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SenSys '22

Proceedings of the Twentieth

ACM Conference on Embedded Networked Sensor Systems

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Message from the ACM SenSys 2022 General Co-Chairs

Welcome to ACM SenSys 2022, the 20th ACM Conference on Embedded Networked Sensor Systems, the premier computer systems conference focused on networked sensing systems and applications. The community's commitment to advancing the state-of-the-art in embedded sensing research allowed us to host the first in-person SenSys since the start of the COVID-19 pandemic and brought special attention to its 20th anniversary, celebrating a long history of impactful research contributions.

For those that made it to the conference in Boston, Massachusetts, we hoped you enjoyed exploring the city and had a chance to see some of its historical roots and experienced the vibrant academic atmosphere resulting from the city's large number of colleges and universities.

For all the participants, whether in-person or remote, we are extremely thankful for your contributions to the success of ACM Sensys 2022, and hope you had a fulfilling conference experience, with a technical program composed of two keynote speeches (one jointly with BuildSys), 52 full papers, 8 workshops (including the PhD forum with BuildSys), 35 posters, and 19 demos. All presentations, whether they were delivered in-person or remotely, were recorded and are being made available after the conference.

SenSys 2022 would not have been possible without the commitment of many people, who generously contributed with their work to a successful conference, specifically the Technical Program Committee Chairs and Members, Workshop Chair, Journal Track Chairs, PhD Forum Chair, Local Arrangements and Online Support Chair, Poster and Demo Chair, Web Chair, Finance Chairs, Publicity Chairs, Publication Chairs, Sponsorship Chairs, and, last but not least, the Student Volunteers.

Last but not least, please join us in thanking our sponsors, namely QUALCOMM, Nokia Bell Labs, Google, and the Manning College of Information and Computer Sciences at UMass Amherst. Special thanks are due to April Mosqus and John Otero, of ACM, for their patience and competent support, and to ACM SIGMOBILE, SIGARCH, and SIGMETRICS for sponsoring 11 student travel grants.

Jeremy Gummeson (University of Massachusetts Amherst)
Sunghoon Ivan Lee (University of Massachusetts Amherst)
ACM SenSys 2022 General Co-Chairs

Message from the ACM SenSys 2022 Program Co-Chairs

Welcome to the 20th ACM Conference on Embedded Networked Sensor Systems (SenSys 2022). SenSys is a highly selective, single-track forum for research on systems issues of sensors and sensor-enabled smart systems.

We are excited to announce this program and witness the field thriving despite the challenges during the COVID pandemic. This year we received a total of 209 submissions, one of the highest numbers in the history of SenSys. All papers went through a rigorous double-blind reviewing process by a Technical Program Committee that consisted of 65 world-class experts. Each of the reviewed papers received at least three reviews. All papers with at least one week-accept entered the second phase, in which they received at least three more reviews. A total of 159 papers entered the second phase, out of which 57 were discussed at two virtual PC meetings held on September 8th and 9th. During these meetings, the TPC selected 52 papers to enter the shepherding process. Each conditionally accepted paper was shepherded by a TPC member to ensure that the reviewers' concerns were addressed. A 'heavy shepherding' policy was adopted, and many papers were asked to provide new experimental results. Finally, all 52 papers were accepted to appear in the program, which rendered an acceptance ratio of 24.8%. The TPC were in general agreement that the quality of conference program is very high. This is also supported by the fact that the average review score of all accepted papers is 3.19 (where 3 corresponds to 'weak accept'), which is consistent with recent years. The accepted papers collectively cover many fundamental and cutting-edge aspects of sensor network systems. These include a broad set of application areas, tools, and hardware/software.

Throughout the review and shepherding process, program committee members including the program co-chairs did not have access to the reviews or discussions of the papers with conflicts of interest. After the shepherding process concluded, we identified the following 7 Best Paper Award finalists according to the review scores and comments:

- Bracelet+: Harvesting the Leaked RF Energy in VLC with Wearable Bracelet Antenna
- Hearing Heartbeat from Voice: Towards Next Generation Voice-User Interfaces with Cardiac Sensing Functions
- MicNest: Long-Range Instant Acoustic Localization of Drones in Precise Landing
- HyLink: Towards High Throughput LPWANs with LoRa Compatible Communication
- BlastNet: Exploiting Duo-Blocks for Cross-Processor Real-Time DNN Inference
- PriMask: Cascadable and Collusion-Resilient Data Masking for Mobile Cloud Inference
- DIPS: Debug Intermittently-Powered Systems Like Any Embedded System

We formed a Best Paper Award Committee, which is chaired by Polly Huang and includes Xiaofan (Fred) Jiang, Julie McCann, and Kay Römer. The committee finally selected a Best Paper Award and a Best Paper Award Runner-Up, which were announced at the conference.

As TPC co-chairs, we would like to thank the authors for submitting their best work to the conference. We are also grateful to have dedicated TPC members who demonstrated great flexibility by accommodating the changing deadlines and the compressed review timeline. Furthermore, despite these challenges, the committee members worked tirelessly to identify novel and significant contributions as well as to provide constructive feedback to the authors of all papers.

Finally, we would like to thank the entire organizing committee, and especially General Co-Chairs Jeremy Gummeson and Sunghoon Ivan Lee for their assistance. This program could not have been organized without their dedication and help. We hope you enjoy the program!

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Guoliang Xing, The Chinese University of Hong Kong

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Message from the ACM SenSys 2022 Workshop Chairs

Welcome to the seven workshops and two tutorials co-located with ACM SenSys in 2022. This year, the workshops and tutorials address a multitude of emerging and interesting research areas. The broad areas of interest in sensor systems design were low-power systems, data collection, AI for IoT, energy storage, and location estimation for blockchain, agriculture, and urban sensing applications. In particular, the following workshops were organized on Sunday November 6th 2022:

- The Tenth Workshop on Energy Harvesting and Energy-Neutral Systems (ENSSys'22), http://www.enssys.org/, organized by: Sebastian Bader (Mid Sweden University), Bashima Islam (Worcester Polytechnic Institute), Michele Magno, (ETH Zurich), Geoff V. Merrett (University of Southampton)

- The Fourth Workshop on Challenges in Artificial Intelligence and Machine Learning for Internet of Things (AIChallengeIoT'22), https://aichallengeiot.github.io/, organized by: Luis Garcia (University of Southern California, ISI), Dezhi Hong (Amazon)

- The First Workshop on Urban Sensor Networks (USN'22), https://sites.google.com/g.harvard.edu/acmusn2022/home, organized by: Alex Cabral (Harvard University), Vikram Iyer (University of Washington)

- The Fifth SenSys+BuildSys Workshop on Data: Acquisition to Analysis (DATA'22), https://data-workshop.github.io/DATA2022/, organized by: Gabe Fierro (Colorado School of Mines), Shiwei Fang (UMass Amherst)

- The Fourth Workshop on Blockchain-enabled Networked Sensor Systems (BlockSys'22), https://acmblocksys.github.io/blocksys2022/, organized by: Gowri Sankar Ramachandran (Queensland University of Technology, Australia), Bhaskar Krishnamachari (University of Southern California), Salil Kanhere (University of New South Wales, Australia)

- The First Workshop on Internet-of-Things and Sensing for Agriculture and Food Systems (AgSys'22), https://sites.google.com/uw.edu/agsys2022/home, organized by: Vaishnavi Ranganathan (Microsoft Research), Zerina Kapetanovic (Microsoft Research and Stanford), Tusher Chakraborty (Microsoft Research)

- The Fourth Workshop on Continual and Multimodal Learning for Internet of Things (CMLIOT' 22), https://cmliot2022.github.io/, organized by: Stephen Xia (University of California, Berkeley and Columbia University), Jingxiao Liu (Stanford University), Tong Yu (Adobe Research), Handong Zhao (Adobe Research), Ruiyi Zhang (Adobe Research)

- Tutorial: Energy storage for low-power wireless embedded systems, organized by: Laura Marie Feeney, Per Gunningberg, and Christian Rohner from Uppsala University
- Tutorial: Location Estimation from the Ground Up, organized by: Sivan Toledo, Tel Aviv University

On behalf of the organizing committee, we appreciate the intellectual and logistical efforts of the workshop organizers. Furthermore, we would like to sincerely thank the workshop authors for submitting their novel work, and the workshop TPC members for their timely and constructive reviews. Last but not least, we would like to explicitly thank the general chairs Jeremy and Ivan for their strong support along the process. We encourage the readers to take advantage of the state-of-the-art research in workshop proceedings. Hopefully, the workshops will be instrumental for shaping your future work and contributions to the research community.

Pat Pannuto (University of California, San Diego), Fatima Anwar (UMass Amherst)
- SenSys 2022 Workshop Chairs

ACM Workshop ENSsys 2022

Message from the Chairs

It is our pleasure to welcome you to the 10th International Workshop on Energy Harvesting & Energy Neutral Sensing Systems – ENSsys ’22, co-located with ACM SenSys ’22. With a long history and previous editions in many places around the world, we are happy that ENSsys continues to be organized as a workshop at SenSys.

ENSsys reflects the growing worldwide interest and research activity in energy-harvesting and energy-neutral sensing systems. Complementing the topics of ACM SenSys, ENSsys brings together international researchers to explore the challenges, issues, and opportunities in the research, design, and engineering of energy-constrained and energy-aware sensing systems. These are a technological cornerstone for new applications in smart energy, future transportation, environmental monitoring, and smart cities.

The call for papers attracted 15 submissions from Australia, Europe, and North America. All papers that were submitted received three reviews from experts in the area, and were evaluated for relevance, novelty, technical contribution, and presentation. Based on these reviews and the high quality of submissions, 12 of the submitted papers were finally included in the program to be presented and discussed at the workshop.

Delivering the ENSsys workshop is a significant undertaking and could not have been achieved without the help of many people. First and foremost, we would like to thank all of the authors who submitted contributions to ENSsys, and the members of the Technical Program Committee for their excellent and timely work reviewing submissions and helping to put together an excellent technical program. We would also like to thank our Website Chair Geoff Merrett for his assistance in promoting ENSsys and soliciting high quality submissions.

Finally, and most of all, we hope that you thoroughly enjoy this year’s workshop – whether you are presenting, attending, or just reading these proceedings on the web! We also hope that you continue to support ENSsys in future years as this exciting field grows and continues to develop.

Enjoy ENSsys@SenSys!

Sebastian Bader	**Bashima Islam**	**Michele Magno**
ENSsys ’22 Technical Program Chair	*ENSsys ’22 General Chair*	*ENSsys ’22 Demo chair*
Mid Sweden University, Sweden	Worcester Polytechnic Institute, USA	ETH Zurich, Switzerland

ACM Workshop ENSsys 2022

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ACM Workshop AIChallengeIoT 2022

Message from Organizers

It is our pleasure to welcome you to the 4th International Workshop on Challenges in Artificial Intelligence and Machine Learning for Internet of Things (AIChallengeIoT 2021), which is held in conjunction with ACM SenSys 2022 on November 6, 2022. Artificial intelligence (AI) and machine learning (ML) are key enabling technologies for many Internet of Things (IoT) applications. However, the collection and processing of data for AI and ML is very challenging in the IoT domain. For example, there are usually a large number of low-powered sensors deployed in large geographical areas with possibly intermittent network connectivity. The sensors and their collected data may be owned by different users or organizations, which can bring further obstacles to data collection due to privacy concerns and noisy labels provided by different users. The successful application of AI/ML approaches in such scenarios with noisy and decentralized data is difficult. In addition, the amount of collected data that can be used for training AI/ML models is usually proportional to the number of users in the system, but the system may not be able to attract many users without a well-trained AI/ML model, and it is challenging to solve this dilemma.

This workshop focuses on how to address the above and other unique challenges of applying AI/ML in IoT systems. The call for papers attracted submissions from Asia, Europe, South America, and North America. Out of 14 submitted papers, 10 regular papers have been accepted after a thorough review by the program. The papers were evaluated for novelty, relevance, and quality. Papers with forward-looking ideas that may initiate new research directions have been particularly encouraged. This workshop would not have been successful without the help of many people. We would like to thank all the authors who submitted their work to AIChallengeIoT and the Technical Program Committee members who provided high-quality and timely reviews for the papers. We also thank the SenSys workshop chairs Pat Pannuto and Fatima Anwar for their assistance in putting together the workshop program and proceedings. Finally, we hope that you enjoy this year's AIChallengeIoT workshop, whether you are presenting, attending, or just reading the proceedings on the web. We appreciate for your support for AIChallengeIoT and hope that you will continue supporting this workshop in future years.

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ACM Workshop USN 2022

Message from Organizers

It is our pleasure to welcome you to the First ACM Workshop on Urban Sensor Networks – USN'22, co-located with ACM SenSys '22. Sustainable and resilient urbanization will be one of humanity's grand challenges as the global urban population grows from about half of all people today to about two-thirds of all people by 2050. The rapid growth of cities presents numerous opportunities to use internet of things and wireless technologies to provide fine-grained insights into air quality, public health, mobility, and more to address the challenges that dense urban populations face today and in the future. Creating truly effective and transformative technology solutions requires a multidisciplinary approach incorporating both computer scientists and electrical engineers developing state of the art sensing, communication, and data science techniques as well as domain experts from urban planning, civil engineering, atmospheric science, and public health. Additionally, deploying sensing solutions at scale remains challenging and requires connecting with city and community leaders and working in partnership to develop effective solutions to power, connect, calibrate, and maintain networks.

This inaugural Urban Sensor Networks workshop aims to bring together this diverse community of researchers to share strategies to make the smart city dream become a reality. The workshop will provide a platform for attendees to share their work and to learn how it fits as part of the broader USN field. Our goal is to connect researchers working in high impact urban sensing problem domains with the cutting-edge technologies of the sensor networking community that can make these solutions a reality.

Our program will begin with presentations of submitted papers as well as invited talks from speakers who have implemented large scale USNs. Following these presentations, we will host a discussion forum to highlight high impact problems in this domain, common challenges and technical solutions. The goal of this discussion is to bring a diverse set of perspectives from different disciplines together and establish new research collaborations.

We would like to thank everyone who submitted contributions to USN'22, the members of the Technical Program Committee for their excellent and timely work reviewing submissions, and our invited speakers. We would also like to thank the organizers of Sensys for all of their hard work organizing the conference and giving us the opportunity to host this workshop. We hope that you enjoy USN'22 whether you are attending in person, virtually, or reading the proceedings. We hope that this will be the first of many events as this research area continues to grow.

Enjoy USN'22!

Alex Cabral
USN '22 Co-Chair
Harvard University, USA

Vikram Iyer
USN '22 Co-Chair
University of Washington, USA

ACM Workshop Urban Sensor Networks 2022

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ACM Workshop DATA 2022

Message from the Chairs

We are happy to welcome you to the technical program of the 5th workshop International Workshop on Data: Acquisition To Analysis --- DATA'22, --- co-located with ACM conferences SenSys '22 and BuildSys '22. As the enthusiasm for and success of the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Smart Buildings grows, so too does the volume and variety of data collected by these systems. How do we ensure that this data is of high quality, and how do we maximize the utility of collected data such that many projects can benefit from the time, cost, and effort of deployments? The Data: Acquisition To Analysis (DATA) workshop aims to look broadly at interesting data, bringing together a community of application and algorithm researchers in the sensing systems and building domains to promote breakthroughs from the integration of the generators and users of datasets.

The workshop is co-located with the SenSys and BuildSys conferences because these communities attract researchers and practitioners who develop new sensors and other sources of data and integrate data into novel applications in a variety of settings. In many cases, interesting data are collected and potentially made available to the broader community, but without any specific venue to advertise and describe the data. Conversely, it can be difficult for data consumers to discover datasets that meet their needs. DATA aims to bridge that gap.

The call for papers resulted in the acceptance of 15 of 20 submissions, comprising 2 fast-track dataset paper from SenSys and BuildSys, 1 short dataset paper and 12 full papers. The DATA workshop incorporates a keynote speech from Prof. Dinesh Bharadia (University of California San Diego) with title "Wireless sensing and robotics meet each other -- Datasets, AI, performance, novel sensing, and speed-ups", and along with more than 30 people participating both in-person and remotely.

We would like to thank the TPC members for their insightful reviews and contributions, the artifact evaluation committee for carefully vetting the datasets, the panel members, and for all those who submitted work for consideration. We would also like to thank the SenSys publication chair Jay Taneja (University of Massachusetts Amherst) as well as the workshop chairs Pat Pannuto (University of California San Diego) and Fatima Anwar (University of Massachusetts Amherst), and general chairs Jeremy Gummeson (University of Massachusetts Amherst) and Sunghoon Ivan Lee (University of Massachusetts Amherst) for giving us the opportunity to hold ACM DATA 2022 this year.

Gabe Fierro
DATA '22 Co-Chair
Colorado School of Mines, USA
National Renewable Energy Laboratory, USA

Shiwei Fang
DATA '22 Co-Chair
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ACM Workshop BlockSys 2022

Message from Organizers

It is with great pleasure that we welcome you to the technical program of BlockSys 2022, the 4th Workshop on Blockchain-enabled Networked Sensor Systems. BlockSys workshop focuses on research problems at the intersection of networked sensor systems and Blockchain. Networked sensor systems, as a key component of internet of things (IoT) have been widely used in various environments such as smart home, smart building, vehicular network, wearable computing, robotics systems, industrial control systems, etc. They capture human and physical-world dynamics and feed the data into large-scale analytical backends. Today's cloud-centric paradigm, however, does not genetically support trust management and privacy preservation; it also does not encourage information sharing in multi-stakeholder settings through incentives and payment mechanisms. As a result, complementary technologies that can offer to ensure data protection, incentivize information exchange, and reduce sharing and maintenance costs are highly desired.

We have seen increasing interest in tackling such problems by using emerging blockchain and other distributed ledger technologies. BlockSys-2022 aims to set up a stage for industry and academia to share wins and lessons. We have five full papers and two posters this year.

We would like to thank the TPC members for providing valuable suggestions and reviews to all the submitted papers. Finally, we would also like to thank the authors for their contributions to BlockSys-2022. We would like to thank the conference organizers, in particular, general chairs Jeremy Gummeson and Sunghoon Ivan Lee, for arranging and diligently monitoring key logistical issues. We also would like to thank the workshop co-chairs, Pat Pannuto and Fatima Anwar, for their support. Last but not least, we would like to thank the attendees for sharing their ideas with others and providing valuable feedback for improvements. We hope you will find the technical program thought-provoking and stimulating. We sincerely hope you enjoy the workshop!

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ACM Workshop AgSys 2022

Message from Organizers

It is with great pleasure that we welcome you to the very first workshop on Agriculture and Food Systems, which was held in conjunction with ACM SenSys 2021.

Meeting the food and nutrition demands of the world population of over 10 billion by 2050 is a grand challenge that humanity is faced with. In its 2019 State of Food and Agriculture report, the UN identified that despite these needs, over 40% of all food grown today is wasted. This can happen anywhere from on the farm to post-harvest stages in the food supply chain. Factors influencing this unsustainable wastage range anywhere from inadequate monitoring to effects of climate change. Data driven agriculture has already shown promise in creating more sustainable agriculture practices. Proper monitoring of the post-harvest environment in which food is grown, stored or transported can also greatly help reduce this waste and make the Agri Food industry on the whole more sustainable and efficient.

With these challenges in mind, the workshop provides a platform for researchers to present their innovations in IoT, sensing, communication networks and optimization strategies that can help create a sustainable future for the food industry. With the involvement of our academic, agriculture and Industry partners, we hope to refine the problem space and connect the technology with practical needs that can help us meet the future food demands.

We would like to thank the attendees, the authors who submitted their valuable research, the program committee, the keynote speakers from Digital Green and Strella Biotech, the expert panelists, and lastly our demo presenter – to all of whom we attribute the success of the workshop. We would also like to thank the SenSys publication and workshop chairs for their valuable time and guidance.

We hope that you enjoy the workshop proceedings and look forward to your support in the future as we establish goals and evolve to address global challenges around agriculture and food.

AgSys Chairs,
Vaishnavi Ranganathan, Zerina Kapetanovic and Tusher Chakraborty
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Vikram Iyer, University of Washington

ACM Workshop CML-IOT 2022

Message from the Chairs

It was with great pleasure to welcome you to the technical program of CML-IOT 2022, the 4th Workshop on Continual and Multimodal Learning for Internet of Things, co-located with ACM SenSys 2022 on November 6, 2022. The Internet of Things (IoT) has brought an ever-growing amount of multimodal sensing data (e.g., natural language, speech, image, video, audio, virtual reality, WiFi, GPS, RFID, vibration). The statistical properties of this data vary significantly over time and depending on the sensing modality; these differences are hardly captured by conventional learning methods. Continual and multimodal learning allows the integration, adaptation and generalization of knowledge learned from experiential and heterogenous data to new situations. Therefore, continual and multimodal learning is an important step to improve the estimation, utilization, and security of real-world data from IoT systems. The Continual and Multimodal Learning for Internet of Things (CML-IOT) workshop aims to foster a community to tackle these challenges for a wide range of sensing modalities and application domains.

Previous years, CML-IOT was hosted in conjunction with the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp) and the International Joint Conferences on Artificial Intelligence Organization (IJCAI). This year, we chose to host CML-IOT with ACM SenSys and BuildSys because of the rich work in all types of sensing and application domains that researchers in these communities work on. Because of the interdisciplinary nature of the challenges we aim to address, we hope to build a diverse community that allows researchers with different backgrounds to come together.

This year, we received 11 submissions from Asia, North America, and Europe. Each paper received at least three reviews from experts, who evaluated submissions based on relevancy, novelty, technical contributions, and presentation quality. In total, 9 high-quality papers were selected for publication and presentation in Boston, Massachusetts, USA. This year, we are fortunate to have two outstanding keynotes from Professor Wen Hu from the University of New South Wales, Australia and Professor Wan Du from the University of California, Merced.
CML-IOT 2022 would not be possible without the help of numerous individuals. We would like to thank all authors and individuals who submitted their contributions to CML-IOT, members of the Technical Program Committee for providing their expertise and hard work in reviewing submissions to create an excellent program, Professor Wen Hu and Professor Wan Du for their excellent keynotes, and all attendees of the workshop. We would also like to express our thanks and gratitude to members of the steering committee, who were very active and provided valuable guidance in organizing CML-IOT 2022, and members of the SenSys 2022 organizing committee for working with us to make CML-IOT 2022 a success.

We hope you enjoy CML-IOT 2022 as much as we enjoyed organizing the workshop, and we hope you can join us this year and future years in helping us grow this wonderful community.

Stephen Xia (University of California, Berkeley, and Columbia University)
Jingxiao Liu (Stanford University)
Tong Yu (Adobe Research)
Handong Zhao (Adobe Research)
Ruiyi Zhang (Adobe Research)
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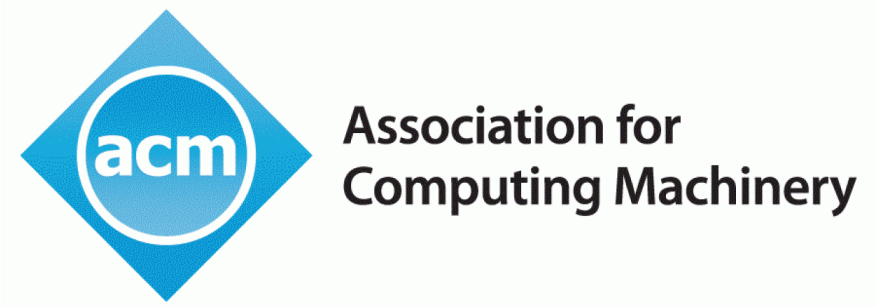

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