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6. AUTHORS James H. Anderson	5d. PROJECT NUMBER
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14. ABSTRACT This project was directed at component-based soft real-time (SRT) systems implemented on multicore platforms. To facilitate the deployment of such systems, multicore resource-allocation infrastructure was developed to support stochastically provisioned SRT software components on multicore platforms. This infrastructure enables different components to be temporally isolated from one another and to be provisioned based upon average-case or near-average-case task execution times. The main intellectual contribution of this project was the development of methods for allocating CPU time to components and associated analysis for validating SRT correctness.

15. SUBJECT TERMS soft real-time, multicore, containers, stochastic analysis, adaptivity

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INVESTIGATOR(S):

Name: James H Anderson
Email: anderson@cs.unc.edu
Phone Number: 9199621757
Principal: Y

Organization: **University of North Carolina - Chapel Hill**

Address: 104 Airport Drive, CB 1350, Chapel Hill, NC 275991350

Country: USA

DUNS Number: 608195277

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Submitted By: James Anderson

Email: anderson@cs.unc.edu

Phone: (919) 962-1757

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Major Goals: This project was directed at soft real-time (SRT) applications implemented on multicore platforms, wherein the definition of "soft real-time" requires that deadline tardiness be (provably) bounded. Our efforts particularly focused on application scenarios where the workload to be supported consists of components or sub-systems that are encapsulated within "containers" that temporally isolate such components or sub-systems from one another. A container is simply a scheduling abstraction: in general, one can imagine a hierarchy of containers, where each parent container can include child containers and the "leaf" containers are simply tasks (i.e., ordinary programs). From a scheduling point of view, thinking about container-based systems is a matter of managing "supply" and "demand": each container receives some amount of processing supply (over time) from its parent and can allocate that processing supply (over time) to its children. The motivation for containers is to enable different sub-systems to be developed and analyzed separately. This is crucial for component-based system design.

In this project, we were interested in increasing the flexibility of container-based systems in two ways. First, we wanted to enable provisioned supplies to be allocated on an average-case or near-average-case basis, i.e., we wanted to be able to provision tasks based upon their average-case, rather than worst-case, execution times. The rationale here is that SRT workloads might more naturally be provisioned on an average-case basis (in contrast to a safety-critical hard-real-time workload, which would require a worst-case provisioning). Enabling provisionings based on the average case necessarily involves the introduction of stochastic analysis methods. Second, we wanted to make such provisionings "adaptive"; that is, we wanted to be able to change the provisioned supply for a container at runtime. The motivation here is to be able to support applications that must dynamically react to environmental changes by reallocating processing resources.

The major goals of this project, as articulated in the project proposal, were as follows: (1) devise appropriate scheduling policies for SRT container hierarchies; (2) devise techniques that enable such hierarchies to be dynamically re-structured or re-provisioned at runtime; (3) devise analysis that enables such provisionings to be based upon average-case or near-average-case task execution times; (4) develop policies for controlling overload, which will be a common-case problem in the kinds of dynamic, adaptive systems that were the main focus of this research; (5) conduct evaluations inspired by use cases involving unmanned aerial vehicles (UAVs) and autonomous automobiles.

Accomplishments: At the outset of this project, we realized that a better understanding was required for how to schedule real-time tasks in situations where the full supply of all processors is not available. When such tasks are encapsulated within a container, they are scheduled using the processing supply that the container makes available. However, because that container may itself be contained within yet another container, the supply that it

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can allocate may or may not correspond to the capacity of an integral number of processors. For example, we can imagine a container that receives the full capacity of one processor and half the capacity of a second processor---the second processor is not fully available to it.

In essence, tasks executing within such a container run on a two-processor system, where one processor is "fast" and one processor is "slow"---the slow processor runs at half the speed of the fast processor. In the scheduling literature, multiprocessor platforms like this where different processors can run at different speeds are called "uniform heterogeneous" multiprocessor platforms. In short, when thinking about the scheduling of tasks within a container, there are deep connections to work on scheduling tasks on uniform heterogeneous multiprocessors.

Realizing this, we determined that the state of knowledge regarding work on uniform heterogeneous multiprocessors was not sufficiently mature to suite our needs in this project. In particular, prior to our project, no work pertaining to SRT task systems had been done with respect to this model. As a result, we spent considerable effort developing SRT scheduling algorithms and associated analysis for uniform heterogeneous platforms. In particular, we wrote five papers on this topic in which optimal scheduling algorithms are presented. This papers were (or will be) presented at RTNS 2014, ESTIMEDIA 2014, ECRIS 2015, RTCSA 2015, and RTSS 2017.

Another issue that we devoted considerable attention to was that of stochastic analysis. In prior work, we presented analysis that enables SRT tasks to be provisioned stochastically and deadline tardiness to be bounded in expectation. However, that analysis requires strong independence assumptions that might not hold in practice. To ease such assumptions, we developed the idea of an "independence threshold." Such a threshold is a "tunable" per-task parameter that can be adjusted to control the extent of dependency in task execution times as assumed in analysis; such thresholds can even be applied in settings where explicit dependencies exist among tasks through resource sharing. A paper on this topic was presented at RTSS 2014. We also devised stochastic analysis that can be applied to mixed-criticality systems to determine failure probabilities. In a mixed-criticality system, tasks exist at different criticality levels, and different levels of reliability are required at different levels. Our specific contribution was to develop a new scheduling algorithm for such systems, along with associated analysis that shows that reliability requirements are met. A paper on this topic was presented at RTCSA 2015.

In work on container-based allocation frameworks, the overarching goal is to enable different real-time software components to share a physical multiprocessor platform by giving each component the "illusion" of executing on a dedicated virtual platform. Such an illusion is supported by specifying a supply interface that indicates how computation time is made available to a component over time. A number of approaches for defining such interfaces have been proposed: so many that sifting through them all can be confusing for the practitioner. In the case of SRT applications, our group showed in prior work that one particular proposed interface, called "minimum-parallelism (MP)" supply, enables the efficient co-scheduling of different components. In the project proposal, we discussed MP supply at length and proposed using it as our main supply interface abstraction. While the emphasis of this project is SRT applications, after thinking further about the avionics and automotive use cases targeted in our experimental research, we realized that many systems that could benefit from our work might have hard real-time (HRT) components as well. As a result, we decided to re-examine MP supply from the perspective of HRT task systems. As a result of this re-examination, we were able to show that MP supply dominates all other notions of multiprocessor supply that have been studied in the literature. This result suggests that MP supply should be the focus in future work on real-time multiprocessor virtualization. It also suggests that our choice of focusing on MP supply was a sound one. A paper on this topic was presented at RTSS 2016.

As noted above, container-based frameworks enable different system components or sub-systems to be temporally isolated from one another. Such isolation enables the timing constraints of different components to be validated independently. Unfortunately, in many applications domains, different system components need to share data. Clearly, any data sharing breaks the illusion of temporal isolation. In recent research, we studied data-sharing-related problems that arise when tasks share data through producer/consumer relationships. In particular, we studied several strategies for allocating shared producer/consumer buffers and evaluated these strategies with respect to their impacts on temporal isolation. A paper on this topic was presented at RTSS 2016. In addition to such "explicit" sharing, tasks may "implicitly" share memory pages by linking in shared libraries. Such sharing can cause memory and cache contention that can also compromise temporal isolation. We investigated this issue as well and presented techniques for sharing libraries that preserve the illusion of temporal isolation. A paper on this topic was presented at RTAS 2017.

A SRT task that is provisioned on an average-case or near-average-case basis might easily overrun its allocated execution budget at runtime. If many tasks experience such overruns concurrently, then the system might become

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temporarily overloaded. As discussed at length in the project proposal, overload-control policies are needed to deal with such situations. We published two papers that focus on such policies. One of these papers was presented at ECRTS 2016. In the approach considered in that paper, tasks are partitioned among different criticality levels and overloads are dealt with by temporarily dropping lower-criticality tasks. The main intellectual challenge addressed in that paper was to devise conditions that determine when an overload has abated and tasks no longer need to be dropped. Our second paper on overload control was published in IEEE Transactions on Neural Networks and Learning Systems. In that paper, overload control was studied as an optimization problem that seeks to maximize overall system "utility." (The concept of "utility" is somewhat related to "criticality." More-critical tasks have higher utility than less-critical ones.) This paper shows that utility can be maximized by using a neural-network-based optimization framework.

One of our project goals was to support dynamic task systems in which system composition may change at runtime. Towards this end, we investigated dynamic mode-change protocols. A paper on this topic is currently under submission.

Another goal of the project was to conduct evaluations inspired by use cases involving UAVs and autonomous automobiles. We spent considerable time trying to better understand the nature of workloads that arise in autonomous-driving applications. To date, we have published six papers on this topic. These papers were (or will be) presented at RTNS 2015, RTSS 2015, OSPERT 2016, RTAS 2017, OSPERT 2017, and RTSS 2017.

Training Opportunities: One student, Kecheng Yang, will complete his Ph.D. degree under this project (this coming year). A second student, Rui Liu, completed his M.S. degree under this project. Several other graduate students have also been partially supported.

Results Dissemination: During this reporting period, presentations concerning the research funded by this project were made at the following conferences:

The 16th International Conference on Embedded Software (EMSOFT), Pittsburgh, PA, October 2016 (one paper).

The 24th International Conference on Real-Time Networks and Systems (RTNS), Brest, France, October 2016 (one paper).

The 36th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS), Chennai, India, December 2016 (one paper).

The 37th IEEE Real-Time Systems Symposium (RTSS), Porto, Portugal, December 2016 (three papers).

The 23rd IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS), Pittsburgh, PA, April 2017 (two papers).

The 29th Euromicro Conference on Real-Time Systems (ECRTS), Dubrovnik, Croatia, June 2017 (two papers).

The 13th Annual Workshop on Operating Systems Platforms for Embedded Real-Time Applications (OSPERT), Dubrovnik, Croatia, June 2017 (one paper).

Additionally, two presentations will be made at the upcoming RTSS conference in Paris, France in December.

Also, Prof. Anderson made presentations at: the Air Force Research Laboratory in Dayton, Ohio in July 2017; the Second TCRTS Workshop on Certifiable Multicore Avionics and Automotive Systems, Pittsburgh, PA, April 2017; the Dagstuhl Seminar on Mixed Criticality on Multicore/Manycore Platforms, Dagstuhl, Germany, March 2017; Northrop Grumman, Los Angeles, CA, January 2017; Invited Speaker Series, Computer Science Department, SUNY Binghamton, October 2016.

Honors and Awards: Nothing to Report

Protocol Activity Status:

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Technology Transfer: We are working with Prakash Sarathy's group at Northrop Grumman Corp. in Los Angeles, CA to apply some of the results of this project to unmanned aerial vehicles (UAVs).

PARTICIPANTS:

Participant Type: Faculty

Participant: James H. Anderson

Person Months Worked:

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member:

Other Collaborators:

Participant Type: Faculty

Participant: Sanjoy K. Baruah

Person Months Worked:

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member:

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Rui Liu

Person Months Worked:

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member:

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Chun Kun Wang

Person Months Worked:

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member:

Other Collaborators:

Participant Type: PD/PI

Participant: James H. Anderson

Person Months Worked: 1.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Co PD/PI

Participant: Sanjoy K. Baruah

Person Months Worked: 1.00

Funding Support:

Project Contribution:

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International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Kecheng Yang

Person Months Worked: 12.00

Funding Support:

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Malcolm Mollison

Person Months Worked: 4.00

Funding Support:

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: PD/PI

Participant: James Anderson

Person Months Worked: 1.00

Funding Support:

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Co PD/PI

Participant: Sanjoy Baruah

Person Months Worked: 1.00

Funding Support:

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Kecheng Yang

Person Months Worked: 12.00

Funding Support:

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Stephen Tang

Person Months Worked: 9.00

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 37th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 01-Aug-2017 Conference Date: 03-Dec-2016 Date Published: 20-Jul-2016
Conference Location: Porto, Portugal
Paper Title: Reconciling the Tension Between Hardware Isolation and Data Sharing in Mixed-Criticality, Multicore Systems
Authors: M. Chisholm, N. Kim, B. Ward, N. Otterness, J. Anderson, F.D. Smith
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 37th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 01-Aug-2017 Conference Date: 03-Dec-2016 Date Published: 20-Jul-2016
Conference Location: Porto, Portugal
Paper Title: On the Dominance of Minimum-Parallelism Multiprocessor Supply
Authors: K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 12th Annual Workshop on Operating Systems Platforms for Embedded Real-Time Applications (OSPERT)
Date Received: 19-Jul-2016 Conference Date: 08-Jul-2016 Date Published: 19-Jul-2016
Conference Location: Toulouse, France
Paper Title: GPU Sharing for Image Processing in Embedded Real-Time Systems
Authors: N. Otterness, V. Miller, M. Yang, J. Anderson, F.D. Smith
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 28th Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 19-Jul-2016 Conference Date: 11-Jul-2016 Date Published: 19-Jul-2016
Conference Location: Toulouse, France
Paper Title: Multiprocessor Real-Time Locking Protocols for Replicated Resources
Authors: C. Nemitz, K. Yang, M. Yang, P. Ekberg, J. Anderson
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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 28th Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 19-Jul-2016 Conference Date: 11-Jul-2016 Date Published: 19-Jul-2016
Conference Location: Toulouse, France
Paper Title: Scheduling Mixed-Criticality Systems to Guarantee Some Service Under All Non-Erroneous Behaviors
Authors: S. Baruah, A. Burns, Z. Guo
Acknowledged Federal Support: **Y**

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Conference Name: 28th Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 20-Jul-2016 Conference Date: 08-Jul-2016 Date Published: 08-Jul-2016
Conference Location: Toulouse, France
Paper Title: ILP-Based Approaches to Partitioning Recurrent Workloads upon Heterogeneous Multiprocessors
Authors: S. Baruah, V. Bonifaci, R. Bruni, A. Marchetti-Spaccamela
Acknowledged Federal Support: **Y**

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Conference Name: 22nd IEEE Real-Time Embedded Technology and Applications Symposium (RTAS)
Date Received: 20-Jul-2016 Conference Date: 08-Apr-2016 Date Published: 15-Apr-2016
Conference Location: Vienna, Austria
Paper Title: Attacking the One-Out-Of-m Multicore Problem by Combining Hardware Management with Mixed-Criticality Provisioning
Authors: N. Kim, B. Ward, M. Chisholm, C.-Y. Fu, J. Anderson, F.D. Smith
Acknowledged Federal Support: **Y**

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Conference Name: 36th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 20-Jul-2016 Conference Date: 04-Dec-2015 Date Published: 04-Dec-2015
Conference Location: San Antonio, TX
Paper Title: MC-Fluid: Simplified and Optimally Quantified
Authors: S. Baruah, A. Easwaran, and Z. Guo
Acknowledged Federal Support: **Y**

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Conference Name: Workshop on Mixed-Critically Systems (WMC)
Date Received: 20-Jul-2016 Conference Date: 04-Dec-2015 Date Published: 04-Dec-2015
Conference Location: San Antonio, TX
Paper Title: Semi-Partitioned Cyclic Executives for Mixed Criticality Systems
Authors: A. Burns, S. Baruah
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Workshop on Mixed-Criticality Systems (WMC)
Date Received: 20-Jul-2016 Conference Date: 04-Dec-2015 Date Published: 04-Dec-2015
Conference Location: San Antonio, TX
Paper Title: Mixed-Criticality Job Models: A Comparison
Authors: S. Baruah, Z. Guo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Symposium on Dependable Software Engineering: Theories, Tools and Applications (SETTA)
Date Received: 20-Jul-2016 Conference Date: 13-Nov-2015 Date Published: 20-Nov-2015
Conference Location: Nanjing, China
Paper Title: Criticality-Cognizant Modeling and Analysis of Mixed-Criticality Systems (Extended Abstract)
Authors: S. Baruah
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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 23rd International Conference on Real-Time Networks and Systems (RTNS)
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Conference Location: Lille, France
Paper Title: A Contention-Sensitive Fine-Grained Locking Protocol for Multiprocessor Real-Time Systems
Authors: C. Jarrett, B. Ward, J. Anderson
Acknowledged Federal Support: **Y**

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Conference Location: Lille, France
Paper Title: Analysis for Supporting Real-Time Computer Vision Workloads using OpenVX on Multicore+GPU Platforms
Authors: K. Yang, G. Elliott, J. Anderson
Acknowledged Federal Support: **Y**

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Conference Name: 20th International Conference on Real-Time and Network Systems (RTNS)
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Conference Location: Lille, France
Paper Title: The Concurrent Consideration of Uncertainty in WCETs and Processor Speeds in Mixed Criticality Systems
Authors: Z. Guo, S. Baruah
Acknowledged Federal Support: **Y**

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Conference Name: 15th International Conference on Embedded Software (EMSOFT)
Date Received: 20-Jul-2016 Conference Date: 16-Oct-2015 Date Published: 23-Oct-2015
Conference Location: Amsterdam, Netherlands
Paper Title: The Federated Scheduling of Systems of Conditional Sporadic DAG Tasks
Authors: S. Baruah
Acknowledged Federal Support: **Y**

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Conference Name: 12th IEEE Symposium on Embedded Systems for Real-Time Multimedia
Date Received: 21-Jul-2016 Conference Date: 04-Oct-2014 Date Published: 08-Oct-2014
Conference Location: New Delhi, India
Paper Title: Optimal GEDF-Based Schedulers that Allow Intra-Task Parallelism on Heterogeneous Multiprocessors
Authors: K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 20-Jul-2016 Conference Date: 10-Jul-2015 Date Published: 17-Jul-2015
Conference Location: Lund, Sweden
Paper Title: The Global EDF scheduling of systems of conditional sporadic DAG tasks
Authors: S. Baruah, V. Bonifaci and A. Marchetti-Spaccamela
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 22nd International Conference on Real-Time Networks and Systems
Date Received: 20-Jul-2016 Conference Date: 08-Oct-2014 Date Published: 10-Oct-2014
Conference Location: Versailles, France
Paper Title: Optimizing Preemption-Overhead Accounting in Multiprocessor Real-Time Systems
Authors: B. Ward, A. Thekkilakattil, J. Anderson
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Conference Name: 27 Euromicro Conference on Real-Time Systems
Date Received: 20-Jul-2016 Conference Date: 10-Jul-2015 Date Published: 17-Jul-2015
Conference Location: Lund, Sweden
Paper Title: An Optimal Semi-Partitioned Scheduler for Uniform Heterogeneous Multiprocessors
Authors: K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

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Conference Name: ACM/IEEE 6th International Conference on Cyber-Physical Systems (ICCPS)
Date Received: 20-Jul-2016 Conference Date: 02-Apr-2015 Date Published: 10-Apr-2015
Conference Location: Seattle, Washington
Paper Title: Uniprocessor EDF scheduling of AVR task systems
Authors: Z. Guo, S. Baruah
Acknowledged Federal Support: **Y**

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Conference Name: 18th International Conference on Hybrid Systems: Computation and Control (HSCC)
Date Received: 20-Jul-2016 Conference Date: 16-Apr-2015 Date Published: 17-Apr-2015
Conference Location: Seattle, Washington
Paper Title: Dynamic scheduling for networked control systems
Authors: I. Saha, S. Baruah, R. Majumdar
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Conference Name: 35th IEEE Real-Time Systems Symposium
Date Received: 20-Jul-2016 Conference Date: 04-Dec-2014 Date Published: 10-Dec-2014
Conference Location: Rome, Italy
Paper Title: Exploring the Multitude of Real-Time Multi-GPU Configurations
Authors: G. Elliott, J. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 35th IEEE Real-Time Systems Symposium
Date Received: 21-Jul-2016 Conference Date: 05-Dec-2014 Date Published: 10-Dec-2014
Conference Location: Rome, Italy
Paper Title: Independence Thresholds: Balancing Tractability and Practicality in Soft Real-Time Stochastic Analysis
Authors: R. Liu, A. Mills, J. Anderson
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Conference Name: EuroMicro Conference on Real-Time Systems (ECRTS)
Date Received: 21-Jul-2016 Conference Date: 10-Jul-2015 Date Published: 15-Jul-2015
Conference Location: Lund, Sweden
Paper Title: Cyclic Executives, Multi-Core Platforms and Mixed Criticality Applications
Authors: A. Burns, T. Fleming, S. Baruah
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Conference Location: San Antonio, Texas
Paper Title: Cache Sharing and Isolation Tradeoffs in Multicore Mixed-Criticality Systems
Authors: M. Chisholm, B. Ward, N. Kim, J. Anderson
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Conference Name: 21st IEEE International Conference on Embedded and Real-Time Computing Systems and Applications
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Conference Location: Hong Kong, China
Paper Title: On the Soft Real-Time Optimality of Global EDF on Multiprocessors: From Identical to Uniform Heterogeneous
Authors: K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

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Conference Name: 36th IEEE Real-Time Systems Symposium
Date Received: 21-Jul-2016 Conference Date: 04-Dec-2015 Date Published: 10-Dec-2015
Conference Location: San Antonio, Texas
Paper Title: Supporting Real-Time Computer Vision Workloads using OpenVX on Multicore+GPU Platforms
Authors: G. Elliott, K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 36th IEEE Real-Time Systems Symposium
Date Received: 21-Jul-2016 Conference Date: 04-Dec-2015 Date Published: 10-Dec-2015
Conference Location: San Antonio, Texas
Paper Title: Relaxing Resource-Sharing Constraints for Improved Hardware Management and Schedulability
Authors: B. Ward
Acknowledged Federal Support: **Y**

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Conference Name: 21st IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCISA)
Date Received: 21-Jul-2016 Conference Date: 21-Aug-2015 Date Published: 25-Aug-2015
Conference Location: Hong Kong, China
Paper Title: EDF schedulability analysis on mixed-criticality systems with permitted failure probability
Authors: Z. Guo, L. Santinalli, K. Yang
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 22nd International Conference on Real-Time Networks and Systems
Date Received: 21-Jul-2016 Conference Date: 10-Oct-2014 Date Published: 15-Oct-2014
Conference Location: Versailles, France
Paper Title: Soft Real-Time Semi-Partitioned Scheduling with Restricted Migrations on Uniform Heterogeneous Multiprocessors
Authors: K. Yang, J. Anderson
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: 37th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 31-Jul-2017 Conference Date: 15-Dec-2017 Date Published:
Conference Location: Paris, France
Paper Title: On the Soft Real-Time Optimality of Global EDF on Uniform Multiprocessors
Authors: Kecheng Yang, James Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 0-Other
Conference Name: 37th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 31-Jul-2017 Conference Date: 15-Dec-2017 Date Published:
Conference Location: Paris, France
Paper Title: GPU Scheduling on the NVIDIA TX2: Hidden Details Revealed
Authors: Tanya Amert, Nathan Otterness, Ming Yang, James Anderson, F. Donelson Smith
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 29th Euromicro Conference on Real-Time Systems (ECRTS) Work in Progress Session
Date Received: 31-Jul-2017 Conference Date: 27-Jun-2017 Date Published:
Conference Location: Dubrovnik, Croatia
Paper Title: Response-Time Bounds for Concurrent GPU Scheduling
Authors: Ming Yang, James H. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 13th Annual Workshop on Operating Systems Platforms for Embedded Real-Time Applications (OSPERT)
Date Received: 01-Aug-2017 Conference Date: 27-Jun-2017 Date Published: 27-Jun-2017
Conference Location: Dubrovnik, Croatia
Paper Title: Inferring the Scheduling Policies of an Embedded CUDA GPU
Authors: Nathan Otterness, Ming Yang, Tanya Amert, James H. Anderson, F. Donelson Smith
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 29th Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 01-Aug-2017 Conference Date: 27-Jun-2017 Date Published: 27-Jun-2017
Conference Location: Dubrovnik, Croatia
Paper Title: Optimal Dataflow Scheduling on a Heterogeneous Multiprocessor with Reduced Response Time Bounds
Authors: Zheng Dong, Cong Liu, Alan Gatherer, Lee McFearin, Peter Yan, James H. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 29th Euromicro Conference on Real-Time Systems (ECRTS)
Date Received: 01-Aug-2017 Conference Date: 27-Jun-2017 Date Published: 27-Jun-2017
Conference Location: Dubrovnik, Croatia
Paper Title: Applying Real-Time Scheduling Theory to the Synchronous Data Flow Model of Computation
Authors: Abhishek Singh, Pontus Ekberg, Sanjoy K. Baruah
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 23rd IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS)
Date Received: 01-Aug-2017 Conference Date: 18-Apr-2017 Date Published: 18-Apr-2017
Conference Location: Pittsburgh, PA
Paper Title: Allowing Shared Libraries while Supporting Hardware Isolation in Multicore Real-Time Systems
Authors: Namhoon Kim, Micaiah Chisholm, Nathan Otterness, James H. Anderson, F. Donelson Smith
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 23rd IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS)
Date Received: 01-Aug-2017 Conference Date: 18-Apr-2017 Date Published: 18-Apr-2017
Conference Location: Pittsburgh, PA
Paper Title: An Evaluation of the NVIDIA TX1 for Supporting Real-Time Computer-Vision Workloads
Authors: Nathan Otterness, Ming Yang, Sarah Rust, Eunbyung Park, James H. Anderson, F. Donelson Smith, Al
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 37th IEEE Real-Time Systems Symposium (RTSS)
Date Received: 01-Aug-2017 Conference Date: 29-Nov-2016 Date Published:
Conference Location: Porto, Portugal
Paper Title: Schedulability Analysis for a General Model of Mixed-Criticality Recurrent Real-Time Tasks
Authors: Sanjoy Baruah
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 36th IARCS Annual Conference on Foundations of Software Technology and Theoretical
Computer Science (FSTTCS)
Date Received: 01-Aug-2017 Conference Date: 13-Dec-2016 Date Published:
Conference Location: Chennai, India
Paper Title: Mixed-criticality Scheduling to Minimize Makespan
Authors: Sanjoy Baruah, Arvind Easwaran, Zhishan Guo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 24th International Conference on Real-Time Networks and Systems
Date Received: 04-Aug-2017 Conference Date: 02-Oct-2016 Date Published:
Conference Location: Brest, France
Paper Title: Reducing Response-Time Bounds for DAG-Based Task Systems on Heterogeneous Multicore
Platforms
Authors: Kecheng Yang, Ming Yang, James H. Anderson
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 16th International Conference on Embedded Software (EMSOFT)
Date Received: 04-Aug-2017 Conference Date: 02-Oct-2016 Date Published: 02-Oct-2016
Conference Location: Pittsburgh, PA
Paper Title: Schedulability Analysis of Mixed-Criticality Systems with Multiple Frequency Specifications
Authors: Sanjoy Baruah
Acknowledged Federal Support: **Y**

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Nothing to report in the uploaded pdf (see accomplishments).