Editors: **Longbing Cao,** University of Technology, Sydney, longbing.cao@uts.edu.au

Behavior Informatics: A New Perspective

Longbing Cao, *University of Technology, Sydney*

Behavior is a concept increasingly recognized in broad communities spreading from social to business, online, mobile, economic, and cultural domains. However, systematic and comprehensive methodologies, theories, tools, and systems aren't ready for deeply, fully, and effectively capturing, representing, quantifying, analyzing, learning, and measuring the semantics, sequencing, networking, evolution, utility and impact of individual, group, and cohort behaviors taking place in the real world. This is becoming fundamental and critical in the age of Big Data. Here, in this installment of "Trends & Controversies," we look at how *behavior informatics* targets the development of effective methodologies and techniques to tackle these issues.

In This Issue

To delve into the state of the field, Thorsten Joachims and I present a high-level overview of research on behavior computing, discussing deep behavior intelligence from a disciplinary perspective.

Then, more specifically, Can Wang and her colleagues discuss the representation, modeling, analysis, and reasoning of coupled group behaviors, in which behaviors share different levels and types of coupling relationships, as usually seen in social networks and community analysis.

Social media involves massive crowds of individuals from different walks of life and generates an unprecedented scale of behaviors. In looking at these behaviors more closely, Reza Zafarani leads a discussion about both individual and collective behaviors in such social media.

Effective recommendation is becoming an increasingly important online and social behavior. Guandong Xu and Zhiang Wu share their view on a topical issue—to involve, consolidate, and evaluate group preference for more targeted group-based recommendation.

Web search requests are more personalized and a context-aware understanding of information and social and collaborative searching activities is needed. Gabriella Pasi presents insights on engaging behaviors in information seeking, especially considering coupled behaviors within certain contexts.

Nowadays, an increasing number of users are interested in IPTV programs online, and generate massive amounts of activities. Ya Zhang and her colleagues lead a discussion about the behaviors of IPTV users that are related to system efficiency, personalization, recommendation, and targeted advertisement.

Finally, Edoardo Serra and V.S. Subrahmanian raise an interesting question: Should behavior models of terror groups be disclosed? They share their research and arguments on strategic disclosures and consequences in tackling today's terrorism.

The seven selected articles paint a snapshot and trigger wide discussions about current behavior informatics research and applications on diverse issues and in different domains. This Trends & Controversies installment hopefully discloses the necessity, challenges, prospects, and opportunities for the deep, broad, and quantitative development and understanding of complex behaviors in the increasingly sophisticated real world.

Longbing Cao is the director of the Advanced Analytics Institute and a professor in the Faculty of Engineering and IT at the University of Technology, Sydney. Contact him at longbing.cao@uts.edu.au.

Behavior Computing

Longbing Cao, *University of Technology, Sydney*
Thorsten Joachims, *Cornell University*

Behavior is an increasingly important concept in the scientific, societal, economic, cultural, political, military, living, and virtual world. In the dictionary,

1541-1672/14/$31.00 © 2014 IEEE
Published by the IEEE Computer Society

"behavior" refers to a manner of behaving or acting, and the action or reaction of any material under given circumstances. In Wikipedia, "behavior" refers to the actions and mannerisms made by organisms, systems, or artificial entities in conjunction with its environment, which includes the other systems or organisms around, as well as the physical environment. It's the response of the system or organism to various stimuli or inputs—whether internal or external, conscious or subconscious, overt or covert, and voluntary or involuntary.

Thus, behavior is ubiquitous and very social. In addition to the common terms, such as consumer behaviors, human behaviors, animal behaviors, and organizational behaviors, behaviors appear everywhere at any time. Behaviors in the physical world are explicit, and have been studied from many different aspects. With the rapid development and deep engagement of social and digitalized life with advanced computing technology, in particular, social networks, social media, online games, mobile applications, virtual reality, multimedia information processing, visualization, machine learning, and pattern recognition, more behaviors in the virtual and social world are emerging. In addition, behaviors in traditional spheres are becoming increasingly complex with the involvement in and marriage of the virtual and social world. Socio-behaviors dominate these areas. Behaviors in more classic areas—including business, living spaces, economics and politics—are also becoming more and more social.

In different applications and scenarios, behaviors present respective social and non-social characteristics, relationships, structures, and effects. For instance, in stock markets, a trader's behavior influences others and is embodied through trading actions and action properties, such as placing a buy quote at a certain time, price, and volume on a target security. The actions, response, or presentation, and the effect associated with the corresponding properties forms a concrete and rich object—the behavior of an individual or a group.

Behavior as a computational concept[1] captures major aspects, including the following: demographics of behavioral subjects and objects; social relationships or norms governing the interactions between behaviors of an individual or a group; behavior sequences or networks and their dynamics; and impact or effect generated by the behaviors on subjects and/or objects. Accordingly, an abstract and generic concept of behavior (γ) may carry (but is not limited to) the following attributes and properties:

- Subject (s)—the entity (or entities) that issues the activity or activity sequence.
- Object (o)—the entity (or entities) on which a behavior is imposed.
- Context (e)—the environment in which a behavior is operated, including the pre-condition and post-condition of a behavior.
- Goal (g)—the objectives that the behavior subject would like to accomplish or bring about.
- Belief (b)—belief represents the informational state and knowledge of the behavior subject about the world.
- Action (a)—what the behavior subject has chosen to do or operate.
- Plan (l)—the sequences of actions that a behavior subject can perform to achieve one or more of its intentions.
- Impact (f)—the results led by the execution of a behavior on its object or context.
- Constraint (c)—what conditions are imposed on the behavior; constraints are instantiated into specific factors in a domain.
- Time (t)—when the behavior occurs.
- Place (w)—where the behavior happens.
- Status (u)—where a behavior is currently located; for instance, status may refer to *passive* (not triggered), *active* (triggered, but not finished yet), or *done* (finished); in some other cases, status may include *valid* or *invalid*.
- Associate (m)—other behavior instances or sequences of actions that are associated with the target one; behavior associates may exist because a behavior has an impact on another or behaviors are related through interaction and business processes to form a behavior network.

Accordingly, a behavior instance (γ) of an individual or group entity can be represented in terms of a behavior vector $\vec{\gamma}$ as follows:

$$\vec{\gamma} = \{s, o, e, g, b, a, l, f, c, t, w, u, m\}. \quad (1)$$

Further, the behaviors of an individual or group form a behavior sequence G that can be represented in terms of a vector sequence $\vec{\Gamma}$, in which behaviors are connected in terms of social relationships R,

$$\vec{\Gamma} = R\{\vec{\gamma}_1, \vec{\gamma}_2, \ldots, \vec{\gamma}_n\}. \quad (2)$$

With the vector-based behavior sequences, further analysis on such vectors can identify vector-oriented behavior patterns. Compared to traditional sequential pattern mining, such vector-oriented behavior pattern analysis is much more comprehensive.

Computing Behaviors

Existing management information systems and enterprise applications don't support the storage of behaviors very well. The entity of physical or social behavior is usually decomposed to multiple transactions without protecting the semantics and complete behavior journey. Behavior as a very

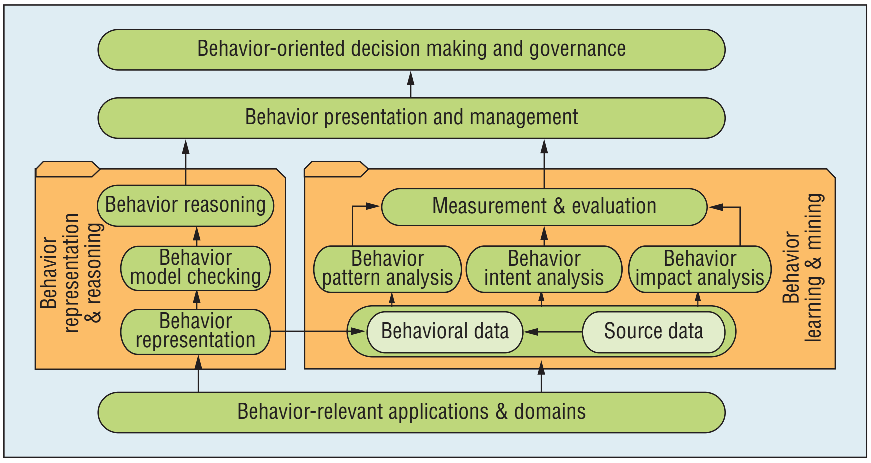

Figure 1. Behavior computing research map. Behavior informatics consists of two major research directions: behavior representation and reasoning to formalize behaviors, and behavior learning and mining to analyze behaviors.

soft buzzword is used widely without a clear definition and systematic representation. Such "implicit" behavior in transactional data isn't consistent with the "explicit" semantic existence in business. Hence, it's necessary and crucial to develop computing techniques for explicit and in-depth quantification and informatics of behaviors.

With the concept of behavior and the introduction of an abstract behavior model, the representation, modeling, data analysis and mining, learning, and decision making of behaviors is becoming doable and increasingly useful, essential, yet challenging in ubiquitous behavioral applications and problem-solving. They form a new computing opportunity, necessity, and technology innovation, which we refer to as *behavior computing* or *behavior informatics*[2,3] for the explicit and in-depth understanding and analysis of genuine behavior-oriented actions, operations, and events associated with many challenging business problems.

Behavior computing (or behavior informatics) consists of methodologies, techniques, and practical tools for representing, modeling, analyzing, learning, discovering, and utilizing human, organismal, organizational, societal, artificial, and virtual behaviors, behavioral interactions and relationships, behavioral networks, behavioral patterns, and behavioral impacts,[4] and forming and decomposing behavior-oriented groups and collective intelligence for the emergence of deep behavioral intelligence in conjunction with their environments. Behavior computing contributes to the in-depth understanding, discovery, applications, services, and management of behavior intelligence.

In more detail, behavior computing addresses the following key aspects (as Figure 1 shows).

- *Extracting behavioral data*. In preparing behavioral data, behavioral elements hidden or dispersed in transactional data must be extracted and connected, and further converted and mapped into a behavior-oriented feature space, called a *behavioral feature space*. In the behavioral feature space, behavioral elements are presented into behavioral item sets. Hence, it's necessary to map and convert transactional data to behavioral data.
- *Representing and modeling behavior*. This involves developing behavior-oriented specifications for describing behavioral elements and the relationships among the elements. The specifications reshape the behavioral elements to suit the presentation and construction of behavioral sequences. Behavioral modeling also provides a unified mechanism for describing and presenting behavioral elements, behavioral impact, and patterns.
- *Analyzing behavioral impact*. In analyzing behavioral data, a person might be particularly interested in those behavioral instances that are associated with a high impact on business processes and/or outcomes. Behavioral impact analysis[4,5] features the modeling of behavioral impact.
- *Discovering behavioral patterns*. There are in general two methods of behavioral pattern analysis. One is to discover behavioral patterns without consideration of the behavioral impact, the other is to analyze the relationships between behavior sequences and particular types of impact.
- *Emerging behavioral intelligence*. To understand behavioral impact and patterns, it's important to scrutinize behavioral occurrences, evolution, and life cycles, as well as the impact of particular behavioral rules and patterns on behavioral evolution and intelligence emergence. An important task in behavioral modeling is to define and model behavioral rules, protocols, and relationships, and their impact on behavioral evolution and intelligence emergence.
- *Understanding behavioral networking*. Multiple sources of behavior may form into a certain behavioral network. Particular human behavior is normally embedded into such a network to fulfill its roles and effects in a particular situation. Behavioral network analysis aims to understand the intrinsic mechanisms inside a network—for instance, behavioral rules, interaction protocols, convergence and divergence of associated behavioral item sets, as well as their effects such as network topological structures, linkage relationships, and impact dynamics.

- *Simulating behaviors*. To understand all of the aforementioned mechanisms that may exist in behavioral data, simulation can play an important role to observing the dynamics, the impact of rules/protocols/patterns, behavioral intelligence emergence, and the formation and dynamics of a social behavioral network.
- *Presenting behaviors*. From analytical and business intelligence perspectives, behavioral presentation aims to explore the presentation means and tools that can effectively describe the motivation and interest of stakeholders on the particular behavioral data. In addition to the traditional presentation of patterns (such as associations), visual behavioral presentation is a major research topic. It's of high interest to analyze behavioral patterns in a visual manner.

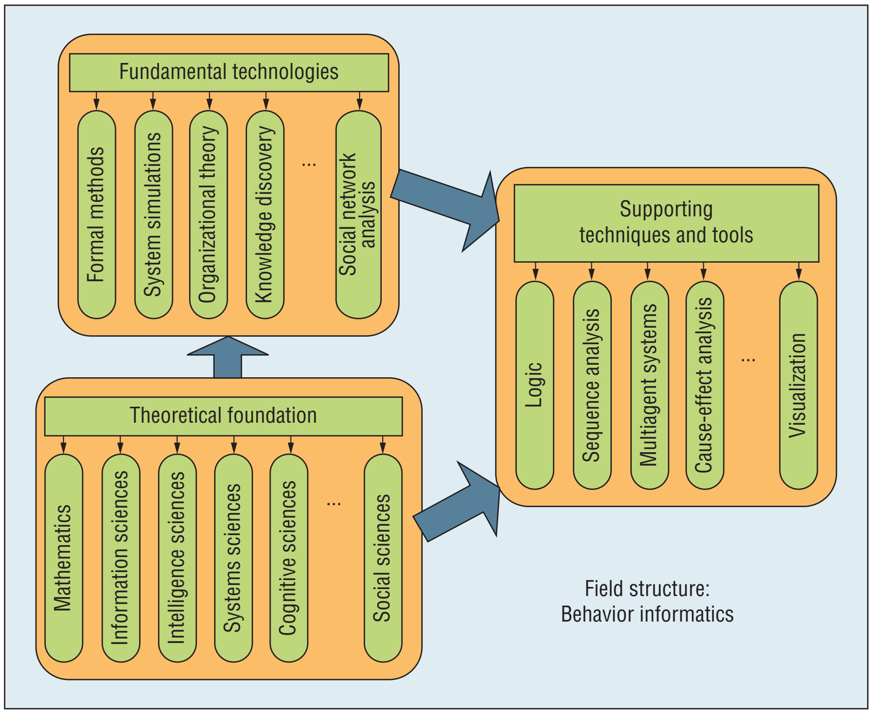

Figure 2. Behavior computing field structure. Behavior informatics, as a research field, delves into three directions: theoretical foundations, fundamental technologies, and supporting techniques and tools.

These tasks form a clear field structure and research map of behavior computing. A generic process of computing behaviors will complement classic approaches toward a more comprehensive and in-depth behavior understanding and problem solving. Given a business application, it first converts entity relationship-oriented transactional data to behavior feature-oriented data through behavior modeling. Behavior patterns, exceptions, dynamics, and impacts are then analyzed through developing corresponding behavior-based analytic and learning methods. The outcomes are then presented as behavior patterns, rules, or visual diagrams, and/or transformed into decision-support business rules to disclose the interior driving forces and causes of business problems and impact.

Prospects and Opportunities

Behavior is becoming an increasingly important asset to be deeply analyzed and understood to disclose its explicit and implicit business value and semantic gain that can't be achieved solely by usually recorded transactional data. The deep values and prospects from computing behaviors may be through

- fully disclosing and utilizing the *behavior semantics* that are usually destroyed in recorded transactions and overlooked in behavior analysis;
- fully and deeply exploring the *behavior sequences* and *behavior matrix* of an actor or a group along a certain time period, in which behavior properties are involved;
- deeply engaging in and learning about the explicit and (especially hidden) *social relationships* governing behavior formation, structuring, networking, evolution, and emergence of behavior intelligence;
- deeply discovering behavior patterns, exceptions, relational patterns, and changes of individuals, groups, or the global population against behavior formation, evolution, and revolution;
- effectively capturing and quantifying the relationships between behaviors, behavior evolution, and their impacts, as well as measuring the *impact and performance* of behaviors and behavior dynamics on business objectives;
- deeply understanding the *belief*, *desire*, and *intent* behind behaviors conducted and the impact caused; and
- actively detecting, early predicting, and intervening in *unexpected behaviors* of individuals, groups, or cohorts so as to convert them to the expected directions and impact.

To access these prospects, cross-disciplinary efforts are needed. In addition to informatics and analytics, theories, methodologies, and tools available in statistics, mathematics, econometrics, marketing, psychologies, social science, behavior science, behavior finance, and so on are necessary. This requires collaboration between disciplines and cross-domain experts (see Figure 2).

There exist unlimited opportunities in deep behavior computing in terms of complementing the existing behavior analysis, data analysis, event detection, behavior economics, and cognitive study towards data-driven, semantics-oriented and process-based quantification and formalization of what exactly takes place in the real world. Many application areas[2,3] from traditional to emergent issues can benefit from it; for instance, exploring the patterns, anomalies, sequencing of, and intent driving customer behaviors in retail and online shopping businesses, Web usage, and interactions in the Internet, trading behaviors in capital markets, and exceptional activities captured on surveillance systems.

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Longbing Cao is the director of the Advanced Analytics Institute and a professor in the Faculty of Engineering and IT at the University of Technology, Sydney. Contact him at longbing.cao@uts.edu.au.

Thorsten Joachims a professor in the Department of Computer Science and in the Department of Information Science at Cornell University. Contact him at tj@cs.cornell.edu.

Coupled Behavior Representation, Modeling, Analysis, and Reasoning

Can Wang, *Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia*
Longbing Cao, *University of Technology, Sydney*
Eric Gaussier, *University of Joseph Fourier,*
Jinjiu Li, Yuming Ou, and Dan Luo, *University of Technology, Sydney*

Behavior refers to the action, reaction, or property of an entity, human or otherwise, to situations or stimuli in its environment.[1] The in-depth analysis of behavior has been increasingly recognized as a crucial means for understanding and disclosing interior driving forces and intrinsic cause-effects on business and social applications, including Web community analysis, counter-terrorism, fraud detection, and customer relationship management. With the deepening and widening of social/business intelligences and their networking, the concept of behavior is in great demand to be consolidated and formalized to deeply scrutinize the native behavior intention, lifecycle, and impact on complex problems and business issues.

Although there's an emerging focus on deep behavior studies, such as social network analysis,[2] periodic behavior analysis[3] and behavior informatics approach,[1] previous research work has mainly focused on individual behaviors without considering the interactions of them. However, with increasing network and community-based events as well as their applications, such as group-based crime and social network interactions, coupling relationships between behaviors contribute to the intrinsic causes and impacts of eventual business and social problems. In the real-world applications, group behavior interactions (that is, coupled behaviors) are widely seen in natural, social, and artificial behavior-related problems. Complex behavior and social applications often exhibit strong explicit or implicit coupling relationships both between their entities and properties. Moreover, it's also quite difficult to model, analyze, and check behaviors coupled with one another due to the complexity from data, domain, context, and impact perspectives.

Due to the emerging popularity and importance of coupled behaviors, the representation, modeling, analysis, mining and learning, and determination of coupled behaviors are becoming increasingly essential yet challenging in ubiquitous behavioral applications and problem-solving techniques. They inevitably and undoubtedly constitute new computing opportunities and technological innovations, and thus we refer to them as *coupled behavior informatics*, which is an important branch of behavior computing and analytics.[4] Coupled behavior informatics consists of methodologies, techniques, and practical tools for exploring human, organizational, artificial/virtual, qualitative, and quantitative behaviors, their interactions and relationships, the formation and decomposition of behavior-oriented groups, and collective intelligence.

Here, we present the limitations of current research, and explore the needs, opportunities, challenges, prospects, and trends of coupled behavior informatics in terms of coupled behavior representation and modeling as well as analysis and reasoning.

Coupled Behavior Representation and Modeling

Coupled behavior representation refers to develop representation and modeling mechanisms, languages, and tools to capture behavior characteristics, intrinsic and contextual properties of behaviors, behavior dynamics, and internal and external communications among behaviors.[5] Those techniques and methods can also be used to understand interaction, causality, convergence, divergence, selection, decision, evolution, emergence, and intelligence of behavior entities, behavior properties, behavior networks, and behavior impact. Both formal and visual specifications can be discussed to represent coupled behaviors and behavior interactions.

Limitations and Challenges

Existing behavior modeling approaches have too many styles and forms according to distinct situations. There's very limited research on formalizing the concept of behavior and its elements, which is too weak to reveal that behavior plays the key role of an internal driving force for social and business activities. Additionally, it's ineffective or even impossible to deeply tease out native behavior intention and impact on complex issues and business problems. There are no formal behavior representation models stated from a general perspective and providing a comprehensive understanding of behavior constitution.

In addition, state-of-the-art research work doesn't explicitly model and analyze complex interactions of group behaviors directly. Complex coupling relationships between behaviors are often ignored or only weakly addressed. Yet these behaviors are often observed to be correlated in terms of certain coupling relationships—for instance, serial or parallel, conjunction or disjunction. Such coupling relationships greatly challenge existing behavior representation methods, since they involve multiple behaviors from different actors, and add constraints on the interactions and behavior evolution, which often aren't obvious and exhibit large complexities. However, a deep exploration of interactive relationships is necessary for us to understand how behaviors are correlated and how those coupled behaviors drive and impact business and social problems.

Group behavior interactions, such as multi-robot teamwork and group communications in social networks, are widely seen in both natural, social, and artificial behavior-related applications. Behavior interactions in a group are often associated with varying coupling relationships—for instance, conjunction or disjunction. Such coupling relationships challenge existing behavior representation methods, because they involve multiple behaviors from different actors, constraints on the interactions, and behavior evolution.

Research Objectives and Issues

Based on the aforementioned limitations and challenges, coupled behavior representation and modeling is to develop behavior-oriented specifications and formalizations to describe coupled behaviors (that is, behaviors from either the same or different actors are often coupled with each other) and the relationships among them. It provides a unified and formalized mechanism for describing, presenting, and aggregating behavior interactions, desired requirements or properties, behavior impact, and patterns.

Several classical theories and techniques are closely relevant to coupled behavior representation and modeling, such as ontology, knowledge representation, software engineering, cognition, agent, logic, and matrix computing. By taking great advantage of those underpinning mechanisms, the representation and modeling of coupled behaviors can be proposed, designed, and constructed in a solid and systematical way. During this process, a lot of research issues are worth investigating, which include but are not limited to the following points:

- How can we define a unified concept of behavior? How can we define a unified concept of coupled behaviors?
- What is a coupling relationship? How do we qualify and quantify the couplings or interactions among a range of behaviors?
- What kinds of basic coupling relationships can we use to represent complex interactions among homogeneous and/or heterogeneous behaviors?
- How do we model coupled behaviors in both visual and formal manners? How do we establish a reversible and unique mapping or link between these two types of representation?
- What are respectively the syntactic and semantic interpretations of coupled behaviors? What is the relationship between them?
- How can we represent and abstract behavior interaction patterns?

Addressing these issues raises opportunities for further analysis and reasoning of coupled behaviors, which are widely seen in community and social networks.

Coupled Behavior Analysis and Reasoning

Coupled behavior analysis and reasoning denote proposing effective methods, techniques, and tools for emergent areas and domains in analyzing and reasoning about coupled behaviors and their properties.[1] Model checking technique is utilized to verify the coupled behavior model with desired requirements, and to further refine the model. Coupled similarities are also introduced to characterize the quantitative behavior

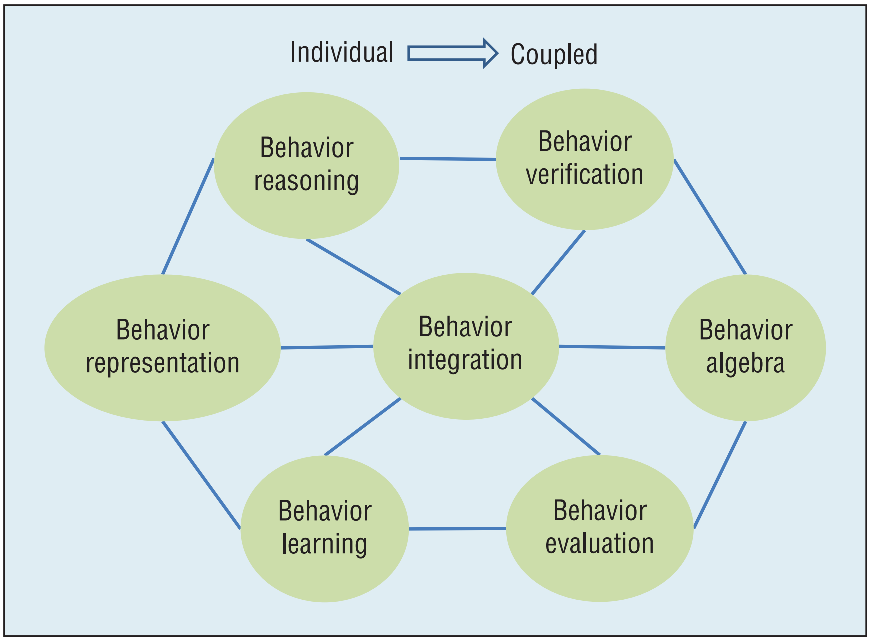

Figure 3. Research issues on coupled behavior informatics. Coupled behavior informatics aims to build systematic tools to address aspects and issues associated with individuals and groups with coupling relationships.

interactions in terms of coupling relationships between properties (such as attributes, features, and variables) and/or entities (such as objects, records, and observations). Algorithms and case studies are discussed to analyze behaviors correlated with one another based on mixed properties and complex coupled interactions. The analytical results will be used for detection, prediction, intervention, and grouping of coupled behaviors as well as their interactive relationships.

Limitations and Challenges

On one hand, traditional behavior analysis is usually built on customer demographics and business usage-related transactions directly. It mainly relies on implicit behavior and explicit business appearance from behavioral and social sciences, often leading to ineffective and limited analysis in understanding business and social activities deeply and accurately. With behavior implied in demographic and transactional data, it's not possible to support in-depth analysis on behavior interior surrounded by behavioral elements, but on behavior exterior such as service usage. The behavior implication in transactional data also determines that it fails to scrutinize behavioral intention and the impact on business appearance and applications.

On the other hand, current research often overlooks the checking of behavior modeling, which weakens the soundness and robustness of models built for complex behavior applications. The quality of behavior interactions aren't checked through verification techniques. Little related work is ready for the formalization and verification of coupled behaviors, including elaborating and representing behavioral elements, specifying behavior-interactive relationships, and checking the modeling of multiple behavior couplings. The engagement of verification in behavior analysis may make the findings much more stable and robust for problem solving.

Research Objectives and Issues

With the formal representation of coupled behaviors, the coupled behavior analytics addresses the task of behavior analysis and reasoning, which are used to analyze, check, and verify complex behavioral elements, relationships, aggregations, properties, and constraints. It accordingly refines sensitive and problematic model proposals, and then guarantees the robustness and stability of coupled behavior representation schemes.

Likewise, strategies and theories including action reasoning and composition, the belief-desire-intention model, situation calculus, behavior compositions, logic reasoning, and model checking have been proposed to analyze and reason about behaviors as well as their interactions. From the perspective of coupled behavior analysis and reasoning, there are many opportunities for us to widely explore. Many open issues are worth widely addressing and systematically investigating. These interesting research points include but are not limited to the following:

- The context of coupled behaviors is to be formalized to control the whole process of coupled behavior analysis and reasoning according to different requirements. More types of consolidated coupling are to be explored and studied, and the soft computing techniques can be adopted to propose the fuzzy or rough coupled behavior informatics.
- Analytical problems such as the convergence or divergence of coupled behavior vectors are to be defined and intensively studied. Limits of converged coupled behavior sequences are to be clarified, which are essential to calculus and can be used to define continuity, derivatives and integrals.
- Some other research issues, including how to define the bases and dimension of such a coupled behavior space, how to do the space decomposition, how to conduct the linear

and nonlinear transformations, are to be addressed and deeply explored.
- How can we use logic-related representations to reason about coupled behaviors and their interactions? How can we adopt verification techniques to check the validity of coupled behaviors via certain properties? How can we extract rules and mine patterns from analyzing and reasoning about coupled behaviors?

As a result of exploring these research issues, we're able to develop a deeper understanding of behaviors, especially coupled behaviors of interested groups.

Based on these discussions, we summarize the associated research issues for coupled behavior informatics (see Figure 3). Here, we mainly focus on coupled behavior representation, coupled behavior reasoning, and coupled behavior verification. In fact, these points are designed for qualitative coupled behaviors, which are qualified by actions. Alternatively, some coupled behaviors are quantified by properties, called quantitative coupled behaviors. Accordingly, coupled behavior learning and coupled behavior evaluation are proposed for the quantitative coupled behaviors. Finally, a coupled behavior algebra can be introduced to integrate the qualitative coupled behaviors and quantitative coupled behaviors, which forms a big picture for coupled behavior informatics.

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Can Wang is a postdoctoral fellow with Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. Contact her at can.wang@csiro.au.

Longbing Cao is the director of the Advanced Analytics Institute and a professor in the Faculty of Engineering and IT at the University of Technology, Sydney. Contact him at longbing.cao@uts.edu.au.

Eric Gaussier is a full professor in computer science at the University of Joseph Fourier. Contact him at eric.gaussier@imag.fr.

Jinjiu Li is a lecturer in the Advanced Analytics Institute and at the University of Technology, Sydney. Contact him at jinjiu.li@uts.edu.au.

Yuming Ou is a lecturer in the Advanced Analytics Institute and at the University of Technology, Sydney. Contact him at yuming.ou@uts.edu.au.

Dan Luo is a research fellow in the Advanced Analytics Institute and at the University of Technology, Sydney. Contact her at dan.luo@uts.edu.au.

Behavior Analysis in Social Media

Reza Zafarani and Huan Liu, *Arizona State University*

With the rise of social media, information sharing has been democratized. As a result, users are given opportunities to exhibit different behaviors such as sharing, posting, liking, commenting, and befriending conveniently and on a daily basis. By carefully analyzing behaviors observed on social media, we can categorize these behaviors into *individual* and *collective* behavior. Individual behavior is exhibited by a single user, whereas collective behavior is observed when a group of users behave together. For instance, users using the same hashtag on Twitter or migrating to another social media site are examples of collective behavior. User activities on social media generate behavioral data, which is massive, expansive, and indicative of user preferences, interests, opinions, and relationships. This behavioral data provides a new lens through which we can observe and analyze individual and collective behaviors of users.

The scale and existence of this new type of data presents behavior analysis on social media with new challenges. We detail first what individual and collective behavior analysis is, and then outline novel challenges with future work.

Individual Behavior Analysis

Individual behavior can be considered one of the following:

- *User-user behavior.* This type of behavior is observed between two users. For example, befriending and following in social media are examples of such behavior.
- *User-entity behavior.* This type of behavior is exhibited with respect to entities on social media (for example, user-generated content). For instance, liking a post on Facebook or posting a tweet on Twitter are examples of user-entity behavior.
- *User-community behavior.* This is the type of behavior that users exhibit with respect to communities. Joining and leaving communities are examples of this type of behavior.