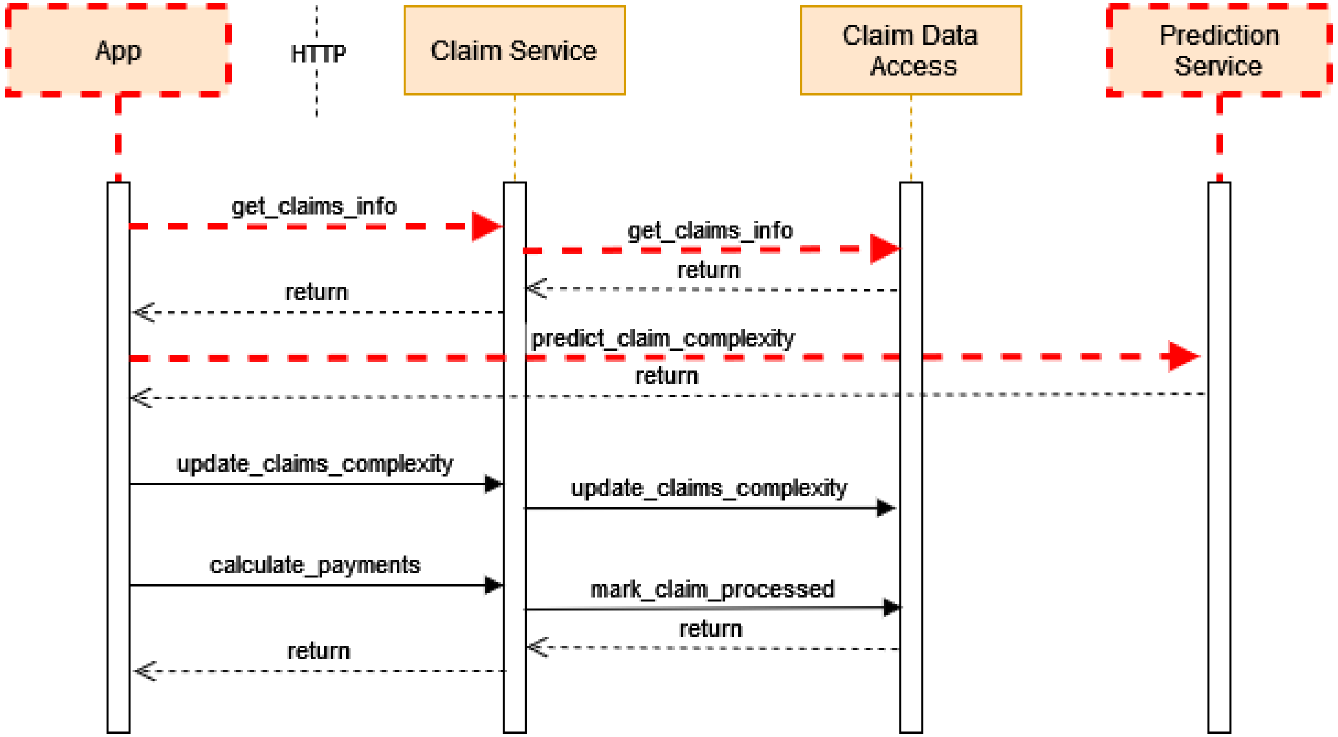
- **We implemented different applications with SOA and FBP and then measured code quality.**

[1] Paleyes, A., Cabrera, C., & Lawrence, N. Towards better data discovery and collection with flow-based programming. In *2021 Neurips Data-Centric AI Workshop (DCAI)*

[2] Paleyes, A., Cabrera, C., & Lawrence, N. An Empirical Evaluation of Flow Based Programming in the Machine Learning Deployment Context. 1st International Conference on AI Engineering – Software Engineering for AI. To Appear, May 2022.

Ongoing Work – Data-Oriented Architectures

- Initial Exploration – SOA vs FBP[1,2]



[1] Paleyes, A., Cabrera, C., & Lawrence, N. Towards better data discovery and collection with flow-based programming. In *2021 Neurips Data-Centric AI Workshop (DCAI)*

[2] Paleyes, A., Cabrera, C., & Lawrence, N. An Empirical Evaluation of Flow Based Programming in the Machine Learning Deployment Context. 1st International Conference on AI Engineering – Software Engineering for AI. To Appear, May 2022.

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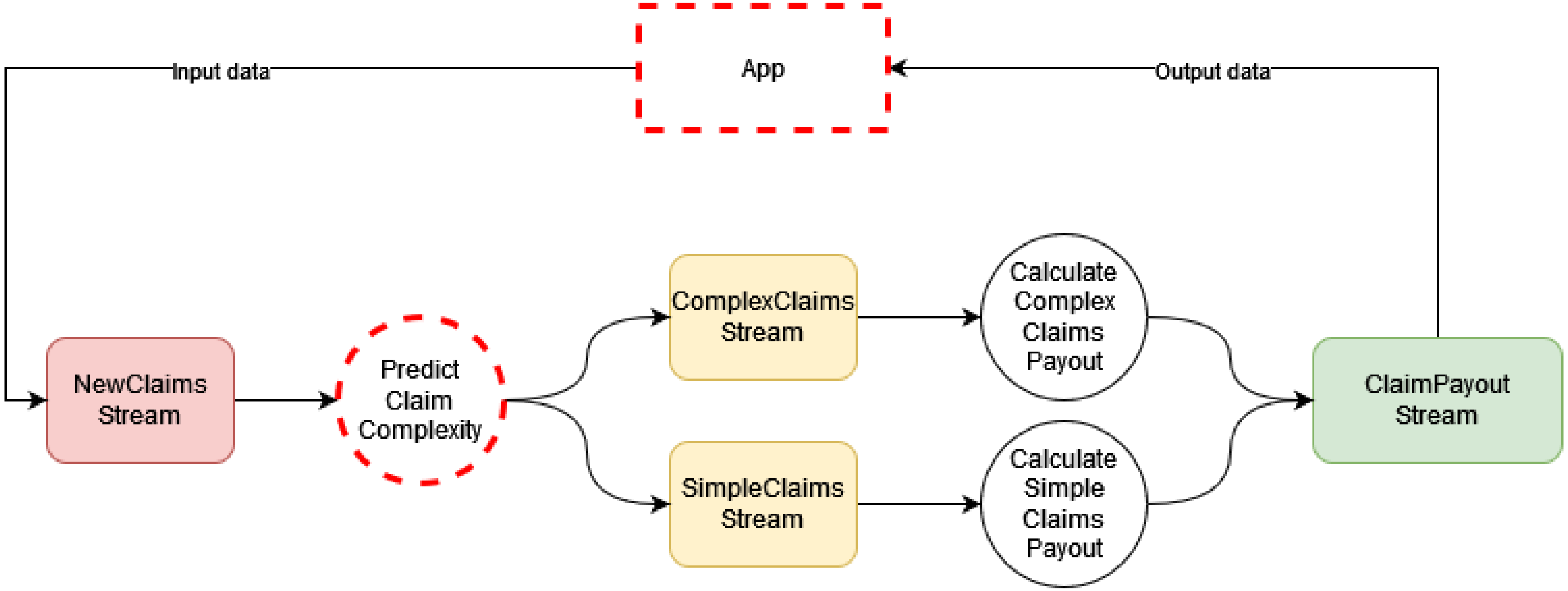

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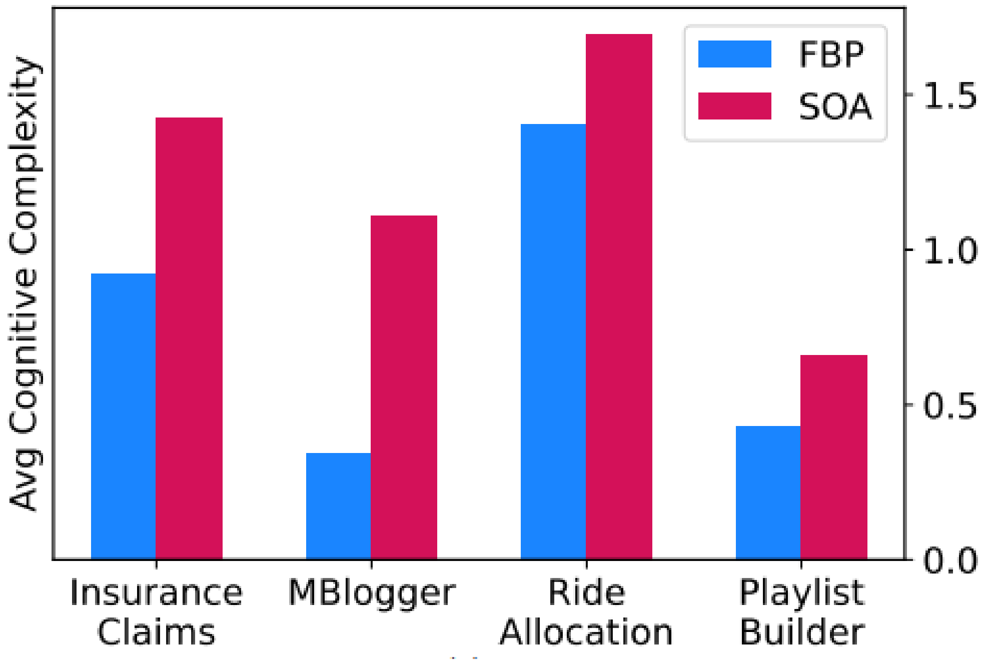

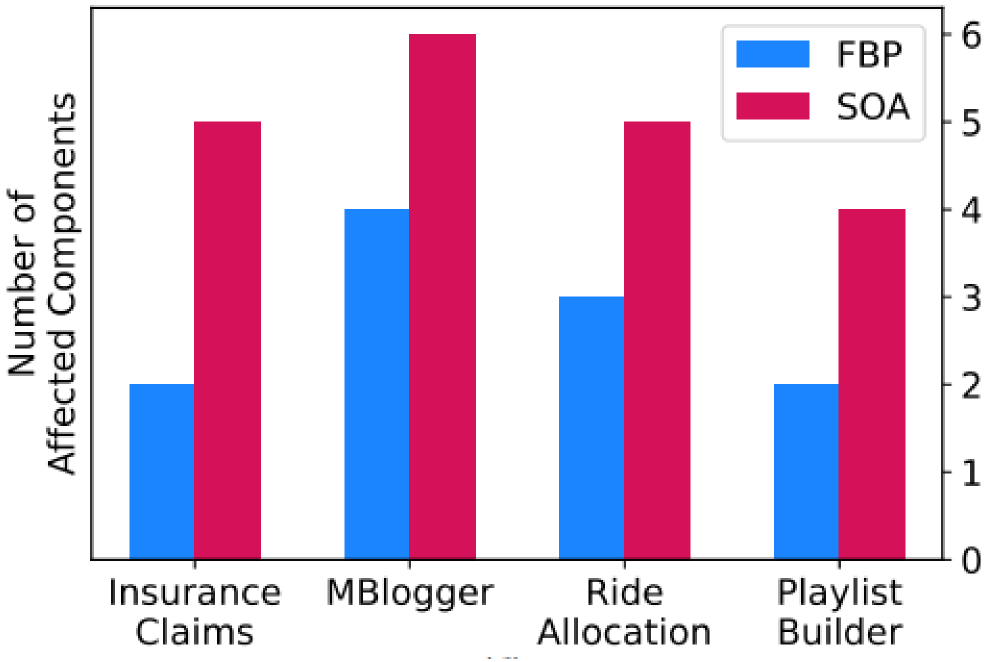

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Take aways…

- It is very likely most of the AI popular predictions will not become real.

- AI has potential but we must be careful with the overwhelmed optimism.

- We must approach AI progress in a scientific way.

- The deployment of AI-based systems in real-world environments is hard.

- New paradigmns are needed to realize the potential of AI.

Thank you!

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