Using Feedback in Real-time Systems: A Literature Review

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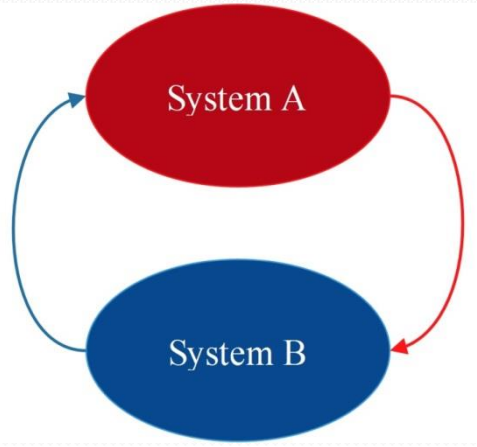
What is Feedback?

- **Feedback** is a structure in which two (or more) systems are coupled and influenced by each other.

- **Feedback** is a natural mechanism, which could be found in biologic and climate systems.



[1] Aström, Karl Johan, and Richard M. Murray. "Feedback systems: an introduction for scientists and engineers". Princeton university press, 2010.

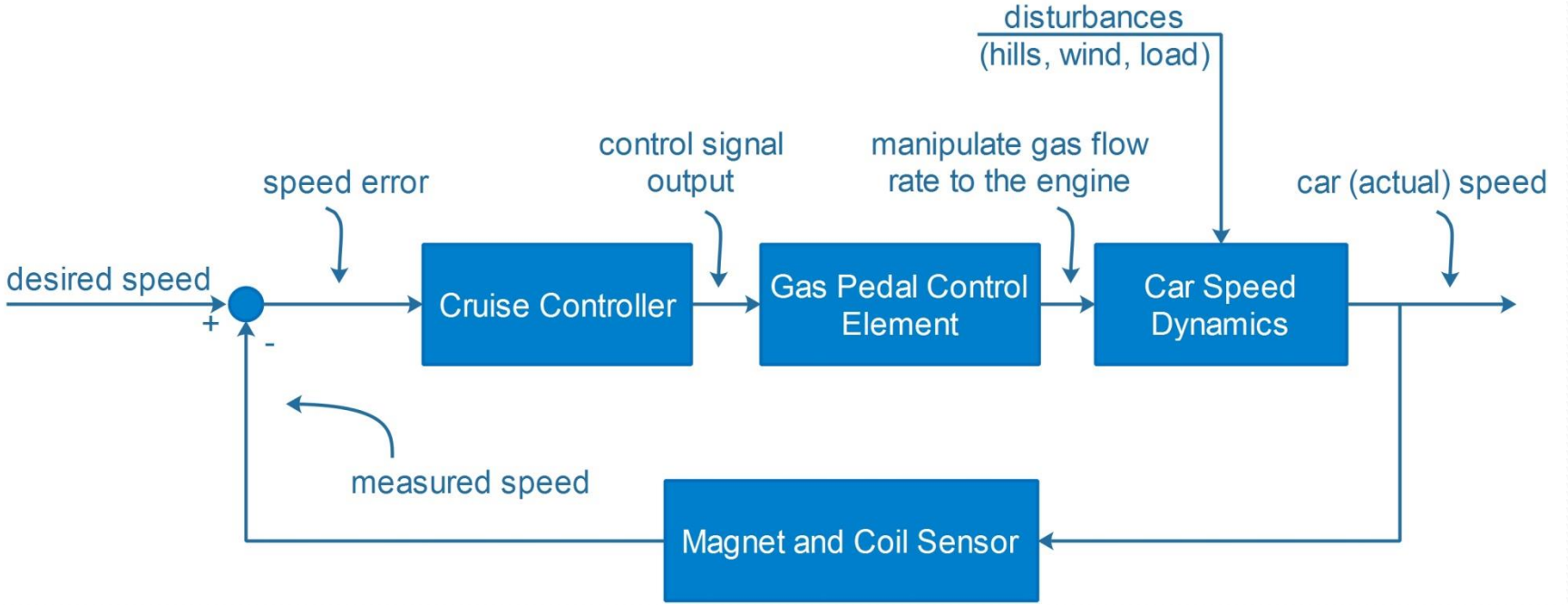
Feedback Control

- **Feedback Control** uses feedback mechanism to form control loops to follow desired references.
- Feedback can make a system robust towards external and internal disturbances and uncertainties [3].
- Consisted of sensor(s), actuator(s) and controller(s).
- def: **Controlled variable**(s), **reference**(s), **manipulated variable**(s) and **control law**(s).
- Widely used in chemical processing, power generation, aerospace, robotics and etc. [1][14].

[1] Aström, Karl Johan, and Richard M. Murray. "Feedback systems: an introduction for scientists and engineers". Princeton university press, 2010.
[3] Sha, Lui, et al. "Real time scheduling theory: A historical perspective." *Real-time systems* 28.2-3 (2004): 101-155.

Feedback Control

- Example: Cruise Control [14]



[14] Dorf, Richard C., and Robert H. Bishop. "Modern control systems." (1998).

Feedback in Real-time Systems

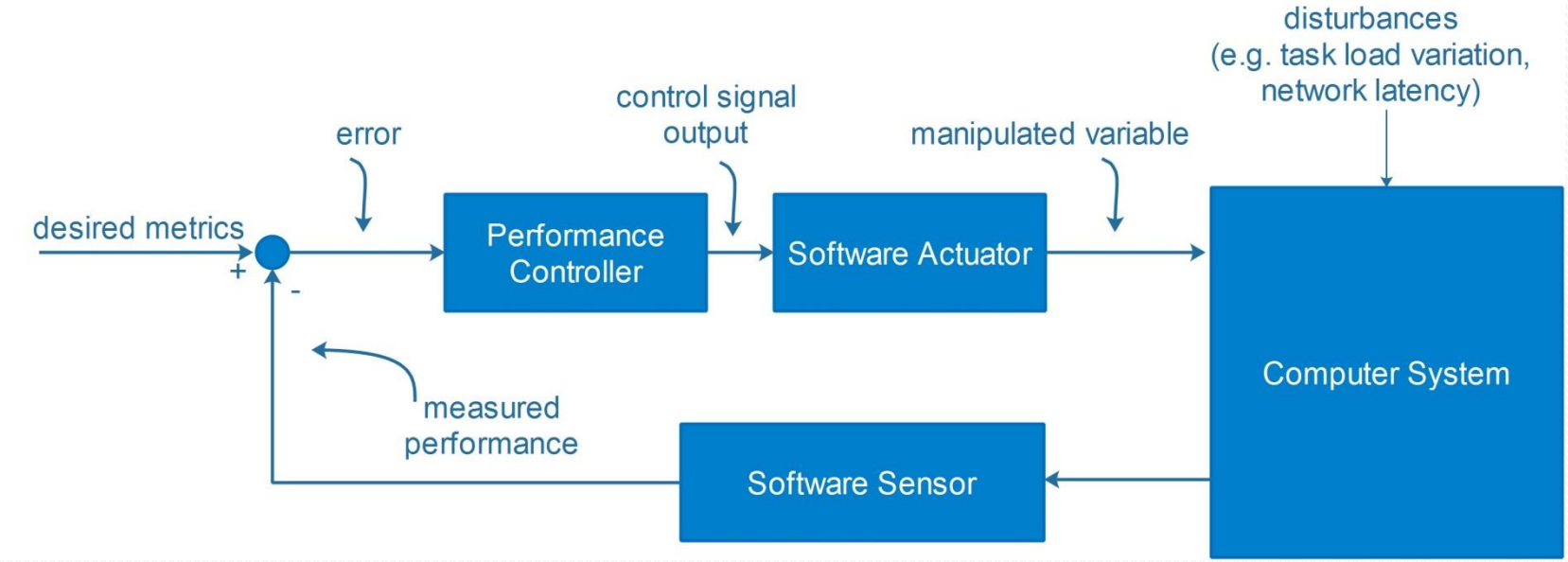
- In an open, dynamic environment, the parameters of incoming tasks are **not known a priori** [2][3][17].
- It is desired for some systems to achieve **absolute** or **relative performance / timeliness guarantees** [2].
- **Imprecise computation**, **elastic scheduling** and **resource allocation** [3]: task attributes and resources per task could be changed on-line.
- Feedback could be applied to address mentioned problems.

[2] T. F. Abdelzaher and J. A. Stankovic, "Feedback performance control in software services - Using a control-theoretic approach to achieve quality of service guarantees", *IEEE Control System Mag.*

[17] Lu, Chenyang, Xiaorui Wang, and Xenofon Koutsoukos. "Feedback utilization control in distributed real-time systems with end-to-end tasks." Parallel and Distributed Systems, IEEE Transactions on 16.6 (2005): 550-561.

Feedback in Real-time Systems

- Basic Structure:



- Applications: multi-media system, distributed database, feedback scheduling, storage management, routing in networks … [2, 4, 5, 6, 7, 8, 9, 17].

Software Sensors

- **Sensors** (or **observers**) refer to the components that monitor and sample some states of the environment.
- Software sensors are used to measure the **performance metrics** of the software system periodically.
- Measured variables: CPU utilization, deadline miss ratio [7], task lateness [12], performance index [16], connection delay [8], power consumption, etc.

[12] Dziurzanski, Piotr, Hashem Ali Ghazzawi, and Leandro Soares Indrusiak. "Feedback-based admission control for task allocation." Reconfigurable and Communication-Centric Systems-on-Chip (ReCoSoC), 2014 9th International Symposium on. IEEE, 2014.

[16] Shin, Kang G., and Charles L. Meissner. "Adaptation and graceful degradation of control system performance by task reallocation and period adjustment." Real-Time Systems, 1999. Proceedings of the 11th Euromicro Conference on. IEEE, 1999.

Software Actuators

- A software actuator provides a method to affect the controlled variable by varying manipulated variable.
- Typical software actuators: admission control as in [12], CPU utilization allocation [16], bandwidth allocation, QoS levels [15], rate modulation [6], execution time, dynamic voltage / frequency scaling [4][5].

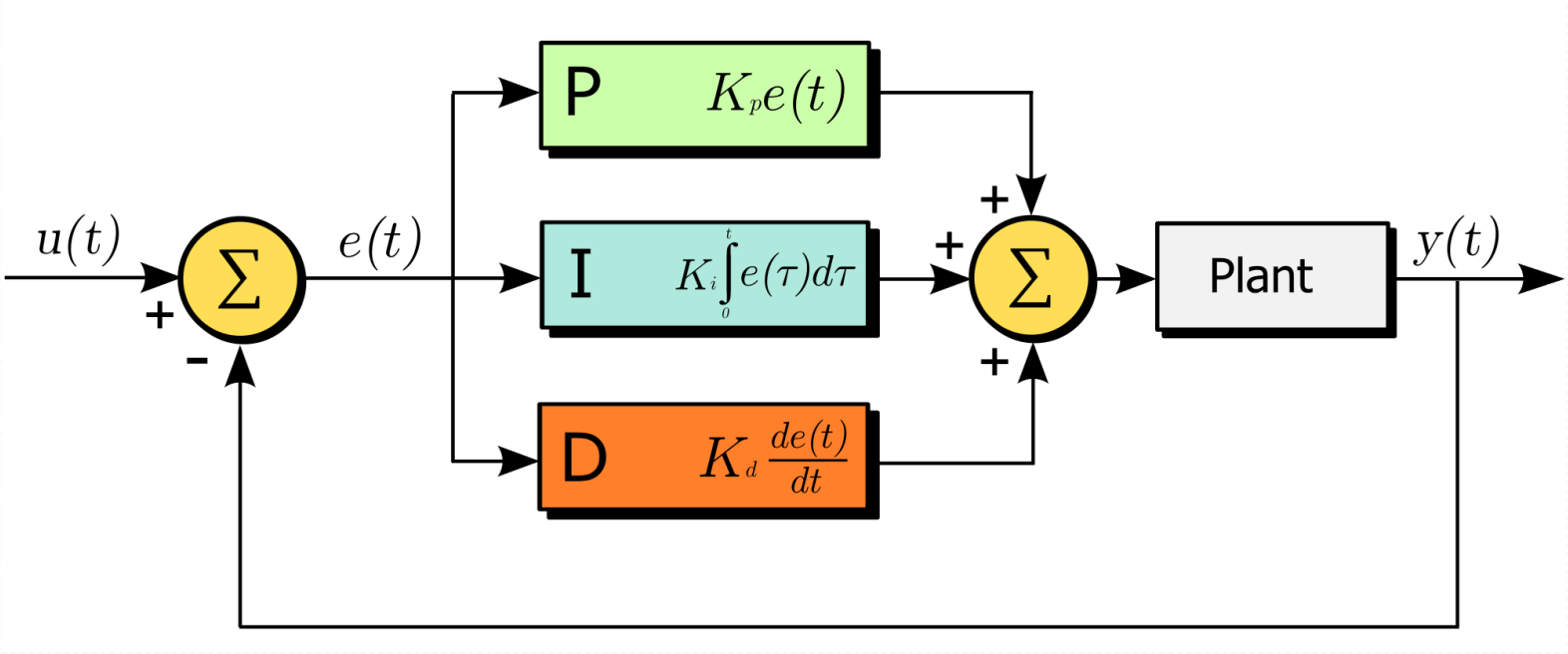
[4] Zhu, Yifan, and Frank Mueller. "Feedback EDF scheduling exploiting dynamic voltage scaling." Real-Time and Embedded Technology and Applications Symposium, 2004. Proceedings. RTAS 2004. 10th IEEE. IEEE, 2004.

[5] Lu, Zhijian, et al. "Control-theoretic dynamic frequency and voltage scaling for multimedia workloads." Proceedings of the 2002 international conference on Compilers, architecture, and synthesis for embedded systems. ACM, 2002.

[6] Beccari, Giuseppe, et al. "Rate modulation of soft real-time tasks in autonomous robot control systems." Real-Time Systems, 1999. Proceedings of the 11th Euromicro Conference on. IEEE, 1999.

Performance Controllers

- Make control decisions based the measurements.
- PID (Proportional-Integral-Derivative) Controller:



- Use the discrete form of PID Controller: t -> kT.

[14] Dorf, Richard C., and Robert H. Bishop. "Modern control systems." (1998).

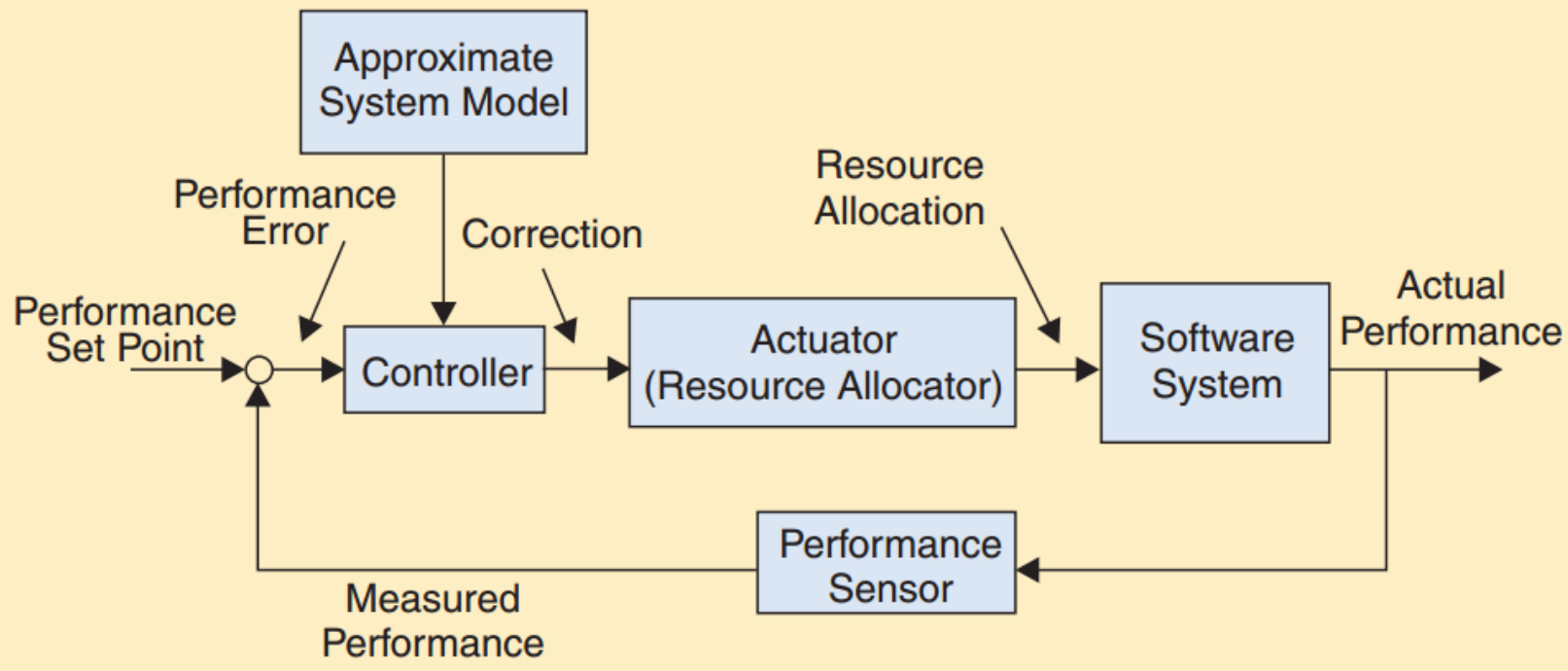
Performance Mapping

- **Performance Mapping** refers to the process that converts the software performance guarantee problem into a feedback control problem.

- Control categories: absolute guarantee, relative guarantee, prioritization or utility optimization [2][9].

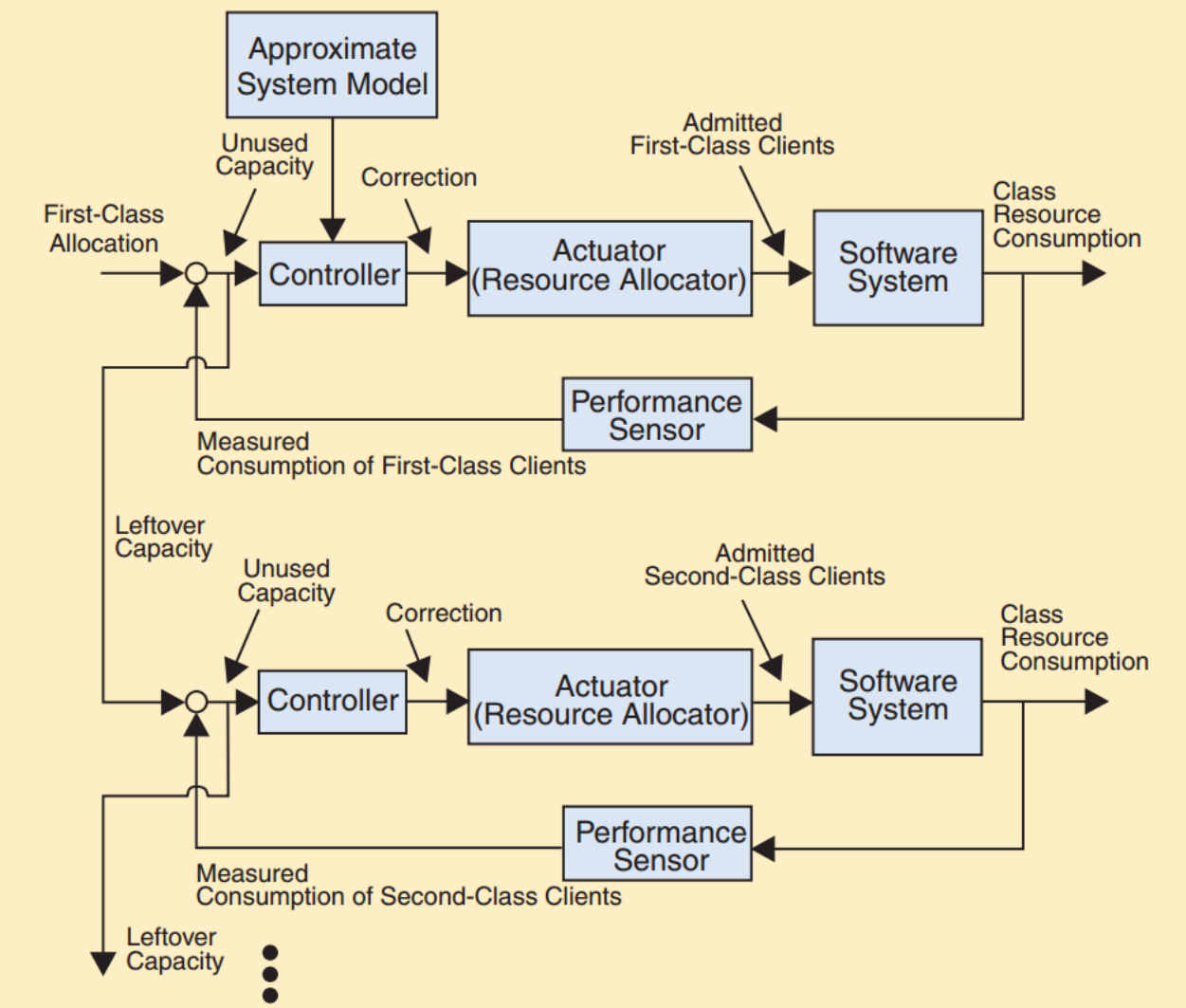
[2] T. F. Abdelzaher and J. A. Stankovic, "Feedback performance control in software services - Using a control-theoretic approach to achieve quality of service guarantees", *IEEE Control System Mag*
[9] Lu, Chenyang, et al. "Feedback control real-time scheduling: Framework, modeling, and algorithms." *Real-Time Systems* 23.1-2 (2002): 85-126.

Performance Mapping: Absolute Guarantee [2]

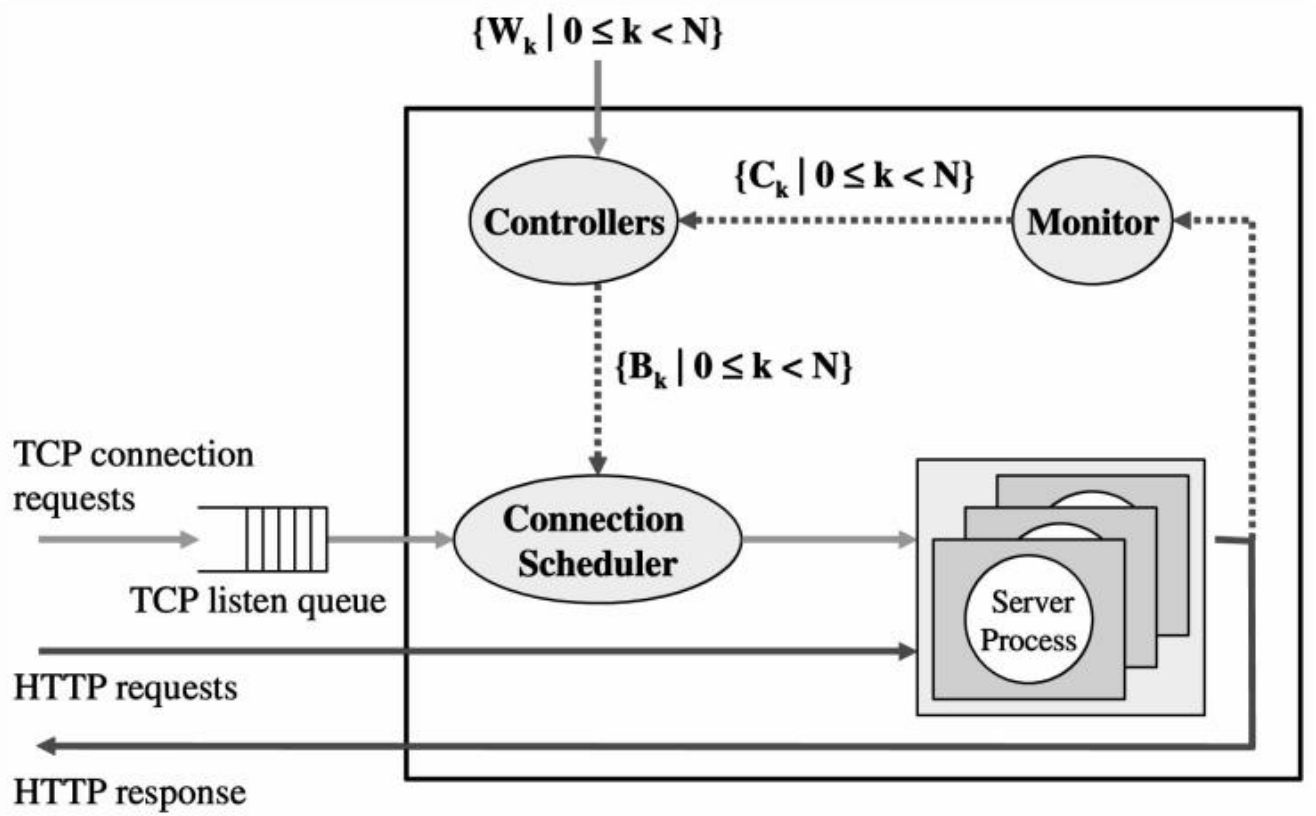


[2] T. F. Abdelzaher and J. A. Stankovic, "Feedback performance control in software services - Using a control-theoretic approach to achieve quality of service guarantees", *IEEE Control System Mag*
[10] Zhang, Ronghua, et al. "Controlware: A middleware architecture for feedback control of software performance." *Distributed Computing Systems*, 2002. *Proceedings. 22nd International Conference* on. IEEE, 2002.

Performance Mapping: Prioritization [2][10]

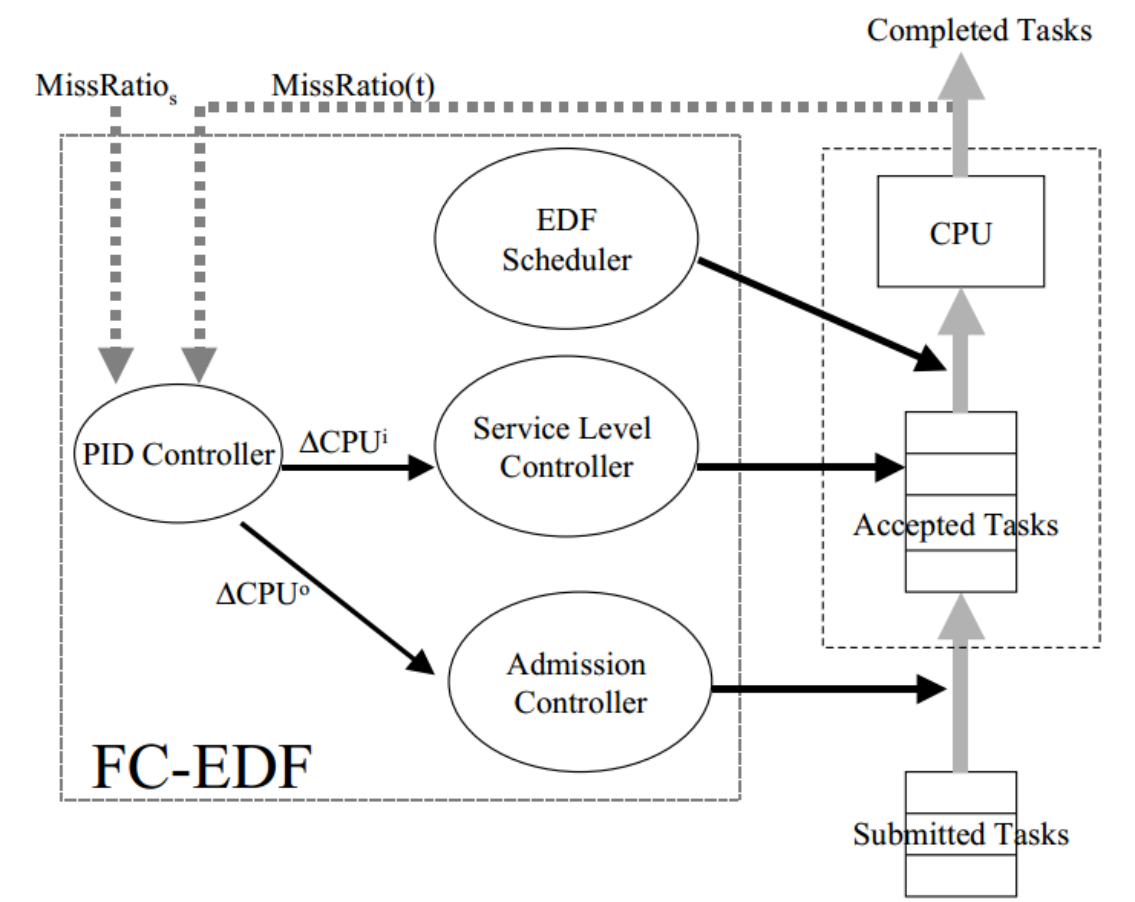


Case Study 1: Web Server [8]



[8] Lu, Chenyang, et al. "Design and evaluation of a feedback control EDF scheduling algorithm." Real-Time Systems Symposium, 1999. Proceedings. The 20th IEEE. IEEE, 1999.

Case Study 2: Feedback EDF [7]



[7] Lu, Chenyang, et al. "Feedback control architecture and design methodology for service delay guarantees in web servers." Parallel and Distributed Systems, IEEE Transactions on 17.9 (2006): 1014-1027.

Related Research

- Queuing theory [3][5]
- ControlWare: A Feedback Scheduling Middleware [10]
- Middleware for QoS Adaptations [15]
- TrueTime and JitterBug [11] – analysis tools for timing

[5] Lu, Zhijian, et al. "Control-theoretic dynamic frequency and voltage scaling for multimedia workloads." Proceedings of the 2002 international conference on Compilers, architecture, and synthesis for embedded systems. ACM, 2002.

[11] Cervin, Anton, et al. "How does control timing affect performance?." IEEE control systems magazine 23.3 (2003): 16-30.

[15] Li, Baochun, and Klara Nahrstedt. "A control-based middleware framework for quality-of-service adaptations." Selected Areas in Communications, IEEE Journal on 17.9 (1999): 1632-1650.

Drawbacks of Using Feedback

- modeling software is not as straight-forward as modeling physical processes [3].
- need a proper way of selecting actuators to specified performance metrics [10].
- stability issues introduced by closed-loop [14].
- introduce extra overhead

Future Work

- Focus on performance improvement for underutilized systems **in a long term**.
- Hard real-time rather than soft real-time.
- More advanced control methods: model-based predictive control (MPC), fuzzy logic control and neural network control.

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- [16] Shin, Kang G., and Charles L. Meissner. "Adaptation and graceful degradation of control system performance by task reallocation and period adjustment." Real-Time Systems, 1999. Proceedings of the 11th Euromicro Conference on. IEEE, 1999.
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THANK YOU!
& Any Questions?