Cyber-Individual Meets Brain Informatics

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To help people live better in today's digitally explosive environment, the authors envision a Cyber-Individual (Cyber-I) that is the counterpart of a real individual in the physical world.

Although they might have almost the same physiological appearance and human genome, all human beings have their own consciousness and unique ways of thinking. As humans, we are continuously exploring our world and ourselves, simultaneously conquering the world and being influenced and changed by it, both directly and indirectly.

The advent of digital spaces has brought about the *cyber world*, which can be regarded as another universe to human beings. With the rapid advances in various technologies, the physical world and this emerging cyber world are being gradually integrated and merged to form a new space, which we call the *hyper world*.[1] The synergy between the two worlds has brought profound revolutionary changes, caused by various digital explosions, including information, connection, service, and intelligence explosions. The question is, how will humans evolve when faced with the hyper world?

To help people live better in today's digitally explosive environment, this article envisions a *cyber-individual* (Cyber-I) that is the counterpart of a real individual in the physical world. Our Cyber-I research places emphasis on individual human information processing characteristics, models, and broad applications. Brain informatics (BI), an emerging interdisciplinary field that systematically studies the human information processing mechanism, provides the principles of individual modeling, guiding Cyber-I's core design and intelligence upgrade. The Cyber-I will create a powerful demand for BI to specifically study individual information processing differences and provide a testbed for the evaluation of results obtained from BI research.

Yet Another You in Another World

The Darwinian evolutionary theory of natural selection tells us that survivors are always those who are better adapted to or fit to their environment. How can individuals then adapt to the new environments in the hyper world? As individuals, we might not know exactly what is most necessary or suitable in the digitally explosive world. Thus, it is necessary for individuals to know both the external worlds and themselves. Lao Tse (c. 604 BC) once said, "Knowing others is wisdom. Knowing yourself is enlightenment." Aristotle (384–322 BC) also

argued that "Knowing yourself is the beginning of all wisdoms."

How can we know ourselves better? Is it possible to create "another self" to help us? Fortunately, the advent of the cyber world brings us the opportunity to create "another self"— a Cyber-I in the cyber world.[2] Every one of us can have a cyber counterpart that is supposed to know us better and can support, help, and present us with appropriate behaviors and necessary adaptations to new environments. This other you could help you survive and live better, no matter the extent of digital explosions. You and your Cyber-I will symbiotically evolve together in the hyper world.

A Cyber-I, then, is your counterpart— a comprehensive digital description of an individual human in the cyber world. The Cyber-I study places emphasis on human individual differences with different models that distinguish an individual's different ways of thinking, emotions, personality, character, behavior, and so forth. With support from various Cyber-I components (which we describe in more detail shortly), a Cyber-I eventually approximates to its Real-I and symbiotically evolves together with its Real-I as a telepathic partner in the cyber world.

Cyber-I and Brain Informatics

A Cyber-I is the counterpart of a real individual (which we refer to as a Real-I) in the physical world.[2] The term *individual* generally refers to a person or any specific object in a collection. Human individuals have their own needs, goals, and desires. There are also countless properties associated with individuals and their various relations with other people. Consequently, the "I" in Cyber-I has double implications: the first is as the pronoun "I," which represents one's

ego status as well as attitudes and behaviors, and the other is the pronoun "me," which we envisage as the individual who is known to others from the viewpoints of other individuals.

Some researchers and engineers in the fields of information technology (IT), AI, user modeling, virtual reality, robotics, and so forth might argue that their studies or applications are somehow, in some aspects, similar to Cyber-I. This is unsurprising because the research on Cyber-I is aimed to systematically study and develop comprehensive individual modeling and associated applications on the basis of fully understanding individual people. Certainly, this research covers, intersects, overlaps with, and

> Cyber-I's ultimate goal is to create a cyber counterpart or special digital clone for each individual.

even joins other related studies, research, and developments.

For instance, Cyber-I is not simply a digitized human used in medical imaging, a symbolic user modeled by some profile, nor a virtual avatar in a digital game or a humanoid robot in reality.[3] Roger Clarke's Digital Persona is close to our Cyber-I, but he only focused on modeling an individual through the collection, storage, and analysis of data about that person without considering its symbiosis with a Real-I and offering services to the Real-I.[4]

Compared to existing research, Cyber-I's ultimate goal is to create a cyber counterpart or special digital clone for each individual and provide

desired services for anyone living in the hyper world. Our study on Cyber-I has four distinguishing features:

- Cyber-I is far beyond a user model or a software agent to assist a user. Its emphasis is on systemic characteristics and models of human individual information processing and its broad applications from the cyber world to the hyper world.
- Cyber-I is aimed at providing the most comprehensive digital entities for its corresponding Real-I in terms of the individual's experience, behavior, and thinking as well as his or her birth, growth, and death.
- Cyber-I enables a Real-I to have a new form of existence in the cyber world and experience a symbiotic relationship with its Cyber-I. A Real-I's abilities can be continuously extended with increasing services or applications based on the Cyber-I.
- The goal of Cyber-I is to form a long-term and integrated research field that will serve as an open platform to aggregate multidisciplinary and interdisciplinary studies as well as a variety of technologies for globally joint work on understanding more about humans and realizing the harmony of humans, computers, and pervasive devices in the emerging hyper world.

The human brain is an individual's core information processing system. BI studies this mechanism from both the macro and micro points of view by combining experimental and cognitive neuroscience with Web intelligence centered on advanced information technologies.[5] BI research is based on the collection of brain data through powerful instrumentations such as functional magnetic
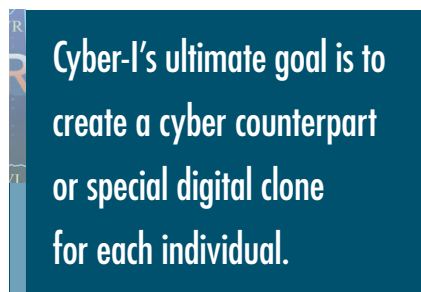
resonance imaging (fMRI) and electroencephalography (EEG). The collected data are then processed with a long-term holistic view and global vision toward understanding the principles and mechanisms of the human information processing system (HIPS). Functions such as attention, memory, reasoning, decision making, learning, discovery, and creativity are also essential factors in our Cyber-I study.[5,6]

When Cyber-I meets BI in the hyper world, they are mutually complementary and will bring about a profound revolution in the HIPS in terms of building general individual models supplemented with identifying special individual differences. As Figure 1 shows, their relationship is bidirectional.

On the one hand, BI will push and accelerate Cyber-I-related research and development. That is, a deep understanding and new discovery of common human intelligence models in BI will provide the principles for individual essential modeling, in particular guiding the core design of Cyber-I when a Cyber-I is born with an *essential model*, or a general model with a human's inner or external elementary features. A Cyber-I's individual intelligence features are then augmented—will become smarter during the progress of approximation to the Real-I—with both experimental cognitive and neuroscience study of the human brain.

On the other hand, Cyber-I will provide a testbed to evaluate the results of both common cognitive models and individual attribute values obtained from BI research.

Together with Web and ubiquitous intelligence, Cyber-I and BI will

Figure 1. Cyber-I meets brain informatics in the hyper world. The relationship between Cyber-I and BI is mutually complementary, with BI augmenting and accelerating Cyber-I-related research and development, and Cyber-I providing a testbed for BI research.

accelerate hyper-world development toward a *holistic wisdom world*, which is a hyper world with the harmonious symbiosis of humans, computers, and things—that is, where things are holistically "intelligentized" to provide active, transparent, safe, and reliable services.[7,8] Web and ubiquitous intelligence provide advanced technologies and developments to create an infrastructure of holistic intelligence in the hyper world. Such infrastructure is strongly demanded as a data-information-intelligence-wisdom circulation system that will provide a common base in the studies of Cyber-I and BI. Ubiquitous intelligence is the study of how to make smart devices pervasive in the real world and to enable them to penetrate cyber worlds.[8,9] Ubiquitous computing technologies made it possible to collect an individual's information wherever, whatever, and whenever necessary. On the other hand, Web intelligence technologies will provide Cyber-I and BI with a powerful platform to realize active and transparent services with long-term integration of an individual's real-time data. Relying on such developments, Cyber-I research supported by BI is a novel way to

reexamine an individual's essence by creating a new form of individual existence and extending individual capabilities toward an efficient, convenient, comfortable life in the emerging hyper world.

By prioritizing the investigation of HIPS as a key research topic, the research results from BI studies—including new theories, principles, and models of how the human brain works as an information processing system—will undoubtedly be a powerful catalyst for Cyber-I research and development. Cyber-I and BI have many things in common—in particular, the goal of helping us learn more about ourselves. They will inevitably meet and support each other as if each is drilling the HIPS "tunnel" from opposite ends and will mutually cooperate when they meet in the middle.

Cyber-I Characteristics and Structure

We can think of a Cyber-I as a concomitant digital clone of a Real-I. It constantly captures and collects the Real-I's scattered personal pieces of information and behavioral traces left in the hyper world. Moreover, it analyzes and synthesizes the personal nature and features to approximate its Real-I's essence. A Cyber-I might accompany its Real-I as a "telepathic partner" at all times after it has been created.

Similar to Isaac Asimov's Three Laws of Robotics, Cyber-I has four basic rules that define the fundamental principles to be strictly followed in Cyber-I studies, developments, and applications:

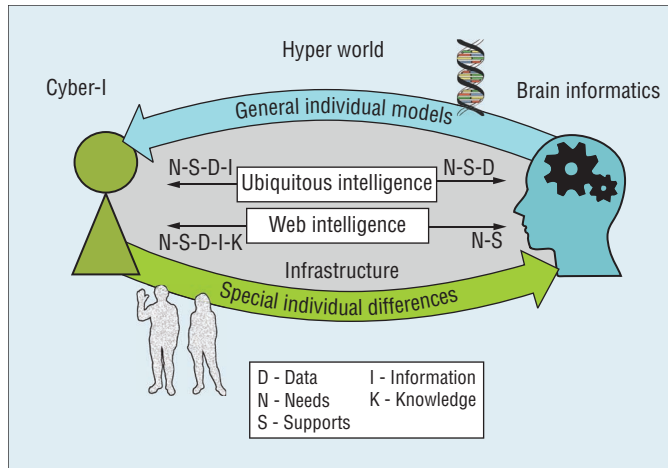1. All of a Cyber-I's rights belong to Real-I.

2. A Cyber-I and its Real-I are one-to-one correspondents, although the Cyber-I might have various forms and different facets.
3. A Cyber-I must not be tampered with deliberately unless such changes would be beneficial to rules 1 and 2.
4. A Cyber-I will be deformed into some kind of synthetic creature if any higher-order rule is violated.

For convenience, we denote things owned by a Cyber-I as its "CI-" and those owned by the Real-I as its "RI-." Hence, the synthetic creature in rule 3 can be expressed as a CI-Creature that is mutated or derived from one or multiple Cyber-I's. It is necessary to point out that a CI-Creature is not a Cyber-I because it is dissociated from a Real-I. The concept of a CI-Creature is useful and can be exploited in many other researches and applications, such as using massive CI-Creatures for large-scale simulations in complex social or economic systems, integrating CI-Creatures into robots as their "brains" or "minds," and so forth.

Taking into account both the cognitive features of HIPS in BI and the nervous system structures as well as the basic characteristics of the hyper world, a Cyber-I conceptually consists of a three-layer structure—namely, the CI-Mind, CI-Pivot, and CI-Spine—around which there are many CI-Applications, as Figure 2 shows.

A human mind works in the context of a physical brain with clear mechanical-like links to the rest of the body, through which an individual shows his or her objective existence. There are various pathways from the brain to the body, with which the

Figure 2. Cyber-I layers and levels. CI-Applications surround the CI-Mind, CI-Pivot, and CI-Spine.

brain communicates or interacts with various parts of the body and controls them. Similarly, CI-Mind, as the core of Cyber-I, is placed on the top layer. It plays an important role, as if it works in the context of Cyber-I's "brain." It is not supposed to completely imitate a human brain, but to model its functionalities or working mechanisms in which the outcome of Cyber-I's CI-Mind approaches or approximates the thinking or mind's working results of a Real-I. The accuracy of approximation is continuously improved by increasing the inputs about the Real-I from or via CI-Applications and by basing it on better HIPS models resulting from a BI study and other brain sciences. We can achieve this approximation by dividing the Real-I into three levels: state, behavior, and mind.

State Level: Classified Data, Associated Memory
In this level, the CI-Mind records and classifies an individual's state data, which includes transient data (such as physical actions and emotional status) and persistent data (such as social relationships and physiological attributes).

The state data consist of log pieces of Real-I's past and present actions and experiences from multiple perspectives. This data is captured, classified,

and structured in logs—examples might include space, life, activity, or health data logs. BI and neuroscience will guide the design of the CI-Mind with respect to how to manipulate brain-related state data and how to provide the mechanisms that can structure memory, recall, and memory-degradation components.

Behavior Level: Abstracted Behaviors, Specified Recurrence
In this level, the CI-Mind extracts the Real-I's behavior-related information from the structured data at the state level and forms the Real-I's behavior descriptions based on human behavior models derived from the following two approaches.

The first is concerned with observable behaviors, in which the mind is treated as a black box. It infers the conditions that affect a given behavior by functional analysis—that is, seeking the link between behavior and exact determining conditions.

The second is a BI-based observable mental process approach in which human mental processes are studied from the viewpoint of informatics by experimental cognitive and neuroscience. Most research has focused on what human brain information processing has in common, but a recent study of individual differences in human information processing systems has received increasing attention.[10–12]

Mind Level: Intention Prediction, Situation Deduction
Combining the behavior descriptions together with BI research results in individual higher-order cognition, where the CI-Mind attempts to study and discover Real-I's ways of thinking
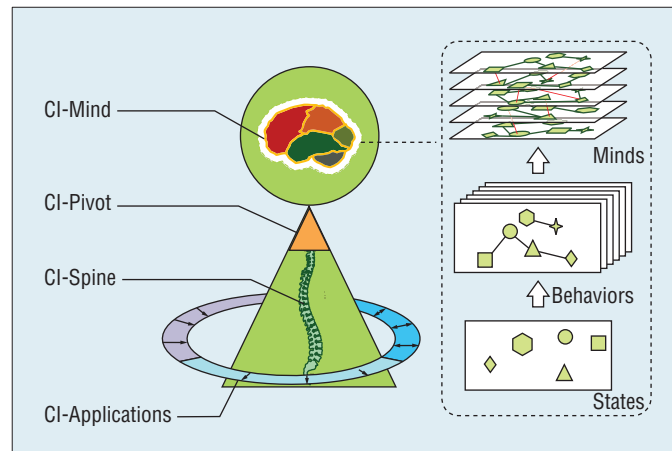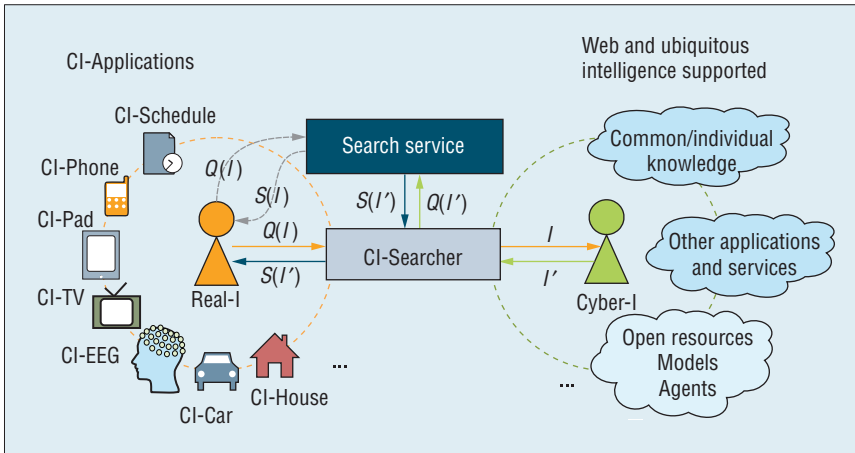
Figure 3. Cyber-I-based personalized searching service. Users can obtain more personalized results as the CI-Searcher helps augment their queries with their personal profile.

and patterns under certain situations to reveal relationships between an individual's actual intentions and observable behaviors. When a Cyber-I's CI-Mind reaches this level, the CI-Mind is expected to infer or predict the Real-I's possible intentions by analyzing, categorizing, matching, and deriving information (categories, features, logical relation, and so forth) from existing domains of behavior occurrence cases. With the identified recurrences in a certain domain, the CI-Mind can simulate the situation deduction and revise the models with the simulation results.

The human nervous system is responsible for delivering and interpreting signals from the brain through the spinal cord, down the spinal column, and finally to the target nerve cells, and vice versa. The CI-Pivot functions similarly to the spinal cord—that is, it is responsible for dispatching and routing information among different layers of a Cyber-I, securing the CI-Mind and protecting the Real-I's personal rights and privacy. Although a Cyber-I has no physiological body in the cyber world, it is expressed in a variety of forms because of unlimited applications and services in the hyper world. Similarly, the CI-Spine functions similarly to the spinal column, providing a set of interfaces—including standard drivers

and protocols between Cyber-I internals and externals, such as smart u-things, software agents, various kinds of applications, services, and so forth in the hyper world.

Communications and interactions between a Cyber-I and its Real-I must be carried out by a number of intermediary entities in the hyper world. These intermediary entities are applications closely related to or affiliated with a Cyber-I, which we call CI-Applications. Positioned in between the Cyber-I and Real-I, the CI-Applications play important roles as messengers, couriers, and assistants in a Cyber-I's growth, and in the provision of better services to its Real-I.

Cyber-I provides a sophisticated platform for a long-term study and emphasizes each Real-I's individual differences—different actions, emotions, attention, behaviors, personalities, characters, speed of information processing, and even ways of thinking. Advances in Web and ubiquitous intelligence made it possible to collect and process a Real-I's individual personalized data and information such as his or her actions, behaviors, events, situations, activities (during a specific period or across his or her lifetime), and so on. The Cyber-I built with the individual personalized data and information, of course, contains strong

individual characteristics. Incorporated with research from BI and other brain sciences, Cyber-I can enhance CI-Mind modeling and build more delicate and accurate individual CI-Mind models with individual observable thought and mental processes.

A Cyber-I will evolve with its Real-I in the hyper world and become a more comprehensive digital description of its Real-I, which can only be achieved with an increasingly dedicated CI-Mind, reinforced CI-Pivot and CI-Spine, and augmented CI-Applications. Research in AI, BI, Web intelligence, ubiquitous intelligence, and other brain sciences are the keys to achieving a higher degree of "telepathy" and "symbiosis" between a Cyber-I and Real-I.

Example Cyber-I-Based Personalized Service

Along with information overload, service flooding caused by service and connection explosions has received much attention in recent years. This explosion of digital services and applications has been permeating our daily lives, and people might not even know what they need and what is the most suitable for them. A conventional search engine searches the Internet/Web or clouds and returns a list of results regardless of who initiated the search. A personal-profile-based service provisioning system takes into account only a limited, incomplete amount of personal information as service querying and processing attributes.

A Cyber-I, on the other hand, is a comprehensive digital description of its Real-I. Thus, a Cyber-I-based personalized service searching system that utilizes comprehensive personalized information about an individual would provide better quality of service (QoS).

Figure 3 illustrates such a Cyber-I-based personalized searching service

system. The Cyber-I continuously grows while interacting with its Real-I via CI-Applications (such as CI-Car, CI-Phone, CI-House, CI-Pad, CI-TV, and CI-EEG) around the Real-I. One such CI-Application, the CI-Searcher, plays dual roles. On the one hand, CI-Searcher takes a Real-I's request $Q(I)$ containing a certain Real-I's personal information I and responds with a better QoS $S(I')$, which is searched from existing clouds by adding a more comprehensive description about the Real-I from its Cyber-I as searching attributes. The Real-I's personal information I is enriched with a detailed and featured personal description to form a more comprehensive personalized description I'. The searching result $S(I')$ to the query $Q(I')$, of course, should be better than the searching result $S(I)$ to the query $Q(I)$ in a conventional or personal-profile-based searching service system. On the other hand, the CI-Searcher passes partial Real-I's personal information I to the Cyber-I, and the Cyber-I grows from each interaction with its Real-I via CI-Searcher.

For example, a man would like to hold his 50th birthday party. Apart from his close friends, he wants to invite some friends from a social network service society such as Twitter. Thus, his service request $Q(I)$ might read, "send me a list of my friends in Twitter to join my 50th birthday," using his Twitter name and ID. Using a conventional searching service system, a service engine might offer $S(I)$, a list of all the names in the Twitter conversation groups to which he belongs. A better response from a personal-profile-based searching service system might give $S(I)$, a list of friends who have ever had conversations with him by using his profile in which his conversations with others in Twitter are kept.

Of course, an even better solution might be to use his Cyber-I. His Cyber-I receives I—his name and ID in Twitter—as input parameters and projects a more specific searching scope I', which includes not only I but also other personalized information such as his cheerful character, social circle, favorites, hobbies, and even his thinking. Thus, the search result $S(I')$ should reflect a better list of friends that he really wants to invite.

Compared with a conventional personal profile service system, a Cyber-I-based personalized service system provides better QoS because

> The CI-Mind is a combination of digital and biological intelligence in which Cyber-I meets brain informatics.

of the comprehensive digital descriptions of the Real-I, which protects an individual's personal information from service providers by CI-Pivot, and enables the efficient use of sharable and controllable Cyber-I information by more than one provider.

Challenges and Issues

The Cyber-I study creates a multidisciplinary and interdisciplinary research field, which requires a cooperative aggregation of various existing, developing, and to-be-developed advanced technologies from many different fields of research. Therefore, the long-term challenges include

- how to bring together researchers from different fields, reach a

consensus, and work cooperatively for the common good, and
- how to design an integrated, open platform with related reference models and standards for the aggregation of various technologies from different fields.

Cyber-I research is aimed at studying the individual human essence, creating the Cyber-I, the new existence of human individuals in the cyber world, and the extension of an individual human's ability. Thus, the primary challenges and hard issues stem from scientific, technological, and social perspectives.

Scientific Perspective

The study of human essence is not an easy issue, and the study of individual human differences is even more challenging. It requires not only the external observation of individual human behaviors but also the understanding of how an individual human's brain works.

In addition, the creation of a comprehensive digital description of individual humans as a counterpart in the cyber world requires not just user modeling but individual human modeling, which is quite challenging.

The CI-Mind is a combination of digital and biological intelligence in which Cyber-I meets BI. The primary challenge is how to build effective bridges between these two intelligences.

Technological Perspective

In the Cyber-I system, CI-Applications not only support the Real-I but also make contributions to Cyber-I's growth. Therefore, it is important to have an open, flexible, and friendly platform for any third party to develop and plug in their CI-Applications.

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The Cyber-I system and its applications will be involved in a sustainable development process. Therefore, another basic challenge is how to design a scalable and sharable system that allows the maximum utilization of limited resources.

Keeping all this in mind, a conflict often exists between a system's openness and security. It is thus a challenge for the Cyber-I system to balance the security and openness in each layer to ensure system security and protect privacy.

Social Perspective

Social problems are always issues in human-related research. In particular, the Cyber-I study might cause many arguments among researchers. Their concerns will likely include the following:

- With creation and growth of a Cyber-I residing in the cyber world, a large cyber social community will form. How will the cyber world change? Do we need regulations or rules for the cyber world?
- How will having a Cyber-I counterpart change its Real-I? What will be the positive impact and negative influences? Is it possible that a Cyber-I will take over or be beyond its Real-I?
- If some individuals have a Cyber-I and others don't, will this create differences or discriminations among individuals? How can we create a harmonious society in the hyper world?

The recent advances in BI, ubiquitous intelligence, Web intelligence, and other research fields have provided the best time and opportunity to study Cyber-I. The Cyber-I basic concepts and principle framework we presented in this article are the first step toward our final goal: a Cyber-I for a real individual. Hereafter, this research will proceed to go through several practical cases so as to discover and study issues concerning the life process of Cyber-I in different stages, such as birth, growth, and death. We are currently designing a more concrete Cyber-I system that will be able to provide a more compatible and flexible open platform, thus paving the way for those interested in a joint research and applications development.∎

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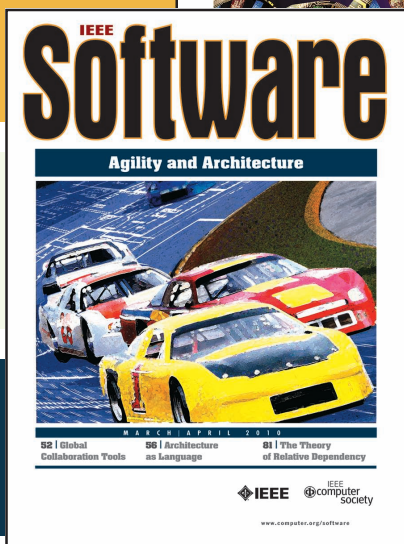
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