Three-level-parallelization support framework for large-scale analytic simulation

Journal of Simulation

pp 1–14

- **Authors**
- **Authors and affiliations**

- Yi-ping Yao
- Dong Meng
- Feng Zhu
- Lai-bin Yan
- Qing-jun Qu
- Zhong-wei Lin
- Hai-bo Ma

- Yi-ping Yao
  - 1
- Dong Meng
  - 1
- Feng Zhu
  - 1
- Lai-bin Yan
  - 1
- Qing-jun Qu
  - 1
- Zhong-wei Lin
  - 1
- Hai-bo Ma
  - 1

1. 1.College of Information System and ManagementNational University of Defense TechnologyChangshaChina

Article

First Online:
22 March 2017

Received:
14 December 2015
Accepted:
13 March 2017

DOI (Digital Object Identifier): 10.1057/s41273-017-0057-x

Cite this article as:
Yao, Y., Meng, D., Zhu, F. et al. J Simulation (2017). doi:10.1057/s41273-017-0057-x

Abstract

Fully exploiting the parallelism in large-scale analytic simulation is an essential way to meet the increasing demand for computing resources. This paper deconstructs large-scale analytic simulation using a hierarchical approach. Five computational characteristics that cause the huge computing requirements of analytic simulation are summarized: “Multi-sample”, “Multi-entity”, “Running-as-fast-as-possible”, “Synchronization for constraint of causality”, and “Complex model calculation”. According to these characteristics, a “Sample, Entity, Model” three-level-Parallelization support framework is proposed to exploit the parallelism on three levels. Under the guidance of this framework, a High-Performance Simulation Computer system which integrated software management and hardware support was designed, and then applied in realistic applications. The experimental results show that the designed system can effectively utilize the potential parallelism characteristics in analytic simulation. Consequently, the simulation performance can be improved dozens or even hundreds of times.

Keywords

large-scale analytic simulation parallel simulation three-level-parallelization high-performance simulation computer

References

1. Aydt H, Turner SJ, Cai W and Low MYH (2009). Research issues in symbiotic simulation. In: *Proceedings of the 2009 Winter Simulation Conference*, pp 1213–1222.
2. Bagrodia RL and Liao WT (1994). Maisie: A language for the design of efficient discrete-event simulations. *IEEE Transactions on Software Engineering* **20**(4): 225–238.CrossRef (http://dx.doi.org/10.1109/32.277572)Google Scholar (http://scholar.google.com/scholar_lookup?title=Maisie%3A%20A%20language%20for%20the%20design%20of%20efficient%20discrete-event%20simulations&author=RL.%20Bagrodia&author=WT.%20Liao&journal=IEEE%20Transactions%20on%20Software%20Engineering&volume=20&issue=4&pages=225-238&publication_year=1994)
3. Bisset KR, Aji AM, Bohm E, Kale LV, Kamal T, Marathe MV and Yeom J-S (2012). Simulating the spread of infectious disease over large realistic social networks using Charm++. In: *Proceedings of IEEE 26th International Parallel and Distributed Processing Symposium Workshops & PhD Forum*, pp 507–518.
4. Buss AH (2002). Simkit: Component based simulation modeling with Simkit. In: *Proceedings of the 2002 Winter Simulation Conference*, pp 243–249.
5. Carothers CD, Bauer D and Pearce S (2002). ROSS: A high-performance, low-memory, modular Time Warp system. *Journal of Parallel and Distributed Computing* **62**(11): 1648–1669.CrossRef (http://dx.doi.org/10.1016/S0743-7315(02)00004-7)Google Scholar (http://scholar.google.com/scholar_lookup?title=ROSS%3A%20A%20high-performance%2C%20low-memory%2C%20modular%20Time%20Warp%20system&author=CD.%20Carothers&author=D.%20Bauer&author=S.%20Pearce&journal=Journal%20of%20Parallel%20and%20Distributed%20Computing&volume=62&issue=11&pages=1648-1669&publication_year=2002)
6. Chen D, Theodoropoulos GK, Turner SJ, Cai W, Minson R and Zhang Y (2008). Large scale agent-based simulation on the grid. *Future Generation Computer Systems* **24**(7): 658–671.CrossRef (http://dx.doi.org/10.1016/j.future.2008.01.004)Google Scholar (http://scholar.google.com/scholar_lookup?title=Large%20scale%20agent-based%20simulation%20on%20the%20grid&author=D.%20Chen&author=GK.%20Theodoropoulos&author=SJ.%20Turner&author=W.%20Cai&author=R.%20Minson&author=Y.%20Zhang&journal=Future%20Generation%20Computer%20Systems&volume=24&issue=7&pages=658-671&publication_year=2008)
7. Chen D, Wang L, Wu X, Chen J, Khan SU, Kołodziej J, Tian M, Huang F and Liu W (2013). Hybrid modelling and simulation of huge crowd over a hierarchical Grid architecture. *Future Generation Computer Systems* **29**(5): 1309–1317.CrossRef (http://dx.doi.org/10.1016/j.future.2012.03.006)Google Scholar (http://scholar.google.com/scholar_lookup?title=Hybrid%20modelling%20and%20simulation%20of%20huge%20crowd%20over%20a%20hierarchical%20Grid%20architecture&author=D.%20Chen&author=L.%20Wang&author=X.%20Wu&author=J.%20Chen&author=SU.%20Khan&author=J.%20Ko%C5%82odziej&author=M.%20Tian&author=F.%20Huang&author=W.%20Liu&journal=Future%20Generation%20Computer%20Systems&volume=29&issue=5&pages=1309-1317&publication_year=2013)
8. Chen L, Yao Y and Cai L (2012). A global schedule mechanism for PDES on multi-core environments. *Journal of National University of Defense Technology* **34**(4): 108–113.Google Scholar (http://scholar.google.com/scholar_lookup?

title=A%20global%20schedule%20mechanism%20for%20PDES%20on%20multi-core%20environments&author=L.%20Chen&author=Y.%20Yao&author=L.%20Cai&journal=Journal%20of%20National%20University%20of%20Defense%20Technology&volume=34&issue=4&pages=108-113&publication_year=2012)

9. Choi C, Seo KM and Kim TG (2014). DEXSim: An experimental environment for distributed execution of replicated simulators using a concept of single simulation multiple scenarios. *Simulation: Transactions of the Society for Modeling and Simulation International* **90**(4): 355–376.Google Scholar (http://scholar.google.com/scholar_lookup?title=DEXSim%3A%20An%20experimental%20environment%20for%20distributed%20execution%20of%20replicated%20simulators%20using%20a%20concept%20of%20single%20simulation%20multiple%20scenarios.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=C.%20Choi&author=KM.%20Seo&author=TG.%20Kim&journal=International&volume=90&issue=4&pages=355-376&publication_year=2014)
10. D'Angelo G, Ferretti S, Marzolla M and Armaroli L (2016). Fault-tolerant adaptive parallel and distributed simulation. In: *Proceedings of the 2016 IEEE/ACM 20th International Symposium on Distributed Simulation and Real Time Applications*. doi:10.1109/DS-RT.2016.11 (http://dx.doi.org/10.1109/DS-RT.2016.11).
11. D'Angelo G and Marzolla M (2014). New trends in parallel and distributed simulation: From many-cores to Cloud Computing. *Simulation Modelling Practice and Theory* **49**: 320–335.CrossRef (http://dx.doi.org/10.1016/j.simpat.2014.06.007)Google Scholar (http://scholar.google.com/scholar_lookup?title=New%20trends%20in%20parallel%20and%20distributed%20simulation%3A%20From%20many-cores%20to%20Cloud%20Computing&author=G.%20D%E2%80%99Angelo&author=M.%20Marzolla&journal=Simulation%20Modelling%20Practice%20and%20Theory&volume=49&pages=320-335&publication_year=2014)
12. Das S, Fujimoto RM, Panesar K, Allison D and Hybinette M (1994). GTW: A time warp system for shared memory multiprocessors. In: *Proceedings of the 26th conference on Winter simulation*, Orlando, Florida, pp 1332–1339.
13. Ewald R, Leye S and Uhrmacher AM (2009). An efficient and adaptive mechanism for parallel simulation replication. In: *2009 ACM/IEEE/SCS 23rd Workshop on Principles of Advanced and Distributed Simulation*, pp 104–113.
14. Forbes J, Drake T, Feeney T, Davis J, Keller R, Conaway K, Davis T, Wilson H and Ortiz S (2007). Recognizing the contribution of modeling and simulation technology to the security and prosperity of the United States, and recognizing modeling and simulation as a National Critical Technology. *Bill H. Res.* 487.
15. Fu Y, Kang F, Qi J and Duan S (2010). Research of dynamic scheduling method for the air-to-ground warfare simulation system based on grid. *Simulation Modelling Practice and Theory* **18**(8): 1116–1129.CrossRef (http://dx.doi.org/10.1016/j.simpat.2010.01.006)Google Scholar (http://scholar.google.com/scholar_lookup?title=Research%20of%20dynamic%20scheduling%20method%20for%20the%20air-to-ground%20warfare%20simulation%20system%20based%20on%20grid&author=Y.%20Fu&author=F.%20Kang&author=J.%20Qi&author=S.%20Duan&journal=Simulation%20Modelling%20Practice%20and%20Theory&volume=18&issue=8&pages=1116-1129&publication_year=2010)
16. Fujimoto RM (2000). *Parallel and Distributed Simulation Systems*. Wiley: New York.Google Scholar (http://scholar.google.com/scholar_lookup?title=Parallel%20and%20Distributed%20Simulation%20Systems&author=RM.%20Fujimoto&publication_year=2000)
17. Fujimoto RM, Malik AW and Park A (2010). Parallel and distributed simulation in the cloud. *The Society for Modeling and Simulation International Magazine* **3**(3): 1–10.Google Scholar (http://scholar.google.com/scholar_lookup?title=Parallel%20and%20distributed%20simulation%20in%20the%20cloud&author=RM.%20Fujimoto&author=AW.%20Malik&author=A.%20Park&journal=The%20Society%20for%20Modeling%20and%20Simulation%20International%20Magazine&volume=3&issue=3&pages=1-10&publication_year=2010)
18. Gray MA (2007). Discrete event simulation: A review of SimEvents. *Computing in Science & Engineering* **9**(6): 62–66.CrossRef (http://dx.doi.org/10.1109/MCSE.2007.112)Google Scholar (http://scholar.google.com/scholar_lookup?title=Discrete%20event%20simulation%3A%20A%20review%20of%20SimEvents&author=MA.%20Gray&journal=Computing%20in%20Science%20%26%20Engineering&volume=9&issue=6&pages=62-66&publication_year=2007)
19. Hao J and Gan B (2009). An air defense radar detection model in complex electromagnetic environment. *Computer Simulation* **26**(6): 33–37.Google Scholar (http://scholar.google.com/scholar_lookup?title=An%20air%20defense%20radar%20detection%20model%20in%20complex%20electromagnetic%20environment&author=J.%20Hao&author=B.%20Gan&journal=Computer%20Simulation&volume=26&issue=6&pages=33-37&publication_year=2009)

20. Herbordt MC (2007). Discrete event simulation of molecular dynamics with configurable logic. In: *2007 International Conference on Field Programmable Logic and Applications*, pp 151–158.
21. Hofmann MA (2004). Challenges of model interoperation in military simulations. *Simulation: Transactions of the Society for Modeling and Simulation International* **80**(12): 659–667.Google Scholar (http://scholar.google.com/scholar_lookup?title=Challenges%20of%20model%20interoperation%20in%20military%20simulations.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=MA.%20Hofmann&journal=International&volume=80&issue=12&pages=659-667&publication_year=2004)
22. Hou B, Yao Y, Wang B and Liao D (2013). Modeling and simulation of large-scale social networks using parallel discrete event simulation. *Simulation: Transactions of the Society for Modeling and Simulation International* **89**(10): 1173–1183.Google Scholar (http://scholar.google.com/scholar_lookup?title=Modeling%20and%20simulation%20of%20large-scale%20social%20networks%20using%20parallel%20discrete%20event%20simulation.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=B.%20Hou&author=Y.%20Yao&author=B.%20Wang&author=D.%20Liao&journal=International&volume=89&issue=10&pages=1173-1183&publication_year=2013)
23. Hybinette M and Fujimoto RM (1997). Cloning: A novel method for interactive parallel simulation. In: *Proceedings of the 29th conference on Winter simulation*, Atlanta, Georgia, pp 444–451.
24. Hybinette M and Fujimoto RM (2001). Cloning parallel simulations. *ACM Transactions on Modeling and Computer Simulation (TOMACS)* **11**(4): 378–407.CrossRef (http://dx.doi.org/10.1145/508366.508370)Google Scholar (http://scholar.google.com/scholar_lookup?title=Cloning%20parallel%20simulations&author=M.%20Hybinette&author=RM.%20Fujimoto&journal=ACM%20Transactions%20on%20Modeling%20and%20Computer%20Simulation%20%28TOMACS%29&volume=11&issue=4&pages=378-407&publication_year=2001)
25. Kite S, Wood C, Taylor SJ and Mustafee N (2011). SakerGrid: Simulation experimentation using grid enabled simulation software. In: *Proceedings of the 2011 Winter Simulation Conference (WSC)*, Phoenix, Arizona, pp 2283–2293.
26. Li BH (2004). Some focusing points in development of modern modeling and simulation technology. In: *Proceedings of the Third Asian simulation conference on Systems Modeling and Simulation: theory and applications*, pp 12–22.
27. Li Z, Cai W and Turner SJ (2014). Un-identical federate replication structure for improving performance of HLA-based simulations. *Simulation Modelling Practice and Theory* **48**: 112–128.CrossRef (http://dx.doi.org/10.1016/j.simpat.2014.06.016)Google Scholar (http://scholar.google.com/scholar_lookup?title=Un-identical%20federate%20replication%20structure%20for%20improving%20performance%20of%20HLA-based%20simulations&author=Z.%20Li&author=W.%20Cai&author=SJ.%20Turner&journal=Simulation%20Modelling%20Practice%20and%20Theory&volume=48&pages=112-128&publication_year=2014)
28. Liang H, Liu L, Yao Y, Liu B, Mu X and Li M (2012). Research on self-adaptive communication mechanism for high performance RTI. *Journal of National University of Defense Technology* **34**(3): 148–153.Google Scholar (http://scholar.google.com/scholar_lookup?title=Research%20on%20self-adaptive%20communication%20mechanism%20for%20high%20performance%20RTI&author=H.%20Liang&author=L.%20Liu&author=Y.%20Yao&author=B.%20Liu&author=X.%20Mu&author=M.%20Li&journal=Journal%20of%20National%20University%20of%20Defense%20Technology&volume=34&issue=3&pages=148-153&publication_year=2012)
29. Liu B, Ji Z, Yao Y and Zhao Y (2011). Design of a multi-sample scheduling tool for two classes of analytic simulations. *Journal of National University of Defense Technology* **5**(4): 21–33.Google Scholar (http://scholar.google.com/scholar_lookup?title=Design%20of%20a%20multi-sample%20scheduling%20tool%20for%20two%20classes%20of%20analytic%20simulations&author=B.%20Liu&author=Z.%20Ji&author=Y.%20Yao&author=Y.%20Zhao&journal=Journal%20of%20National%20University%20of%20Defense%20Technology&volume=5&issue=4&pages=21-33&publication_year=2011)
30. Liu B, Yao Y and Wang H (2012). On the technology of high-performance parallel simulation. *Chinese Journal of Electronics* **21**(1): 1–6.Google Scholar (http://scholar.google.com/scholar_lookup?title=On%20the%20technology%20of%20high-performance%20parallel%20simulation&author=B.%20Liu&author=Y.%20Yao&author=H.%20Wang&journal=Chinese%20Journal%20of%20Electronics&volume=21&issue=1&pages=1-6&publication_year=2012)
31. Liu Q and Wainer G (2012). Multicore acceleration of discrete event system specification systems. *Simulation: Transactions of the Society for Modeling and*

Simulation International **88**(7): 801–831.Google Scholar (http://scholar.google.com/scholar_lookup?title=Multicore%20acceleration%20of%20discrete%20event%20system%20specification%20systems.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=Q.%20Liu&author=G.%20Wainer&journal=International&volume=88&issue=7&pages=801-831&publication_year=2012)

32. Lynch EW and Riley GF (2009). Hardware supported time synchronization in multi-core architectures. In: *2009 ACM/IEEE/SCS 23rd Workshop on Principles of Advanced and Distributed Simulation*, pp 88–94.
33. Mcgeoch C (1992). Analyzing algorithms by simulation: Variance reduction techniques and simulation speedups. *ACM Computing Surveys (CSUR)* **24**(2): 195–212.CrossRef (http://dx.doi.org/10.1145/130844.130853)Google Scholar (http://scholar.google.com/scholar_lookup?title=Analyzing%20algorithms%20by%20simulation%3A%20Variance%20reduction%20techniques%20and%20simulation%20speedups&author=C.%20Mcgeoch&journal=ACM%20Computing%20Surveys%20%28CSUR%29&volume=24&issue=2&pages=195-212&publication_year=1992)
34. Meng D, Yao Y and Hu T (2016). A model framework for supporting online construction of low-fidelity kinematic models. In: *16th Asia Simulation Conference and SCS Autumn Simulation Multi-Conference (AsiaSim/SCS AutumnSim)*, pp 356–363.
35. Mustafee N, Katsaliaki K, Taylor SJ and Brailsford S (2009). Facilitating the analysis of a UK national blood service supply chain using distributed simulation. *Simulation: Transactions of the Society for Modeling and Simulation International* **85**(2): 113–128.Google Scholar (http://scholar.google.com/scholar_lookup?title=Facilitating%20the%20analysis%20of%20a%20UK%20national%20blood%20service%20supply%20chain%20using%20distributed%20simulation.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=N.%20Mustafee&author=K.%20Katsaliaki&author=SJ.%20Taylor&author=S.%20Brailsford&journal=International&volume=85&issue=2&pages=113-128&publication_year=2009)
36. Perles A, Molero X, Marti A and Serrano JJ (2002). Analysis of coverage and performance of the variable sized replications simulation method in parallel. In: *Proceedings of the 16th European Simulation Multiconference on Modelling and Simulation*, pp 219–223.
37. Perumalla KS (2005). µsik-a micro-kernel for parallel/distributed simulation systems. In: *2005 ACM/IEEE/SCS 19rd Workshop on Principles of Advanced and Distributed Simulation*, CA, USA, pp 59–68.
38. Perumalla KS and Seal SK (2011). Discrete event modeling and massively parallel execution of epidemic outbreak phenomena. *Simulation: Transactions of the Society for Modeling and Simulation International* **88**(7): 768–783.Google Scholar (http://scholar.google.com/scholar_lookup?title=Discrete%20event%20modeling%20and%20massively%20parallel%20execution%20of%20epidemic%20outbreak%20phenomena.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=KS.%20Perumalla&author=SK.%20Seal&journal=International&volume=88&issue=7&pages=768-783&publication_year=2011)
39. Quaglia F (2015). A low-overhead constant-time Lowest-Timestamp-First CPU scheduler for high-performance optimistic simulation platforms. *Simulation Modelling Practice and Theory* **53**: 103–122.CrossRef (http://dx.doi.org/10.1016/j.simpat.2015.01.009)Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20low-overhead%20constant-time%20Lowest-Timestamp-First%20CPU%20scheduler%20for%20high-performance%20optimistic%20simulation%20platforms&author=F.%20Quaglia&journal=Simulation%20Modelling%20Practice%20and%20Theory&volume=53&pages=103-122&publication_year=2015)
40. Rak M, Cuomo A and Villano U (2012). Mjades: Concurrent simulation in the cloud. In: *2012 Sixth International Conference on Complex, Intelligent and Software Intensive Systems (CISIS)*, pp 853–860.
41. Steinman JS (1993). Incremental state saving in SPEEDES using C++. In: *Proceedings of the 1993 Winter Simulation Conference (WSC)*, pp 687–696.
42. Steinman JS (2005). The WarpIV simulation kernel. In: *Proceedings of the 19th Workshop on Principles of Advanced and Distributed Simulation*, pp 161–170.
43. Sutter H (2005). The free lunch is over: A fundamental turn toward concurrency in software. *Dr. Dobb's Journal* **30**(3): 202–210.Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20free%20lunch%20is%20over%3A%20A%20fundamental%20turn%20toward%20concurrency%20in%20software&author=H.%20Sutter&journal=Dr.%20Dobb%E2%80%99s%20Journal&volume=30&issue=3&pages=202-210&publication_year=2005)

44. Tang W and Yao Y (2013). A GPU-based discrete event simulation kernel. *Simulation: Transactions of the Society for Modeling and Simulation International* **89**(11): 1335–1354.Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20GPU-based%20discrete%20event%20simulation%20kernel.%20Simulation%3A%20Transactions%20of%20the%20Society%20for%20Modeling%20and%20Simulation%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20&author=W.%20Tang&author=Y.%20Yao&journal=International&volume=89&issue=11&pages=1335-1354&publication_year=2013)
45. Wilmarth TL and Kale LV (2004). Pose: Getting over grainsize in parallel discrete event simulation. In: *International Conference on Parallel Processing (ICPP)*, pp 12–19.
46. Yao Y, Meng D, Qu Q, Li J and Jiang Z (2016). Development and experimentation of PDES-based analytic simulation. In: *Proceedings of the 2016 annual ACM Conference on SIGSIM Principles of Advanced Discrete Simulation*. Banff, Alberta, Canada, pp 123–126.
47. Yao Y and Zhang Y (2008). Solution for analytic simulation based on parallel processing. *Journal of System Simulation* **20**(24): 6617–6621.Google Scholar (http://scholar.google.com/scholar_lookup?title=Solution%20for%20analytic%20simulation%20based%20on%20parallel%20processing&author=Y.%20Yao&author=Y.%20Zhang&journal=Journal%20of%20System%20Simulation&volume=20&issue=24&pages=6617-6621&publication_year=2008)
48. Yilmaz L, Taylor SJ, Fujimoto RM and Darema F (2014). Panel: The future of research in modeling & simulation. In: *Proceedings of the 2014 Winter Simulation Conference (WSC)*, pp 2797–2811.
49. Zeigler BP, Praehofer H and Kim TG (2000). *Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems*. Academic Press, New York.Google Scholar (http://scholar.google.com/scholar_lookup?title=Theory%20of%20Modeling%20and%20Simulation%3A%20Integrating%20Discrete%20Event%20and%20Continuous%20Complex%20Dynamic%20Systems&author=BP.%20Zeigler&author=H.%20Praehofer&author=TG.%20Kim&publication_year=2000)
50. Zhang Y and Yao Y (2010). Dynamic matching approach for interest management in distributed agent-based simulation. In: *2010 International Conference on Computer Application and System Modeling (ICCASM)*, pp 432–436.
51. Zhu F, Yao Y, Tang W and Chen D (2015). A high performance framework for modeling and simulation of large-scale complex systems. *Future Generation Computer Systems* **51**: 132–141.CrossRef (http://dx.doi.org/10.1016/j.future.2014.11.018)Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20high%20performance%20framework%20for%20modeling%20and%20simulation%20of%20large-scale%20complex%20systems&author=F.%20Zhu&author=Y.%20Yao&author=W.%20Tang&author=D.%20Chen&journal=Future%20Generation%20Computer%20Systems&volume=51&pages=132-141&publication_year=2015)

Copyright information

About this article

- Publisher Name Palgrave Macmillan UK
- Print ISSN 1747-7778
- Online ISSN 1747-7786

- About this journal
- Reprints and Permissions

palgrave macmillan

- Co-published with

Palgrave Macmillan

SPRINGER NATURE