REPORT

of the

1st International Interdisciplinary Workshop
Semantic Analysis of Multi-Scale Health Dynamics

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Collegium Helveticum, Zurich, March 14-16, 2018

This workshop was part of the focal topic „Digital Societies“ of the fellow period 2016-2020 at Collegium Helveticum.
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Semantic Analysis of Multi-Scale Health Dynamics

Workshop

Organized by Mike Martin and Harald Atmanspacher

The Workshop is part of the focal topic «Digital Societies» of the fellow period 2016–2020 at Collegium Helveticum.
This three-day workshop is designed to better understand and develop theoretical and analytical approaches from different disciplines for the semantic analysis of multi-scale health dynamics within and across individuals and time. At present we see an increasing potential for within-person time-series data available from all conceivable levels of health, from cells to organs, from behavior to cognition, within multiple contexts. In accordance with current WHO efforts to establish dynamical-systems grounded models of health, we are convinced that the collection and analysis of data should be informed by theoretical models of the health-related meaning of these data and their dynamics.

A number of theoretical models and analytical approaches have been developed by the invited participants that we believe can be used to better understand the development of health. Among them are (a) dynamical-systems models of functional ability, intrinsic capacity, and environments, (b) action vocabularies and action grammars of health, (c) bio-psycho-socio-technical models of health, (d) methods of segmenting and mapping multiple levels of health activities, (e) sampling from health-relevant situations versus health-relevant person characteristics, (f) local versus global (non-)predictors of health dynamics, (g) producing health as a meaningful task produced by a complex pattern of dynamic factors.

The workshop will pursue three goals: (1) understanding theoretical and analytical approaches of participants from different backgrounds, (2) developing ideas for how to apply these approaches for a semantic analysis of multi-scale health data, and (3) mapping pathways to systematically and rapidly extract the health-related meaning (semantics) of multi-scale health data. For this purpose there will be input presentations by participants in the morning at each of the three workshop days with ample time for discussion. Afternoons will provide opportunities for bilateral and multilateral discussions among participants.
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Prof. Kamiar Aminian [EPF Lausanne]

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Prof. Alexander Borbély [University of Zurich]

Prof. Jesus Favela [CICESE, Ensenada]

Dr. Peter beim Graben [University of Cottbus]

Prof. Thomas Kirste [University of Rostock]

Dr. Franz Liem [University of Zurich]

Prof. Mike Martin [Collegium Helveticum, Zurich]

Prof. Tobias Nef [University of Bern]

Prof. Lawrence Schulman [Clarkson University, Potsdam]

Prof. Khena Swallow [Cornell University, Ithaca]

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2. Executive Summary

The semantic analytics of multi-scale health data (Martin et al., 2018) is the new frontier of our understanding of healthy aging. Once we can extract semantic information (i.e., meaning) from health-related syntactic data of multi-scale measurements of health, the generation and test of contextualized individual healthy aging outcomes can be scaled to the level of populations.

Healthy aging research marks a paradigm change in biomedical science. It needs to answer two main questions. One is about the frequency and likelihood of „illness symptoms“ and their absence in the population. Estimators of population likelihoods are typically inferred from sampling individuals from the population. The other is about the likelihood of interventions helping a given individual to maintain or improve health and quality of life. A calculation of these likelihoods requires frequently measured activity data from each individual as well as the semantic analysis of these data. This allows to calculate both within-person likelihood models and population likelihood models (Boker & Martin, 2018).

At present, we see increasing amounts of within-person time-series data available from all conceivable scales (levels) of health, from cells to organs, from behavior to cognition, within multiple contexts from within-person, between-person, and outside-of-person studies. In accordance with current WHO efforts to establish dynamical-systems grounded models of health, the collection and analysis of data needs to be informed by theoretical models of these data, their dynamics, and their semantic content (Atmanspacher 2016; Atmanspacher & Demmel 2016; Yordanova et al., 2017).

The key challenge of a paradigm shift towards a contextualized understanding of health is to exploit the health-related meaning of high-density data from individuals and populations at as many scales (levels) as possible. Simply due to the enormous amounts of these data, assigning interpretative values to the measurements has to be automated. Thus, automated segmentations, annotations, pattern identification, and pattern indicator calculations are needed to inform the measurement and interpretation of contextualized health.

The semantic interpretation of contextual health data based on multi-scale within-person information ideally uses the options developed in all relevant fields of research. Until now, healthy aging research was a domain of medical, geriatric, gerontological, psychological, sociological, health services, nursing sciences, or public health research. In the era of digitalization, increasingly available sensor technology, affordable data acquisition and storage devices, and big data, a joint effort together with researchers from computer science, robotics, geoinformatics, ubiquitous computing, neuroscience, and physics is needed. Only by cooperative efforts across these disciplines can we find ways of upscaling the measurement of data and their semantic analysis from individuals to whole populations to facilitate a population-wide contextualized understanding and improvement of health.
3. Consensus Report

Participants noted the healthy aging paradigm promoted by WHO’s World Report on Ageing and Health (2015) and the Global Strategy and Action Plan on Healthy Aging (2017). The report promotes a contextualized and dynamic understanding of health in advanced age. It combines several focal aspects:

1. Focus on „functional ability“, i.e., „to be and do what people have reason to value“. This means that individuals are an essential part of the definition of health outcomes.

2. Focus on „intrinsic capacity“, i.e., all abilities, skills, traits, activities, diseases, biological factors potentially supporting an individual’s functional ability.

3. Focus on environmental opportunities, i.e., environments as defining part of health.

4. Focus on decision-making individuals, i.e., individuals perceive, evaluate, decide on use of opportunities and activities to increase, stabilize or decrease intrinsic capacities, environments and functional ability.

Consequences of the report include that the basic theoretical framework has to be a dynamic systems model. All elements of the model can be adapted or changed to stabilize functional abilities. Healthy aging can only be understood contextually, because measures of health at different scales refer to the same overall notion of health and quality of life. Context is crucial because any change of scale (level) of information can potentially change the interpretation of a particular set of health data. Healthy aging is always defined as an interplay between all factors and cannot be reduced to one observable symptom or its absence. In other words, individuals can be healthy agers with good functional ability with and without particular symptoms. The model is the first to conceptualize single morbidity and multimorbidity research by understanding individuals with (multiple chronic) morbidities as individuals with, at the same
time, multiple abilities, traits, activities, environments. Reflecting and decision-making ideally allows them to achieve, maintain, and adapt high levels of functional ability.

Participants agreed that, from a research perspective, **key challenges** to establish the new healthy aging paradigm are:

(a) find ways to **objectively measure healthy aging dynamics that stabilizes contextualized functional ability in every individual** with and without explicit feedback from them;

(b) find ways to **upscale measurement to all individuals and contexts in a population over time in an affordable and legally, ethically, technically, socially, and educationally acceptable manner**.

Participants identified the following problems to be solved to make this possible:

(1) **Clarify terminology.** In order to facilitate the collaboration of specialists from different disciplines and research traditions, a dictionary of terms is needed. It should contain agreed-upon definitions and translations of terms referring to health and healthy aging (such as health, healthy aging, contextualized health, personalized health, individualized health, functional ability, intrinsic capacity, environment, context, decision, action, possibility space, meaning) as well as methodological approaches (such as dynamic systems, ontologies, multi-scale dynamics, segmentation, annotation, semantic analytics, reliability, validity).

(2) **Specify the theoretical models of healthy aging dynamics** and clarify the distinctions between different models. The distinctions include possibilities and differences in operationalization and study designs (Boker & Martin, 2018). This may require building capacity and incentives for theory development on dynamic healthy aging models, first focusing on particular activity domains (cognitive, physical, mobility, motivation, sleep etc.), then integrating across domains.

(3) **Develop testable theoretical ideas** about how which patterns of (real-life) activities over which periods of time and their contexts might be related to long-term maintenance of functional ability. Examples may be the fractality of physical activities, the degree of entropy between activity changes, recurrence of activity patterns, regularity of activity patterns, situational change detection, communication symmetry, location pattern, home range analysis, complexity measures (Atmanspacher et al. 1997), pragmatic information analysis (Atmanspacher & Scheingaber 1990, beim Graben 2006).

(4) **Find ways to automatically segment** relevant activity and context patterns guided by expert input. The workshop presented a range of examples and ideas for segmentation on some levels of observation (Atmanspacher, 2016; beim Graben et al., 2016; Gaveau et al., 2006; Swallow et al., 2011; Zacks et al. 2007), and demonstrated the need to use expert input to decide on their relevance (Castro et al., 2015; Yordanova et al., 2017). This problem may require building transdisciplinary working groups focusing on specific
activity domains or populations. Several ways are conceivable to go from sensor data to automated segmentation, e.g., from outside observer, participant as observer, then machine learning for semi-automatic and automatic segmentation and interpretation. Citizen science approaches may be helpful to crowdsourc.

(5) Improve acquisition and accessibility of data. To understand the dynamics of healthy aging it would be ideal to have activity data from the past (retrospectively) as well as plans for acquiring them as part of ongoing study efforts (prospectively). More and more individuals will have collected activity data, e.g., by sensors on their smartphones and wearables, or in an analog fashion. Retro-digitalization and measures to harvest existing data sources create new opportunities for faster knowledge acquisition, e.g., by conducting prospective studies retrospectively.

(6) Improve usefulness of existing data. The healthy aging model requires upscaling individual contextualized health dynamics to the level of populations. This requires the aggregation of information for each individual in the population before combining individuals at the ensemble level, i.e., data must be clearly assignable to particular individuals. Once we know for each individual what trait, ability, activities, symptoms, brain structure data are available, they can be used to test within- and between-individual dynamical models. Current regulatory frameworks requiring the anonymization of research data make this impossible. Thus, establishing a socially, legally and ethically acceptable technical framework for using individual-specific data for health monitoring and improvement would improve the usefulness of the existing data massively. A framework also allowing to combine self-collected data and data from different acquisition devices would add value. A competition for data preprocessing applications that automatize the detection of semantic segmentation (Atmanspacher, 2016; beim Graben et al., 2016) or annotation of health-related data (Kirste 2011; Yordanova et al., 2018) would accelerate the use of existing data. Ways of mapping data from different devices to the same construct of healthy aging dynamics (translator) instead of having to standardize the data format would allow to use data from any device to improve or understanding of health dynamics.

(7) Increase methodological capacity. The dynamic healthy aging paradigm requires the understanding of dynamic systems modeling, symbolic dynamics, machine-learning approaches, multi-scale longitudinal analysis, and computational activity analysis. As previously methods for randomized controlled trial designs massively improved the evidence base for medical decisions, today an initiative to train a substantial part of healthy aging experts in novel methods can provide momentum for an evidence-based design of functional-ability oriented contextualized health interventions. This initiative should focus on exploring and validating novel methods (cf (3)). As limited methodological expertise also limits the interpretation of data and the development of theoretical models, such an initiative would contribute to an improved practice of healthy aging research.
(8) **Increase storage and computational power and develop models of data collection and analysis in partnerships between academic and citizen researchers.** Massively larger amounts of data being collected and releasing them to citizen science researchers will require an effort into building trustworthy health data banks and health data analysis infrastructures. In addition, educational tools will have to be developed to learn how to collect, annotate, and analyze data for all interested individuals.

(9) **Establish business models for sustainability of contextualized health dynamics research.** As governments with an interest in population distributions of health and illness are funding population-based studies, individuals with an interest in evidence-based contextualized decision-support may have an interest in supporting and funding research that generates the relevant evidence. In this situation, governments may develop responsibility for helping individuals to follow the road to healthy aging and individuals themselves may be interested in traveling well on that road. Governments may be convinced that research on both aspects is in the interest of a just and healthy society.
4. Actions

Participants agreed that concrete actions should be specified and implemented to advance mastering the identified challenges. These actions include:

**Ontology development**: Experts from health domains working with experts on segmentation, annotation, and automatic interpretation of observed multi-scale behavior streams can most quickly define ontologies for particular situations or persons. These ontologies (understood as machine-useable interpretation systems) are key to eventually automatize the interpretation of large-scale data streams.

**Dictionary**: Terminology across disciplines may vary but represents the same ideas; or terminology may be similar but represents substantially different concepts. Thus, identifying key terms and clarifying their conceptual basis is mandatory to improve transdisciplinary collaborations (translational research).

**Illustrate multi-scale healthy aging models**: To convey the healthy aging model used in the workshop it should be illustrated such that it can be used to relate to specialists across disciplines.

**Mapping possibility spaces**: Health research currently focuses often on finding evidence for what works as THE intervention for groups of potential or actual patients. However, multiple equally effective interventions may work within and across individuals. In addition to existing approaches, ways of mapping the behavioral possibility space would provide substantially new information. For instance, individual behavioral pathways could be represented in behavioral possibility spaces. Or the effects of changing relations between the behavioral activity space and the behavioral possibility space could be explored.

**Open science**: The models and approaches discussed ideally require a research infrastructure that allows to combine high-density individual data with low-density laboratory data and openly accessible datasets. The opportunities and challenges of using such data to improve measurement across levels of health are huge. An open science approach can increase the creative power of many individuals. A concept of how to organize an open science approach in the field is needed.

**Interdisciplinarity**: The challenge of how to semantically interpret multi-scale health data by nature requires the collaboration between experts from content domain fields and methodologically versatile data scientists. Institutional ways of setting up efficient transdisciplinary teams and stakeholders are needed.

**Semantic multi-scale analysis bullets competition**: The organization of competitions for improving the quality of rapid behavior data segmentation, annotation and interpretation is desirable. The „semantic multi-scale analysis bullets“ developed can be published and used by individuals and researchers.

**Innovation challenge**: A key task is to apply multi-scale health analytics for more efficient usage
of available data from databanks and individuals. Differences and changes in data acquisition devices and their software, sampling rates, or data formats still need to allow to extract information about health and its dynamics homogeneously. Finding solutions to efficiently use this information is decisive for speeding up the knowledge gain on health development as we need good information on what keeps individuals healthy over the next 50 years in 3 years, not 50. Specifying the innovation challenge in more detail and sustainably organizing it is needed.

Theory development: To exploit the potential richness of information in large multi-scale health data crunching numbers is not enough. Causal dynamical systems models can never be inferred from whatever huge source of data alone: They require theoretical models that formulate the assumptions about such causal systems. Only with such models the proper meaning of data can be understood across scales. While current tests of models by data are often limited by the lack of available data, increasingly available and accessible data could stimulate theory development enormously. Within a few years, a codebook of THE ultimate healthy aging study could contain data of 100'000 persons in 100 countries over 100 years on 10'000 variables (or basically all the data one can possibly have).

Network building: Participants agreed to continue working on the actions, establish and widen the network to include the perspectives of the current workshop and extend them to include experts from health content domains with an interest in contextualized health dynamics measurement and analysis.
5. Bibliography


https://doi.org/10.1037/0033-2909.133.2.273

*Note.* The articles of this bibliography are ordered alphabetically by authors. These and other relevant full-text articles can be found in a separate reader.