Designing Cyber-Physical Systems with aDSL: a Domain-Specific Language and Toolchain

Freek van den Berg
DACS, University of Twente
Email: f.g.b.vandenberg@utwente.nl
Phone number: +31 53 489 3899
PO Box 217, Enschede, The Netherlands

Vahid Garousi
and Bedir Tekinerdogan
Information Technology
Wageningen University & Research
Wageningen, The Netherlands

Boudewijn R. Haverkort
DACS, University of Twente
Enschede, The Netherlands

Keywords: Embedded systems, Domain-specific languages, Cyber-physical systems, Systems-of-Systems, Design space exploration.

Purpose: An embedded system is a computer system that has a dedicated function within a larger system. It is frequently used to perform safety critical tasks. Multiple approaches exist, which are based on Domain-Specific Languages (DSLs), that include safety and performance evaluation of an embedded system as an integral part of the design process. We would like to achieve a similar approach for Cyber-Physical Systems (CPSs). A CPS is the integration of computation, software, networking, and physical processes. Consequently, CPS models extend embedded systems models with an increased support for hybrid and heterogeneous models, networking, interoperability and time synchronization. The current approaches for embedded systems are not adequate for evaluating the safety and performance of a CPS.

Methods: We introduce an approach which comprises a DSL and a fully automated toolchain named aDSL, which particularly addresses the interoperability of CPSs. The toolchain provides: (i) interactive model description with input validation; (ii) the computation of possible operation modes of subsystems and parts; (iii) checking the adherence to requirements for different designs; (iv) detecting the Pareto optimal designs out of many designs; and, (v) intuitive visualizations throughout the toolchain which help the system designer to better understand the results and communicate them to stakeholders.

Results: aDSL has been tested on an agricultural case study in which a tractor, with different engine fuels and kinds of transmissions, is connected to different trailers; aDSL evaluated 48 designs and rendered all the visualizations, including one that concisely illustrates to which degree each design is Pareto optimal, in a matter of seconds.

References

[1] I. Lee, J. Y. Leung, and S. H. Son, *Handbook of real-time and embedded systems*. CRC Press, 2007.

[2] A. J. Mooij, J. Hooman, and R. Albers, "Gaining industrial confidence for the introduction of domain-specific languages," in *Computer Software and Applications Conference Workshops (COMPSACW), 2013 IEEE 37th Annual*. IEEE, 2013, pp. 662–667.

[3] S. Keshishzadeh, A. J. Mooij, and M. R. Mousavi, "Early fault detection in dsls using SMT solving and automated debugging," in *Software Engineering and Formal Methods - 11th International Conference, SEFM 2013, Madrid, Spain, September 25-27, 2013. Proceedings*. Springer, 2013, pp. 182–196.

[4] F. van den Berg, A. Remke, A. Mooij, and B.R. Haverkort, "Performance Evaluation for Collision Prevention Based on a Domain Specific Language," in *Computer Performance Engineering*, ser. Lecture Notes in Computer Science. Springer, 2013, vol. 8168, pp. 276–287.

[5] F. van den Berg, A. Remke, and B.R. Haverkort, "A Domain Specific Language for Performance Evaluation of Medical Imaging Systems," in *5th Workshop on Medical Cyber-Physical Systems*, ser. OpenAccess Series in Informatics, vol. 36. Schloss Dagstuhl, 2014, pp. 80–93.

[6] F. van den Berg, "Automated Performance Evaluation of Service-Oriented Systems," Ph.D. dissertation, University of Twente, 2017.

[7] E. A. Lee, "Cyber-physical systems-are computing foundations adequate," in *Position Paper for NSF Workshop On Cyber-Physical Systems: Research Motivation, Techniques and Roadmap*, vol. 2, 2006.

[8] R. R. Rajkumar, I. Lee, L. Sha, and J. Stankovic, "Cyber-physical systems: the next computing revolution," in *Proceedings of the 47th Design Automation Conference*. ACM, 2010, pp. 731–736.

[9] S. Graham, G. Baliga, and P. Kumar, "Abstractions, architecture, mechanisms, and a middleware for networked control," *IEEE Transactions on Automatic Control*, vol. 54, no. 7, pp. 1490–1503, 2009.

[10] B. Balaji, A. Faruque, M. Abdullah, N. Dutt, R. Gupta, and Y. Agarwal, "Models, abstractions, and architectures: the missing links in cyber-physical systems," in *Proceedings of the 52nd Annual Design Automation Conference*. ACM, 2015, p. 82.

[11] R. R. Rajkumar, I. Lee, L. Sha, and J. Stankovic, "Cyber-physical systems: the next computing revolution," in *Proceedings of the 47th Design Automation Conference*. ACM, 2010, pp. 731–736.

[12] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for industry 4.0-based manufacturing systems," *Manufacturing Letters*, vol. 3, pp. 18–23, 2015.

[13] L. R. Power, "Post-facto integration technology: new discipline for an old practice," in *Systems Integration, 1990. Systems Integration'90., Proceedings of the First International Conference on*. IEEE, 1990, pp. 4–13.

[14] P. Miller, "Interoperability: What is it and why should i want it?" *Ariadne*, no. 24, 2000.

[15] F. Standard, "1037c," *Department of Defense Dictionary of Military and Associated Terms in support of MIL-STD-188*, 1996.

[16] D. K. Allen, S. Karanasios, and A. Norman, "Information sharing and interoperability: the case of major incident management," *European Journal of Information Systems*, vol. 23, no. 4, pp. 418–432, 2014.

[17] J. Searle and J. Brennan, "General interoperability concepts," Tech. Rep., 2006.

[18] A.-J. Berre, B. Elvesæter, N. Figay, C. Guglielmina, S. Johnsen, D. Karlsen, T. Knothe, and S. Lippe, "The athena interoperability framework." in *IESA*. Springer, 2007, pp. 569–580.

[19] W. Wang, A. Tolk, and W. Wang, "The levels of conceptual interoperability model: applying systems engineering principles to m&s," in *Proceedings of the 2009 Spring Simulation Multiconference*. Society for Computer Simulation International, 2009, p. 168.