Emergent Interaction: Complexity, Dynamics, and Enaction in HCI

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ABSTRACT

We propose a workshop on methods and theories for dealing with complex dynamical systems, and their application in HCI. Such methods are increasingly relevant across a wide range of disciplines which focus on human behaviour, applied to understand the role of context and interactions in the behaviour of individuals and groups, and how they unfold over time. Traditional approaches to quantifying and modelling behaviour in HCI have tended to focus primarily on individuals and components. Complexity methods shift the focus onto interactions between components, and the emergence of behaviour from complex networks of interactions, as for example in Enactivist approaches to cognitive science. While we believe that complexity methods can be highly informative to HCI researchers, uptake in the community remains low due to widespread unfamiliarity. This one-day workshop will introduce, support, and encourage the development and adoption of complexity methods within HCI. Reflecting the multidisciplinary mix within complexity science, we will draw on examples of complexity-oriented theories and methods from a range of disciplines, including Control-Theory, Social Science, and Cognitive Science. Attendees will engage in group discussions and a Q&A with a panel, and a discussion group will be set up ahead of time to encourage exploratory conversations. In this way, diverse backgrounds can be brought together, matched, and inform one another.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *Interaction design theory, concepts and paradigms*; *Ubiquitous and mobile computing theory, concepts and paradigms.*

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KEYWORDS

Human Computer Interaction, ubicomp, complexity, causality, control theory, computational interaction, embodiment, cognitive science, enactivism

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1 BACKGROUND

Recent work in Human-Computer Interaction (HCI) has suggested that interaction is often well modelled as a complex system — a dynamic interaction among elements (humans and technologies) in which behaviours arise from interactions between these elements, and the co-evolution of their behaviours [4]. While the framing in terms of complex systems is relatively new, this focus on interactivity as a driver of human behaviour joins a well established tradition in HCI which has emphasised the "interactivity" in interaction. Since at least the 1980s, researchers have emphasised the way behaviour arises from ongoing adaptation between interacting elements: human(s) and technology(ies), as well as other humans and aspects of the environment, with technologies conditioning humans just as users manipulate technologies [5, 12, 18, 42]. In particular, a focus on interaction as a complex system re-establishes the connection between HCI and the *enactivist* approach to cognitive science [42]. This approach emphasises complex dynamical formalisms, and the "active, embodied, and embedded" aspects of cognition [7, 17, 40].

This workshop will investigate the opportunities and challenges of this new approach to HCI, discussing methodologies, heuristics and theories for understanding complexity in HCI, grounded in Complexity Science.

Complexity Science is a loosely bounded, multidisciplinary field, with diverse roots in Physics, Biology, Chemistry, Computer Science, and the Social Sciences [22, 30]. It deals, generally, with systems composed of many interacting elements, where higher-level system behaviour can be said to "emerge" from the interactions. It is easiest to illustrate this with a classic example unrelated to technology: the example of predators and prey, such as wolves and sheep, and overall vs individual behaviour in the interaction between their populations. In this example wolves kill sheep, and so naturally, over time, the number of wolves will affect the number of sheep. Equally, since the sheep serve as food for the wolves, the number of sheep will also affect the survival of the wolves. These effects occur simultaneously, which is to say that there is a bi-directional feedback relationship between these populations. Because of this, fluctuations in populations quickly become complex, and the system may not tend towards equilibrium or stabilit. Numbers in the two populations, over time, may fluctuate wildly.

In systems like this predator-prey example, global system dynamics are complex and cannot be predicted from even a detailed understanding of its isolated components. Instead, the interactions between these components drive "*global behaviour that is, in some sense, disconnected from its origins*" [30] — behaviour which "emerges" from the underlying interactions. Conventional statistical techniques, with their assumptions of independence and linearity, can be invalidated by such conditions. Complexity Science provides a range of techniques for understanding and modelling them.

Researchers in HCI have recently argued that interaction with technology forms just a complex dynamical system [4]. Here it is argued that a relationship like that between predator and prey occurs between human and technology. Users have habits and goals which drive their behaviour at the technology interface, and result in changes to the system state. At the same time, system state influences the user, affecting their goals and behaviours. Altered goals and behaviours, in turn, affect the use of the interface, which in turn affects the user, and so forth. Examples of this can be seen in the relationship between user engagement and smartphone notifications, where notifications affect engagement, and engagement affect notifications [4], and between visual analytic-pipelines and decision-making processes [11]. Again, we see bidirectional and potentially non-linear, complex, interaction between elements [4].

The explicit framing of this situation in terms of complex systems is recent, but the problem has long been long acknowledged. Classic texts from Carroll and Norman describe how bidirectional processes drive interaction [4], and theories of *affordances* and *situated action* emphasise the ways in which technology and circumstances of interaction condition the user, just as the user manipulates the technology [18]. When discussing such scenarios, researchers have critiqued the ability of existing quantitative methods to account for this complexity, turning to other approaches, including "in-the-wild" studies, and ethnographic methods designed to give *thick* descriptions of how intentions and behaviours are moulded in the complex, situated, dynamics of interaction [34]. However, this still leaves a lack of fine-grained *quantitative* methods for observing complex dynamics in the moment-to-moment, low-level user behaviour. This has arguably limited possibilities for directly incorporating insights about interactive complexity into system design, via metrics and adaptive models.

This workshop will bring together researchers from HCI, cognitive science, and other disciplines to discuss understandings of complexity in HCI, and to explore how methods from complexity science might augment and extend existing methods and further our understanding of interaction. In the next section, we outline five broad themes to guide this discussion. First, we discuss how complexity methods might bear on our understanding of **context** — observing and analysing data captured in-the-wild, and allowing us to quantify adaptation to context. Second, we discuss some ways that approaches such as Control Theory might bear on the **dynamics** of interaction — how interactions unfold over time. Third, we point to new opportunities for quantitative **small data** approaches based on complexity-grounded research in recent psychology, working with individual cases, and small samples, to gain the kind of detailed, localised insight which may be valuable in personal training and tracking scenarios. Fourth, we discuss the multi-**scale** nature of complex phenomena, and the challenges this poses for HCI. Finally, we outline **theoretical** challenges and opportunities that come with complexity methods: heuristics and new perspectives which can influence design thinking and experimental design.

2 THEMES

2.1 Context: How do interactions unfold and emerge in real contexts?

Researchers in HCI have often argued that mainstream quantitative approaches fail to account adequately for the influence of context and situatedness [12, 42]. In mathematical terms, one issue here is that, as interaction contexts grow in complexity, standard equation modelling approaches lose their effectiveness, due to the impossibility of parameterising all relative aspects of the environment [4]. Complexity science offers alternative quantitative research paradigms which can address this issue. In HCI, Van Berkel et al., have investigated this direction, developing Multiple Convergent Cross Mapping (MCMM) — an approach which allows the data to directly determine the model, and which can be used to infer the direction of causal effects from data captured in real-world interaction scenarios [4].

HCI research has often turned to lab experiments, in order to bring real-world complexity under manageable control. However, this has some obvious drawbacks — artificial controls often diminish ecological validity of results, and lab experiments can be time-intensive to conduct, limiting sample sizes compared to capturing data from devices in everyday use. Even with such careful experimental design and effective control, it can be hard to demonstrate causality rather than correlation. For example, Van Berkel et al. consider phone notifications: using a phone more often increases the number of notifications, but at the same time notifications attract attention, driving engagement with the phone. In situations like this, correlation can occur without causation, and causation may also occur in the absence of correlation [6], making standard methods unsuitable. Complexity methods such as MCMM offer ways of disentangling these factors and measuring both magnitude and direction of causality. And since the approach does not rely on the parameterisation of all relevant aspects of the interaction environment, this also supports the analysis of data captured "in-the-wild", allowing larger, more representative samples, and avoiding overly artificial lab restrictions.

Complexity methods may also extend existing theories of context in HCI, around embodiment and affordances. In the decades since HCI first engaged with Gibson's theory of affordances [18], and Varela and Maturana's enactivism [42], these research programs have developed considerably, leading to the so-called 4E (Embodied, Embedded, Extended, Enactive) approach to cognitive science. 4E research now offers a rich resource of quantitative methodologies for understanding complexity and dynamics in cognition, in context [7].

These examples indicate ways in which complexity methods may raise new questions for HCI research, and prompt new attitudes to context in experimental work. They offer opportunities to work quantitatively in-the-wild, and to focus on interaction and adaptation, in the spirit of ethnographic approaches which have often inspired and informed in-the-wild work. In discussing these approaches at the workshop we encourage reflection on how complexity methods might change the design of experiments in HCI, and whether, for example in-the-wild and embodied research can benefit from incorporating a complexity theory mindset into their approaches.

2.2 Dynamics: How do interactions play out over time?

Hornbæk and Oulasvirta have suggested that HCI lacks accounts of how intentions are formed, affected, and evolved by interaction [24]. This points to a lack of tools and theories for understanding the *dynamics* of interaction. Rather than assuming the more-or-less smooth execution of users' action plans, approaches based in complex dynamical systems offer theories and methodologies for understanding how interaction arises and develops over time, through interactions, adaptations, and the constraints of the interaction context.

Dynamics are a significant issue in interaction with technology, since a user can only control what they can perceive. In principle, we can navigate instantly in an arbitrary information space, given a static interaction mechanism (e.g. tapping on an image on a small screen). However, if we are dependent on the display of feedback while pursuing our goals, there will be upper limits on the speed at which the display can change and information be perceived. This is especially true in cases where there is uncertainty in the user's mind about where to go; when they have the option to change their goal on route; as more information becomes available. In order to cope with this, interface designers have a long history of hand-crafting transition effects in a case-by-case manner. Nonlinear mouse transfer functions are long-established examples of finely-tuned dynamic systems driven by user input.

One goal of this workshop is to investigate whether describing the dynamics of interaction using the tools of control engineers allows us a more consistent approach to analysing, developing and comparing the 'look-and-feel' of an interface — or in control terms, its 'handling qualities'. Control synthesis often focuses on the analysis of coupling among system states. Examples of such coupling have been demonstrated on tilt-controlled interaction with handheld devices [13, 14]. Control methods are likely to be especially important for design for mobile devices, where sensor noise, disturbance rejection, sensor fusion, adaptive self-calibration, and the incorporation of models of human control behaviour are all important research challenges.

While there are a number of well-explored approaches in HCI to model human operator behaviour based on, e.g. device interfaces and task-analytic models in interaction with devices, continuous interaction, for example with tilt-controlled devices are not easily modelled by such approaches. These interactions can be modelled using a control-theoretic feedback loop. Manual control theory offers a powerful and flexible approach for describing human behaviour and analyzing human–machine systems [35]. This theory has been applied to modelling human behaviour and solving human factors problems for more than 60 years [35]. For example, Niezen and Eslambolchilar [31], describe a control-theoretic model that can be used to model both the discrete and continuous behaviour of a human operator in interaction with a device model of a commercial syringe pump with chevron keys, described as a formal specification. This case study demonstrates that it is possible to simulate aspects of user interaction at a high resolution that compares well to real-world data. Although such examples can be extended and modified for different use cases and can be connected to a variety of device models, manual control theory has been largely overlooked outside the engineering arena.

There are also opportunities for HCI to investigate models for flexible synchronisation between the dynamics of user and technology. One promising route here is the use of Central Pattern Generator networks — adaptive neural networks long deployed in robotics, and more recently in music software [3].

2.3 Small Data: Idiographic approaches

In psychology, researchers have pointed to the way complexity methods support 'idiographic' or 'small data' approaches [28, 32], where researchers and practitioners work with data from only one individual, or a small number of individuals. Hasselman notes that these approaches can bring great specificity to interventions and understandings [22]. In contrast to this, most mainstream quantitative approaches are 'nomothetic': they begin with large samples and generalise rules. These approaches have most success in situations where data is abundant, and where variation is uniform. They have less success in dealing with outlier groups (*i.e. a small group of users with substantially different product usage*), and situations dominated by 'long tails', (*where e.g. interaction effects in the data significantly skew distributions away from normality*). Idiographic approaches can complement conventional approaches by supporting the rigorous quantitative investigation and modelling of particular cases. They work with small $N_{participants}$, large $N_{observations}$ and allow the modelling of behaviour over time for individuals and small groups. In HCI, such approaches may be relevant, for example, in self-tracking, personalised digital healthcare, and working with minority groups, and hard-to-access groups where large numbers of participants may be difficult to recruit [2]

2.4 Scale

As HCI begins to deal with complexity, it will be important to consider issues of scale. Complex systems often demonstrate discontinuity between behaviour at different scales of observation [30], and at times this will prompt consideration of multiple scales of behaviour in a system, and interaction between them. Scale can be important both in terms of time, and in terms of the number of agents/elements. Many phenomena of interest in HCI may demonstrate activity on multiple timescales, and in some cases it may be useful to understand how these different time-scales interact, for example the way communication strategies change if channels are slower than tasks [10] or the way small delays can influence fine-scale interaction strategies [37]. Some HCI phenomena such as those we describe in relation to control theory, are very fine scaled. Others such as the city-scale modelling can operate at the level of average behaviour. However, much of HCI lives in the most complex mid-scale regions where tacit fine-motor behaviour behaviour, subconscious cognition, conscious deliberation and human interactions all have a part to play. No single process dominates: sometimes subconscious processes apprehend faster than conscious ones [1], sometimes subjects rely on memory where perception would be more efficient [20], or perception may be affected by implicit memory [15], sometimes devices that are easy to consciously understand are near impossible for our motor systems and vice versa [19]. Techniques such as multifractal analysis might be applied to gain insights into the interactions between scales in such systems [25], but different scales may need to be treated by quite different modes of data capture and analysis, and it will be a necessary and difficult task to identify adequate approaches to integrating these different-scaled views of the system.

2.5 Theory: Concepts and Challenges

Just as in other disciplines, engagement with complexity methods and issues in HCI seems likely to require new metaphors, heuristics and metatheoretical foundations [23, 29]. The language and ideas of complexity science may influence new ways of looking at interaction phenomena: concepts such as phase transition, tipping point, hysteresis, feedback, and fractality may influence heuristics and concepts in HCI as much as they play a role in new quantitative approaches. Complexity methods may also prompt significant shifts in methodological practice, and offer new opportunities for theory building — how can the idiographic research approaches described above be incorporated alongside the generalised and population-level methodologies? How can we incorporate insights from the in-the-wild "computational ethnography" explored by Van Berkel et al. alongside results from lab experiments and the descriptive work of traditional ethnography [4]. Even greater uptake of well-established approaches, such as Control Theory, may prompt reflection on how thesemodels and tools can be incorporated into design thinking and workflows.

Complexity methods may make significant contributions in embodied approaches to interaction. Embodied research in HCI currently lacks quantitative methods, and in some ways has not kept pace with developments in embodied cognitive science. In the years since Gaver and Winograd and Flores articulated affordances and enactivism for HCI [18, 42], embodied approaches to cognitive science have developed and refined their theories and quantitative methods, often through engagement with theories of complex dynamical systems [7, 41]. While HCI has also updated its theories around embodiment [27], it has diverged from this research in cognitive science. There is now an opportunity to review more recent work in embodied and enactive cognitive science, draw on its methodologies, and potentially harmonise theoretical positions allowing HCI to draw upon and incorporate new results and methodologies.

The "Skilled Intentionality Framework" (SIF) for instance provides a new theoretical account of Gibsonian affordances which draws on complex dynamical systems accounts of cognition [38], though in common with much embodied work in HCI it also retains a connection to phenomenology and qualitative, descriptive work [21]. Gibsonian accounts of affordances have sometimes been criticised for failing to account for "higher" cognition and the design of new affordances, but the SIF often focuses on “higher” and creative behaviours such as architectural practice [38], and on the creation and design of affordances [33] — issues often emphasised in HCI's discussions of affordances [27]. This account of affordances contributes to a wider and more-or-less unified “radical embodied” program in cognitive science [7, 41], applying theories of complex dynamical systems to elucidate and update the insights of Gibson, Varela and others. This framework might offer a strong theory-building foundation for qualitative and quantitative embodied research in HCI. It may support a move away from the “*overwhelming tendency [of HCI researchers] to understand interaction as one-sided — as channelling and realisation of human intentions through a computer*” [24], and towards an understanding of agency grounded not (only) in the individual, but in emergence during embodied, social, behaviour, in context [9, 26, 39].

Finally, engagement with complexity accounts of behaviour may support a shift in emphasis away from the behaviour of individual components — humans, computers — instead viewing components and their interactions as co-constructed inside a broader interactional system [8]. As substrates or mediums for interactions, digital systems play a critical role in the co-construction of agency and meaning. A complexity perspective may help us to understand the kinds of agency and social understanding that a given system enables or co-determines. How does a given system frame intentions, agency and interactions, and support their co-emergence? What is prevented from developing? How do the systems incorporate disagreements, interactions with significantly misunderstood others, or neurodiversity [16]. Finally how can users participate in complex systems, appropriate them, and contribute to their development. How far can the separate roles of user and creator be brought together, giving the possibility for users to fully participate in the development of those components that mediate their subjectivity? How far can such appropriability go? [36]

3 PRE-WORKSHOP PLANS

We will broadly advertise the workshop to different communities of researchers and practitioners. This will include posting announcements to distribution lists as CHI-ANNOUNCEMENTS and social media, such as Twitter and Facebook. We will send targeted email invitations to leading researchers in different academic institutions inviting them to participate and with a request to distribute the announcement within their organisations. Our website https://emergentinteraction.github.io/ hosts our Call for participation, information about the workshop's organisers, news and announcements, and paper submission instructions. This website will also host participants' finalised workshop submissions prior to, and after the workshop.

3.1 Paper Submission and Review Procedure

Submissions will be divided for review among the workshop organisers and invited reviewers. Reviews will be based on quality and relevance to the themes of the workshop. After discussion of all submissions, successful submissions will be invited to the workshop. At this point (after selection, to avoid fear of biasing acceptance) participants will be asked to express any accessibility concerns which might mar participation for them so that we can address them appropriately. Beyond the quality and relevance of submissions, we will aim to ensure an interdisciplinary and balanced group of researchers in this field. We will solicit widely and internationally for contributions to the workshop. We intend for 15-20 participants at the workshop. This will both support the interactivity of the networking activities and also reflect the growing relevance and potential of Complexity methods across a range of HCI sub-disciplines.

3.2 The fortnight before the workshop

This workshop aims to foster effective interdisciplinary collaboration around complexity methods within HCI: bringing together challenges and methodologies that might not otherwise come into contact with one another. As such, our one-day workshop will focus on meetings and interactions between the participants, including the panel, while also allowing researchers a brief time to present their own work.

To support this, while avoiding video-call burnout, we will combine asynchronous with the synchronous aspects described below. To help participants familiarise themselves with one-anothers' work and interests ahead of the workshop, participants will prepare a short (c 1.5-2 min) presentation and record it in time to upload to e.g. YouTube a fortnight before the workshop. Links to these will be shared among all participants, alongside submitted papers to allow them to familiarise themselves with the other participants' work. A Slack or Discord group for the workshop will open at the same time, to allow participants to discuss each others' papers and interests, ask questions and self-select discussion groups for activities at the workshop. We will provide a system for this group-selection (to be determined).

4 WORKSHOP STRUCTURE - ON THE DAY

The workshop will be held on Zoom, using an organiser's institutional account, and will make use of captioning for hard-of-hearing users. The workshop has been scheduled so as to minimise disruption across a range of time-zones, supporting broad participation across US West, US East, Europe, Asia, Australia, and to fall within normal working hours for the conference's host country, Japan. Presentations in the second half of the conference will be recorded, to allow tired participants in US timezones to review later. When combined with post-workshop discussion activities on our Slack, we hope this will allow good participation for as many as possible. Introductions and sessions will each be chaired by different members of the organising committee to provide different perspectives. The second half of the conference (Group Presentations and Panel Talk) will be streamed on YouTube to support wider participation and questions.

Below is a preliminary schedule - to be taken as an example, and subject to change.

05:30-06:00 (UTC+1): Introduction - A brief introduction. We outline the workshop's schedule, its goals, introduce the panel. We also give an overview of the collaborative tools we'll be using, and an introduction to some material to guide discussion.

06:00-07:00: Group Discussion: in around 4 small groups, selected in pre-workshop activities. This will focus on defining key challenges and opportunities around Complexity in HCI. Discussion will be supported by a collaborative sketching tool such as Google Jamboard, and groups will create posters for presentation after the lunch break

07:00-07:20: 20 minute break

07:20-08:20: Group Presentations of posters, presenting the issues and ideas which arose in discussion. Each presentation will begin with a brief introduction to each member of the group. 10 minutes presentation, 5 minute Q&A per group.

08:20-08:40: 20 minute Break

08:40-09:55: Panel Discussion Invited panel members will give brief 5 minute presentations, then conduct a discussion on issues around complexity in HCI, addressing themes that arose in the group presentations.

09:55-10:00: Announcements and close

5 POST WORKSHOP PLANS

The results of the workshop will be summarised and published on the workshop's website. The posters developed by participants during the workshop, and the panel-discussion will be linked on the project website and via social media to provoke further discussion in the community. Participants will also be invited to revise, develop, and submit extended versions of their position papers, based on their discussions at the workshop. If the quality of these submissions is sufficient we will invite participants to author a joint review of the field as a journal article (*e.g.*, CHI, TOCHI, IJHCS, HCI journal). The Slack group will be maintained after the event to allow future collaborations and sharing of datasets, code, and best practices, and to act as a focus for a reading group on complexity in Human-Computer Interaction.

6 ORGANISERS

The workshop has a broad international group of organisers, including established researchers, and younger perspectives; researchers with interests in HCI, control theory, cognitive science, linguistics and computational interaction.

Daniel Bennett is a PhD researcher at Bristol Interaction Group with Oussama Metatla and Anne Roudaut. His PhD work focuses on applying dynamical-systems methods from 4E cognitive science to understand technology use. He is also interested in generative dynamical systems models for musical interaction.

Alan Dix is an author, researcher, and university professor, specialising in human–computer interaction. Dix is currently the Director of the Computational Foundry at Swansea University, Wales. A mathematician by training, his work has included applying formal methods and statistics in HCI as well as many other areas including creativity and physical design.

Parisa Eslambolchilar is currently a Reader in Human–Computer Interaction (HCI) at Cardiff University and leads the Complex Systems Research Group and the Human Factors Technology Research Priority Area at the School. Her research interests include HCI, ubiquitous computing, and designing interactive systems to support self-reflection, self-monitoring, feedback (audio, haptic, visual, and soma), persuasion, immersion, and navigation.

Feng Feng is a Research Associate at University of Eastern Finland and Microsurgery centre in Kuopio University Hospital. She has a background in both Industrial Design and Cognitive Science. Her interests include embodied cognition, multi-sensory perception, Human-Computer-Interaction and Human-Robot-Interaction, and the development of multi-sensory technologies.

Tom Froese is head of Head of Okinawa's Embodied Cognitive Science Unit. A cognitive scientist with a background in computer science and complex systems, he applies diverse methods to investigate the interactive basis of life and mind. He is particularly known for his contributions in artificial life and the enactive approach to cognitive science.

Vassilis Kostakos is Professor of Human-Computer Interaction at University of Melbourne. His research interests include ubiquitous computing (Ubicomp), human-computer interaction (HCI), social computing, Internet of Things.

Sébastien Lerique is a Postdoctoral Scholar in cognitive science at Okinawa's Embodied Cognitive Science Unit, with interests in the role of embodiment in interactions, complex systems, and the emergence of language.

Niels van Berkel is an Assistant Professor at the Human-Centered Computing Group (HCC) at Aalborg University. His research interests lay in Human-Computer Interaction, Social Computing, and Ubiquitous Computing. In particular, he has focused on self-report studies, crowdsourcing, and Human-AI interaction.

7 CALL FOR PARTICIPATION

The study of Complex Dynamical Systems is a topic of growing importance across human centred disciplines, from economics and sociology to psychology and healthcare. The theories and methods of Complexity Science are driving significant progress in the understanding of phenomena driven by interaction between components. They have opened up new quantitative approaches in embodied cognitive science, and methods for inferring causal patterns in complex social networks and ecosystems. The goal of this workshop is to begin a discussion on the contribution these techniques can make in HCI, both methodological and theoretical, as outlined in the Key Topics below.

Potential participants should submit a 4 to 8 page long position paper (including references), in the CHI Extended Abstracts Format, that addresses at least one of the key topic(s)of the workshop. The paper should also include a statement on the potential goals of their research and the problem(s) it aims to address. Please read our workshop proposal paper (above) for more information. Submission will be via EasyChair. For more information contact complexity.chi@gmail.com.

We will select papers based on relevance, quality, and diversity. At least one author of each accepted position paper must attend the workshop and all participants must register for both the workshop and for at least one day of the conference.

7.1 Key Topics

- Application of methods and approaches from complexity science and dynamical systems theory to problems in HCI
- Drawing connections between existing HCI approaches and accounts in complexity theory, dynamical systems and enactivism
- Applications of Control Theory and other dynamical approaches to help understand users and design systems
- Discussion of what HCI can learn from recent work on dynamical and enactivist approaches to cognitive science?
- Methodological or theoretical contributions from complexity theory, dynamical systems theory, drawn from other disciplines, such as control theory, enactivist cognitive science, computational social science
- Issues raised by the application of complexity methods in HCI
- Software and other tools to support researchers in applying complexity methods in HCI

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REFERENCES

[1] A. Bechara, hanna damasio, Daniel tranel, and Antonio Damasio. 1997. Deciding Advantageously Before Knowing the Advantageous Strategy. *Science* 275, 5304 (Feb. 1997), 1293–1295. https://doi.org/10.1126/science.275.5304.1293

[2] Howard S. Becker. 1996. The epistemology of qualitative research. In *Ethnography and human development*. Number 27 in Context and meaning in social inquiry. The University of Chicago Press., Chicaco, 53–71.

[3] Dan Bennett, Anne Roudaut, and Peter Bennett. 2018. Neurythmic: A Rhythm Creation Tool Based on Central Pattern Generators. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. ACM, Virginia Tech, 210–215. https://doi.org/10.5281/zenodo.1302555

[4] Niels van Berkel, Simon Dennis, Michael Zyphur, Jinjing Li, Andrew Heathcote, and Vassilis Kostakos. 2020. Modeling interaction as a complex system. *Human–Computer Interaction* 0, 0 (Jan. 2020), 1–27. https://doi.org/10.1080/07370024.2020.1715221

[5] John M. Carroll. 2004. Beyond Fun. *interactions* 11, 5 (Sept. 2004), 38–40. https://doi.org/10.1145/1015530.1015547

[6] Chun-Wei Chang, Masayuki Ushio, and Chih-hao Hsieh. 2017. Empirical dynamic modeling for beginners. *Ecological Research* 32, 6 (Nov. 2017), 785–796. https://doi.org/10.1007/s11284-017-1469-9

[7] Anthony Chemero. 2011. *Radical embodied cognitive science*. MIT press, Cambridge, MA.

[8] Ezequiel Di Paolo and Hanne De Jaegher. 2017. Neither individualistic nor interactionist. In *Embodiment, enaction, and culture*, Christoph Durt, Thomas Fuchs, and Christian Tewes (Eds.). MIT Press, Cambridge, MA, 87–105.

[9] Ezequiel Alejandro Di Paolo and Hanne De Jaegher. 2012. The interactive brain hypothesis. *Frontiers in Human Neuroscience* 6 (2012), 163. https://doi.org/10.3389/fnhum.2012.00163 Publisher: Frontiers.

[10] Alan Dix. 1992. Pace and interaction. In *HCI'92 People and computers*, A Monk, D diaper, and M Harrison (Eds.). Human Computer Interaction Specialist Group.,

Vol. 7. British Computer Society, London, 193–193. Publisher: Cambridge University Press.

[11] Alan Dix, margit Pohl, and Geoffrey Ellis. 2011. Chapter 7: Perception and Cognitive Aspects. In *Mastering the Information Age Solving Problems with Visual Analytics*, Daniel Keim, Jörn Kohlhammer, Geoffrey Ellis, and Florian Mansmann (Eds.). Eurographics Association, GENEVE, 109–130. https://www.vismaster.eu/book/

[12] Paul Dourish. 2004. *Where the action is: the foundations of embodied interaction*. MIT press, Cambridge, MA.

[13] Parisa Eslambolchilar. 2006. *Making Sense of Interaction Using a Model-Based Approach*. PhD Thesis. National University of Ireland Maynooth.

[14] Parisa Eslambolchilar and Roderick Murray-Smith. 2004. Tilt-based automatic zooming and scaling in mobile devices–a state-space implementation. In *International Conference on Mobile Human-Computer Interaction*. Springer, Berlin, Heidelberg, 120–131.

[15] Feng Feng, Puhong Li, and Tony Stockman. 2020. Exploring crossmodal perceptual enhancement and integration in a sequence-reproducing task with cognitive priming. *Journal on Multimodal User Interfaces* n/a (July 2020), 15. https://doi.org/10.1007/s12193-020-00326-y

[16] Sue Fletcher-Watson, Hanne De Jaegher, Jelle van Dijk, Christopher Frauenberger, Maurice Magnée, and Juan Ye. 2018. Diversity computing. *Interactions* 25, 5 (Aug. 2018), 28–33. https://doi.org/10.1145/3243461

[17] Tom Froese and Ezequiel A. Di Paolo. 2011. The enactive approach: Theoretical sketches from cell to society. *Pragmatics & Cognition* 19, 1 (2011), 1–36. Publisher: John Benjamins.

[18] William W. Gaver. 1992. The affordances of media spaces for collaboration. In *Computer Supported Cooperative Work: Proceedings of the 1992 ACM conference on Computer-supported cooperative work*, Vol. 1. ACM, Toronto, 17–24.

[19] Masitah Ghazali, Alan Dix, and Kiel Gilleade. 2015. THE RELATIONSHIP OF PHYSICALITY AND ITS UNDERLYING MAPPING. *ARPN Journal of Engineering and Applied Sciences* 10, 23 (2015), 10.

[20] Wayne D Gray and Wai-Tat Fu. 2001. Ignoring Perfect Knowledge In-The-World for Imperfect Knowledge In-The-Head. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, Seattle, 8.

[21] Sanneke de Haan, Erik Rietveld, Martin Stokhof, and Damiaan Denys. 2015. Effects of Deep Brain Stimulation on the Lived Experience of Obsessive-Compulsive Disorder Patients. *PLOS ONE* 10, 8 (Aug. 2015), e0135524. https://doi.org/10.1371/journal.pone.0135524

[22] Fred Hasselman. 2020. Complexity Science – It's about time (Fred Hasselman) - YouTube. https://www.youtube.com/watch?v=BXJN_KhGtrs&list=WL&index=5

[23] Penelope Hawe. 2015. Lessons from Complex Interventions to Improve Health. *Annual Review of Public Health* 36, 1 (March 2015), 307–323. https://doi.org/10.1146/annurev-publhealth-031912-114421 Publisher: Annual Reviews.

[24] Kasper Hornbæk and Antti Oulasvirta. 2017. What Is Interaction?. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM Press, Denver, Colorado, USA, 5040–5052. https://doi.org/10.1145/3025453.3025765

[25] Zhi-Qiang Jiang, Wen-Jie Xie, Wei-Xing Zhou, and Didier Sornette. 2019. Multifractal analysis of financial markets: a review. *Reports on Progress in Physics* 82, 12 (Nov. 2019), 125901. https://doi.org/10.1088/1361-6633/ab42fb Publisher: IOP Publishing.

[26] Alicia Juarrero. 1999. *Dynamics in action: intentional behavior as a complex system*. MIT Press, Cambridge, Mass.

[27] Kaptelinin, Victor. 2014. *Affordances and Design*. Interaction Design Foundation, Online.

[28] Anna Lichtwarck-Aschoff, Fred Hasselman, Ralf Cox, Debra Pepler, and Isabela Granic. 2012. A Characteristic Destabilization Profile in Parent-Child Interactions Associated with Treatment Efficacy for Aggressive Children. *Nonlinear Dynamics-Psychology and Life Sciences* 16, 3 (2012), 28.

[29] Donella Meadows. 1997. Leverage Points: Places to Intervene in a System. *Whole Earth* 1, Winter (1997), 21. http://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf

[30] John H. Miller and Scott E. Page. 2009. *Complex adaptive systems: An introduction to computational models of social life*. Princeton university press, Princeton, New Jersey.

[31] Gerrit Niezen and Parisa Eslambolchilar. 2015. A human operator model for medical device interaction using behavior-based hybrid automata. *IEEE Transactions on Human-Machine Systems* 46, 2 (2015), 291–302. Publisher: IEEE.

[32] Merlijn Olthof, Fred Hasselman, Guido Strunk, Benjamin Aas, Günter Schiepek, and Anna Lichtwarck-Aschoff. 2020. Destabilization in self-ratings of the psychotherapeutic process is associated with better treatment outcome in patients with mood disorders. *Psychotherapy Research* 30, 4 (May 2020), 520–531. https://doi.org/10.1080/10503307.2019.1633484

[33] Erik Rietveld and Julian Kiverstein. 2014. A Rich Landscape of Affordances. *Ecological Psychology* 26, 4 (Oct. 2014), 325–352. https://doi.org/10.1080/10407413.2014.958035

[34] Yvonne Rogers. 2011. Interaction design gone wild: striving for wild theory. *interactions* 18, 4 (2011), 58–62. Publisher: ACM New York, NY, USA.

[35] William B. Rouse and Daniel Gopher. 1977. Estimation and control theory: Application to modeling human behavior. *Human Factors* 19, 4 (1977), 315–329. Publisher: SAGE Publications Sage CA: Los Angeles, CA.

[36] Gilbert Simondon. 2011. On the mode of existence of technical objects. *Deleuze Studies* 5, 3 (2011), 407–424. Edinburgh University Press.

[37] Steven L. Teal and Alexander I. Rudnicky. 1992. A performance model of system delay and user strategy selection. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, Monterey, California, 295–305.

[38] Ludger van Dijk and Erik Rietveld. 2017. Foregrounding Sociomaterial Practice in Our Understanding of Affordances: The Skilled Intentionality Framework. *Frontiers in Psychology* 7 (Jan. 2017), 12. https://doi.org/10.3389/fpsyg.2016.01969

[39] Guy Van Orden. 2010. Voluntary performance. *Medicina* 46, 9 (2010), 581. Publisher: Multidisciplinary Digital Publishing Institute.

[40] Francisco J. Varela, Evan Thompson, and Eleanor Rosch. 2016. *The embodied mind: Cognitive science and human experience*. MIT press, Cambridge, MA.

[41] Lawrence M. Ward. 2002. *Dynamical cognitive science*. MIT press, Cambridge, MA.

[42] Terry Winograd, Fernando Flores, and Fernando F. Flores. 1986. *Understanding computers and cognition: A new foundation for design*. Intellect Books, Bristol.