S4 Science of Sensor System Software Research Retreat 8-10 January 2020 REPORT

Muffy Calder (PI) 11 January 2020

16 members of the EPSRC S4 programme grant (PIs, Postdocs and 1 PhD student) went on our third annual "research retreat" at a hotel in North Berwick. As before, the aim is *not* to have a standard meeting where individuals talk about their latest paper, but to spend time together, working as a *team*, to uncover some of the deep and hard research problems that span the entire research programme, critically assess our progress so far, and discuss and plan future research directions. Each year, we have different model of working. This year we organised our programme according to three major themes:

1. Reports on current research problems and how we are tackling them. Nearly all are being worked on by researchers from more than one site.

2. Explorations of possible research topics/mini-projects for the next year, in parallel working groups. Agreement about which ones we would take forward and the next steps for each.

3. Individuals' research challenges within S4 and their perspectives on challenges for our field and broader Computing Science/Engineering.

This short report summarises outcomes, concluding with the agenda and participant list.

Current Research and the sites involved

CTRL-MAC How to transmit sensed data. Modelling as the protocol is developed, how modelling can inform the design process? Imperial, Liverpool, Glasgow

Consensus, interference and network stability What constructs can provide transactional guarantees under unreliable radio communications, can radio be used to power sensors as well as communicate? Imperial

BT Data event stream problem What to do with sensed data. Applying our temporal analytics to a problem from BT. Glasgow (note BT was not an original S4 partner)

Spatial topology of data sensors Where to put sensors, how to interpolate data from sensed points, and the effect of topology on interpolation. St Andrews

Closure spaces and bisimulations Deep theory of spatial relationships. Liverpool, Glasgow

Runtime monitoring Where to monitor and when to change the system. Liverpool

Network infrastructure modelling Sensor network as service. Synchronicity of model/ digital twin with system – when does it matter? Imperial, Glasgow

Reasoning about energy Economic Frame of reference, BDI agents. How much energy is needed, how much is available. Can we develop faithful models? Liverpool

Recurring theme: modelling and analysis by queueing theory, reactive systems models and probabilistic model checking, or FOTL. How to choose, and how to compare?

Future Research mini-projects

1. Temporal analytics for a sensor system (St. Andrews, Imperial, Glasgow) System data *not* payload data. Sensor nodes emulated by Cooja. Assume periodic logging Julie and Mike will interfere with system, but not tell Lei and Oana! eg. jamming, temp. changes Infer events from data, Markov models (HMM, DLM) unsupervised what questions to ask (how to express, how to answer) what changes could we recommend? Tx rates, px can we tell difference between 20 nodes, 10000 nodes? Nodes as process, but possibly network as process

2. Security, modelling, verification (Liverpool, Glasgow, Imperial)

4 mini-mini projects

- a. abstractions for large populations
- b. develop CTRL-MAC models for security properties
- c. what properties do we want for CTRL-MAC,
- where to "get" them, what guarantees do we want if we were to we "sell" CTRL-MAC?
- d. LoRA security guarantees can they be justified/verified?
 - from application requirements (e.g. what does wide area "mean")

3. Topology and spatial logics – what can we do in logic framework? (St. Andrews, Glasgow, Liverpool)

What questions would you ask of the interpolation?

If knock out sensor, what can I guarantee about interpolation (that doesn't involve the domain, i.e. weather), or if add more sensors in a particular area?

multiple layers: actual phenomena, point observations, inferred pattern

Don't have ground truth!

Data vs sensor topology (what exactly does that mean –geometric to topological)

Yasmin will do some more experiments – then group will look at properties and if/how can be formulated in existing logic (or need further one)

4. Sensor network testbeds (Glasgow St. Andrews, Liverpool, Imperial)

What do we want of such a thing, can we spec it/them so we could accommodate all the frames of reference? Can one testbed accommodate all the degrees of "in the wild"- from ability to experiment with and control aspects (e.g. of communications, of locations) to behaviours that emerge under harsh conditions (e.g. fluctuating weather, moisture, communications links). Muffy to write first draft.

Research Challenge – highlights

End of Life and Decomissioning Who is using the model, and why, and how to "get" the properties from them Is all self-organising bio-inspired Close the loop – it's not all dashboards Layers of space: phenomenon ground truth sensed data network Space as first class (research) object – we need good abstractions Applying known method or original research research in Engineering vs CS vs Maths Minimise amount of sensed data for maximum value of interpretation Replication of existing research Inference method – will it fit on a sensor node (and be accurate enough) Spatio-temporal abstractions (many mentions) Scheduling or random access (comms) Topological changes ⇔ interpolated data changes Verification in context of black boxes

Footnote: We are proud to be a diverse team from 10 countries (UK, Ireland, Italy, Germany, Romania, Bulgaria, USA, China, Tunisia, Pakistan) and over 40% female.

The S4 team



Theorems for dinner



The retreat was a resounding success, we came away energised and inspired. This was our most successful retreat – more relaxed, more discussion, more hard thinking, more sharing. Our next All-Hands meeting will be in London June 11,12 2020 - we will look forward to hearing about progress on the research projects.

S4 North Berwick Retreat 8-10 January 2020

Macdonald Marine Hotel & Spa, Cromwell Rd, North Berwick EH39 4LZ

Outline Timetable

WedThurFri9-12:30Technical talks// sessions// sessions next steps; Which testbeds?15:30-18:30Technical talksChallengesBuffet Lunch available 12:30-14:30, Drinks in Drawing Room 18:30, Dinner 19:00Finish Friday 12:00

Detailed Timetable

<u>Wednesday</u>

Торіс	Speaker(s)
CTRL-MAC modelling and analysis	Ivalyo
CTRL-MAC verification	Clare
Sensor placement and degradation	Simon, Yasmeen
Bisimulations for closure spaces	Sven, Michele
Consensus	Mike, Fatma
BT interactions temporal analytics	Oana
Network infrastructure modelling	Blair, Michele
Battery modelling	Fabio
Runtime ROS verification	Michael

<u>Thursday</u>

Morning 3 Parallel sessions, session leaders in italics temporal analytics in a sensor network – *Muffy*, Julie, Oana, Mike, Lei network and data topologies – *Simon*, Michele, Sven, Yasmeen, Fabio security, modelling and verification – *Michael*, Aisha, Clare, Fatma, Ivalyo, Blair,

Afternoon Challenges session

All participants (except Muffy, Michael, Simon, Julie) present 3 slides (5 mins max) addressing

- 1. What is the biggest challenge (that interests you) in your current research?
- 2. What is the biggest challenge (that interests you) in sensor systems research?
- 3. What is the biggest challenge (that interests you) in Computing Science/Engineering?

Team building exercise

<u>Friday</u>

a. The three // sessions report on what they discussed and the agreed next steps.
b. Sensor System Testbeds – specifying a small set (3-4) that would exemplify our research questions and challenges. Do we want to do this, and how will we do it over the next year? Muffy

c. Wrap-up

Preparation

Technical talks: named speakers prepare slides/talk // sessions: no preparation required, unless you are a session leader Challenges: everyone except the gang of 4

Attendees

Professor Muffy Calder	Gla
Professor Michael Fisher	Liv
Professor Simon Dobson	St A
Professor Julie McCann	Imp
Dr Clare Dixon	Liv
Dr Oana Andrei	Gla
Dr Michele Sevegnani	Gla
Dr Blair Archibald	Gla
Dr Lei Fang	St A
Dr Yasmin Rafiq	St A
Dr Sven Linker	Liv
Dr Michael Breza	Imp
Dr Fatma Benkhelifa	Imp
Mr Ivaylo Valkov	Gla
Dr Aisha Junejo	Imp
Dr Fabio Papacchini	Liv
	Professor Muffy Calder Professor Michael Fisher Professor Simon Dobson Professor Julie McCann Dr Clare Dixon Dr Oana Andrei Dr Michele Sevegnani Dr Blair Archibald Dr Lei Fang Dr Yasmin Rafiq Dr Sven Linker Dr Michael Breza Dr Fatma Benkhelifa Mr Ivaylo Valkov Dr Aisha Junejo Dr Fabio Papacchini