Supplemental File 5

Differences in terminology in human computation

Context: Terminology impacts how we develop knowledge. The field of human computation includes several terms that can be associated with similar concepts - for example, distributed cognition and distributed intelligence - and teasing out the nuances among them can be tricky. The existence of several closely related terms may reflect a quickly evolving scientific field in which, when studying the relationships between humans and machines, researchers encounter or create new forms of collaboration and need to categorize and distinguish between them. We are aware that terms should be chosen carefully and their use explained, because no single term is appropriate for all contexts.

The collected terms are based on the discussion of human computation terms in the context of citizen science.

Using primarily the *Handbook of Human Computation* edited by Pietro Michelucci as a broad knowledge base, we have collected about 30 terms and expressions used by scholars in their conceptual and empirical works.

Terms from the following book:
Michelucci, P. (2013). Synthesis and Taxonomy of Human Computation. *Handbook of Human Computation*, 83–86. doi: 10.1007/978-1-4614-8806-4_9
(PDF) Synthesis and Taxonomy of Human Computation. Available from: https://www.researchgate.net/publication/273317467_Synthesis_and_Taxonomy_of_Human_Computation
Also
Quinn, A. J., & Bederson, B.B. (2011) Human Computation: A Survey and Taxonomy of a Growing Field. In *Proceedings of SIGCHI 2011,* May 7–12, 2011, Vancouver, BC, Canada http://wwww.alexquinn.org/papers/Human%20Computation,%20A%20Survey%20and%20Taxonomy%20of%20a%20Growing%20Field%20(CHI%202011).pdf (the article contains a comparison between the terms human computation and related ideas)

Collective Action	**Original definition** First relevant book is by Olson (2012) - describes theory of collective action, but gives no explicit definition of the term, describes free-rider problem and group-size in collective action, from political science/sociology perspective **Current interpretations** Often not defined in or used broadly *Behaviour of participants in collaborative problem solving and other forms of voluntary cooperation towards the* ***creation of public goods*** (Novak, 2013) *Human computation in which individual behaviors* ***contribute to a collective product*** *that* ***benefits all members*** *of the collective* (Michelucci, 2013c).

	*Wide array of phenomena with **mutual interests** and the possibility of **benefits from coordinated action*** (Marwell & Oliver, 1993)
Collective Intelligence	**Original definition** *intelligence that emerges from the collaboration and competition of many individuals* (Lévy & Bononno, 1997; Russell, 1995) (originally for describing the future effect of Internet technologies on knowledge, where members go from consumers to actively start working with inventing new ways of thinking etc.) **Current interpretations** ● are either more broad, refers to a **group's ability to find more or better solutions** than the whole of all solutions that would be found by its members working individually (Heylighen, 1999; Leimeister, 2010) ○ *A group's ability to perform and solve problems and the process by which this occurs* (Michelucci, 2013c; Woolley et al., 2015) ○ *groups of individuals doing things collectively that seem intelligent* (Malone & Bernstein, 2015) ● Or focused on **information/data aggregation**, especially over the internet: ○ *the synergistic and cumulative channeling of the vast human and technical resources now available over the internet* (Malone & Klein, 2007) ○ *aggregating contributions from multiple sources in order to collect data for a variety of task* (Qi et al., 2013) Buecheler et al., (2010) describe **crowdsourcing** as a special case of collective intelligence Collective vs Hybrid intelligence Collective intelligence typically refers to large groups of homogenous individuals (i.e., humans or animals), whereas Hybrid Intelligence combines the complementary intelligence of heterogeneous agents (i.e., humans and machines) (Dellermann et al., 2019).
Crowdsourcing	**Original definition** Crowdsourcing represents the act of a company or institution **taking a function** once performed by employees **and outsourcing it to an undefined** (and generally large) **network** of people in the form of an **open call**. (originally by Howe, 2006) **Current interpretations** Varying definitions exist, often opposing each other in some characteristics and look at it from different points of view; it encompasses many practices and characteristics depending on the specific initiative. a type of **participative online activity** in which **an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge**, **heterogeneity**, and **number**, via a **flexible open call**, the **voluntary undertaking of a task**. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails **mutual benefit**. The user will receive the satisfaction of a given type of need, be it **economic, social recognition, self-esteem, or the development of individual skills**, while the crowdsourcer will obtain and utilize to their advantage what the user has brought to the venture, whose form will depend on the type of activity undertaken." (Definition by Estellés-Arolas & González-Ladrón-de-Guevara (2012) based on a literature review.) The process in which a crowd ● Who are a **generic mass of people** (Howe, 2008). According to some definitions, individuals of the crowd can be amateurs (Schenk & Guittard, 2009), and in others it's well-trained people (Howe, 2008). ● a) **undertake tasks** (Vukovic, 2009; Whitla, 2009 ; Yang et al., 2008), or more specifically b) has to **solve problems** (eg. Brabham, 2008; Kazai, 2011). ● **Receiving compensation** Type differs in different definitions, can depend on the specific case: economic, skill development, social recognition and entertainment (Kazai, 2011) ● **Initiated by a number of different entities** in different views, often companies (eg. Whitla, 2009); but can also be other organizations (Howe, 2006), who **get the result they seek** for a

	given task in the process (eg. Vukovic, 2009; Kazai, 2011) ● The call used can vary, some authors emphasize an **open call** (Kazai, 2011, Whitla, 2009) so that participants are not limited to eg. experts ● Through the **internet** (eg. Brabham, 2008; Whitla, 2009; Yang et al., 2008 Some definitions: *an open call for contributions from members of the crowd to solve a problem or carry out human intelligence tasks, often in exchange for micro-payments, social recognition or entertainment value* (Kazai, 2011) *online distributed problem-solving and production model in which networked people collaborate to complete a task.*(Vukovic, 2009) *a process of outsourcing of activities by a firm to an online community or crowd in the form of an 'open call', a process of organizing labour, where firms parcel out work to some form of (normally online) community, offering payment for anyone within the 'crowd' who completes the tasks the firm has set* (Whitla, 2009) *an intentional mobilization, through Web 2.0, of creative and innovative ideas or stimuli, to solve a problem, where voluntary users are included by a firm within the internal problem-solving process […] to solve a specific problem*. (Mazzola & Distefano, 2010)
Distributed Cognition	**Original definition** Framework developed by Hutchins in the 80's *knowledge and cognition do not exist solely within one's head;* ***knowledge and cognition is distributed across objects, individuals, artifacts, and tools in the environment*** Its goal is to describe how distributed units are coordinated by analyzing the interactions between individuals, the representational media used, and the environment within which the activity takes place. It describes group activity similarly to individual cognition — computation realized through the creation, transformation, and propagation of representational states. Individual cognition is also considered distributed (functions are distributed across layers of neurons) (Hutchins, 1995, 2000 and 2006). Hutchins proposes three tenets of distributed cognition. 1) social distributed cognition involving the information processed between the individual and the grou 2) embodied cognition involving the study of ergonomics and the physical interaction with the environment 3) the study of human social behavior in the cultural environment. (Hollan et al., 2000) **Current interpretations** The term "distributed cognition" has been used in different ways. (Zhang & Patel, 2006) Most prominent: The scientific discipline that is concerned with the **distribution of information and knowledge between and human minds, external cognitive artifacts, and groups of people, and how it is distributed across space and time**. (Zhang & Patel, 2006; Hutchins, 1995; Flor & Hutchins, 1991; Nagar, 2011) Internal representations: knowledge and structure in individuals' minds External representations: knowledge and structure in the external environment. Thus DCog can be between an individual mind and an external artifact and between individual minds (Zhang & Patel, 2006) Other definitions ● *how intelligent processes in human activity transcend the boundaries of the individual actor.* (Rogers, 1997) ● *The use of information technologies to make distributed information processing by humans much more powerful, focused and efficient* (Gershenson, 2013)
Collective cognition	**Original definition** One of the first descriptions from Hutchins (1991)

	Current interpretations ● **group mind** that resides ***in the interrelations between the activities of group members*****,** four phases: accumulation (i.e., knowledge perceiving, filtering, & storing), interaction (i.e., information retrieving, exchanging, & structuring), examination (i.e., idea negotiating, interpreting, & evaluating), and accommodation (i.e., idea integrating, deciding, & acting) (Gibson, 2001, p. 123) *the group processes involved in the acquisition, storage, transmission, manipulation, and use of information* (Gibson, 2001) ● *the* ***content of the combination of individual perspectives*** *and the* ***structural characteristics*** *of that combination* (West, 200, p. 84) ● *a* ***group-level representation of a knowledge structure*** *that is* ***held in common*** *by members of the collective* (Sitkin, 2000) ● ***ability of groups to solve cognitive problems that exceed individual ability****, also referred to as the many wrongs principle, swarm intelligence and wisdom of crowds* (Clément et al., 2013)*, an* ***emergent*** *phenomenon more than the sum of individual cognitions that happens when individuals* ***meet cognitive congruency*** *together* (Ke & Im, 2014) ● Also referred to as *socially shared cognition* (Resnick, 1991). **On the difference between distributed and collective cognition** ● Cetina (2009) uses DC and CC interchangeably, but they are often distinguished: ● DC is a distribution of CC, CC is a transcendent and emergent product of interindividual distributed cognitive processing. The sum of individual distributed cognitive processes does not equal collective cognition (Hung, 2013). ● CC special case of DC in which two or more individuals reach a cognitive outcome simply by combining individual knowledge not initially shared with the others (Giere, 2002) CC involves only people (agents), while DC also includes external representations and instruments (Giere, 2007). - DC is broader ● CC is "distributed" in the sense that the cognitive structures that give rise to the emergent, collective cognition are heterogeneously distributed across the minds of the members of the group (Sharifian, 2009). ● DC depicts CC as the shared knowledge achieved by team communication and as a coordination of distributed expertise to reduce cognitive load (Hutchins, 1991), whereas constructivism explains collective cognition as a result of overcoming socio-cognitive conflict. (Ke & Im, 2014)
Distributed Intelligence	**Original definition** Originates from Pea (1993), and further described by Hutchins (1995) and Salomon (1997) A central assumption is that **intelligence is distributed across minds**, **persons, and the symbolic and physical environments, both natural and artificia**l. Resources that shape and enable activity are distributed. The primary sense of distributed intelligence arises from thinking of people in action, intelligence being an activity. For some, DI is used interchangeably with distributed cognition (Fischer, 2009), while some make a distinction, eg. "because people, not designed objects,' "do' ' cognition". (Pea, 1993) **Current interpretations** Rarely defined explicitly or described in relation to DC. The **problem-solving capacity of distributed cognitive systems** (Heylighen, 2013) ● *The ability to* solve problems collaboratively*, by integrating the contributions from a broad assembly of human and technological agents. Distributed Intelligence is the* ***coordinated activity of a collective of agents*** *(human or technological)* ***that process and propagate information between them.*** (Heylighen, 1999) ● *Systems of entities (any type of intelligent process or system, including agents, humans, robots, smart sensors etc.) working together to reason, plan, solve problems, think abstractly, comprehend ideas and language, and learn. In these systems, different entities commonly specialize in certain aspects of the task at hand* (Parker, 2007) ● *based on the idea that knowledge is always and irreducibly distributed into multiple contexts of knowledge production (individuals, groups, time periods and spatial locations, and so on), and therefore cannot in general be straightforwardly organized into a single, shared and coherent*

	structure (Bonifacio et al., 2000)
Distributed Problem Solving	**Original definition** **Cooperative solution of problems by the activity of a group of decentralized and loosely coupled knowledge sources** (KS) Cooperative: no KS has sufficient information to solve the entire problem; mutual sharing of information is necessary to allow the group as a whole to produce an answer. Decentralized: both control and data are logically and often geographically distributed; there is neither global control nor global data storage Loosely coupled: individual KS's spend most of their time on computation rather than communication (Smith & Davis, 1988) DPS is studied mainly in the field of distributed AI (DAI) "a subfield of artificial intelligence that deals with the interactions of groups of intelligent agents attempting to cooperate to solve problems" (Decker, 1987). It is different from distributed processing, or DAI. (Decker, 1987). **Related terms are:** ● Collaborative problem solving ● Collective problem solving ● Coordinated problem solving ● Cooperative problem solving ● Cooperative distributed problem solving Coordinated, Cooperative and Cooperative Distributed Problem Solving can be used as synonyms for DPS (Gasser & Hill Jr, 1990), but can also be used as slightly different terms, as seen in other papers. Crowdsourcing may be an example of distributed problem-solving. (Brabham, 2008) Cooperative and collaborative problem-solving can (but are not always) distinguished: Cooperative problem solving is accomplished by the division of labour among participants, as an activity where each person is responsible for a portion of the problem solving Collaborative problem solving is the mutual engagement of participants in a coordinated effort to solve the problem together (Roschelle & Teasley, 1995) **Current interpretations** **Distributed problem solving** ● *The application of massively distributed cognitive systems to solving problems - massive scale collaboration, enables distributed individuals to describe a complex problem and to explore possible solutions* (Greene & Young, 2013) ● *Group of decentralized agents cooperating to solve problems* (Fisher & Wooldridge, 1997) **Cooperative distributed problem-solving** ● *Loosely-coupled* distributed network of semi-autonomous problem solvers (nodes) working together to solve problems that are beyond their individual capabilities. Each problem-solving node in the network is capable of sophisticated problem solving and can work independently, but the problems faced by the nodes cannot be completed without cooperation, because no single node has sufficient expertise, resources, and information to solve a problem, and different nodes might have expertise for solving different parts of the problem. The agents work together by identifying subproblems each should solve, solving them concurrently, and integrating their results. (Durfee et al.,1989, Decker et al., 1989) ● *Problem-solving by a group of loosely-coupled computational agents involved in extensive local computations* (Armstrong & Durfee, 1997)
Distributed Thinking	**Original definition** One of the first definitions is by (Lipman, 1998), where ***shared cognition*** is used as a synonym for it. **Various kinds of mental acts causally or logically connected with one another (thinking) that is spread out among a number of different individuals.** **Current interpretations** It is rarely defined, or distinguished from distributed intelligence or distributed cognition. ● *The effective distribution and coordination of information processing tasks among human computational agents informed by cognitive architecture* (Blumberg, 2013); information-processing load is spread across human computational agents (Michelucci, 2013a). ● *A distributed thinking system is a group of thinkers who coordinate their thinking activities. They do some thinking on their own, and then information is aggregated and a collective output is*

	produced. (Spiekermann, 2013)
Human Computation / Distributed Human Computation	**Original definition:** a paradigm for **utilizing human processing power to solve problems that computers cannot yet solve** (von Ahn, 2005) **Current interpretations:** ● The design and analysis of multi-agent information processing systems in which humans participate as computational elements. The subset of systems theory in which the systems are composed of machines and humans connected by communications networks. The strategy of combining the strengths of computers and humans by delegating parts of the problem to large numbers of humans connected via the internet – usually spread out geographically… With DHC, humans help computers to do computer-type tasks. (Quinn & Bederson, 2011) ● *Humans act as processors in a distributed system, perform small parts of the computation process, where the problems fit the general paradigm of computation, and which one day might be solvable by computers* (Quinn & Bederson, 2011; Von Ahn, 2008) **Distributed Human Computation** *systems of computers and large numbers of humans that work together in order to solve problems that could not be solved by either computers or humans alone* (Quinn & Bederson, 2009)
Organismic computing	**Original definition** **Augmented human collaboration characterized by shared sensing, collective reasoning, and coordinated action.** A human computation paradigm that seeks to use technology to enable a group of human collaborators to function simultaneously as independent agents and as tightly integrated parts of a collective "superorganism" (Michelucci, 2013b). **Current interpretations** The term hasn't been used in literature, except for Michelucci (2013 and 2015) and Greene and Young (2013) who define an organismic computing system as: a community of human and/or software agents that pursues a shared goal by communicating indirectly through an environment, enabled by computational mechanisms. Specifically, individuals will share their discoveries by placing information in the environment, where others can see. Ultimately, organismic computing should encourage shared sensing, collective reasoning and coordinated action.
Participatory Sensing	**Original definition** Paradigm by (Burke et al., 2006), and (Campbell et al., 2006). Definition:s **tasking everyday mobile devices**, such as cellular phones, **to form interactive, participatory sensor networks** that **enable public and professional users to gather, analyze and share local knowledge** (Burke et al., 2006) **Current interpretations** Consistent definitions, **voluntary nature** of data collection is emphasized, some define it more narrowly (focusing on smartphones), some more broadly. People voluntarily **collect data** in **different modalities** in their environment, using devices such as smartphones and share it for large-scale applications. Humans are incorporated in a sensing data collecting loop (Lee & Hoh, 2010) ● *The human use of sensor enhanced devices for spatially distributed data collection, enabled by pervasive computing* (Lathia, 2013) ● *Paradigm that allows people to voluntarily sense their environment using readily available sensor devices such as smart phones, and share this information using existing cellular and Internet communication infrastructure.* (Dua et al., 2009; Kanhere, 2013) ● *distributed data collection and analysis at the personal, urban, and global scale, in which participants make key decisions about what, where, and when to sense* (Mun et al., 2009) ● *the public crowd rather than professionals undertake various sensing activities with inbuilt sensors on their smartphones* (Luo et al., 2014)

Social Computing	**Original definition** any type of **computing application** in which **software serves as an intermediary or a focus for a social relation** (Schuler, 1994, p. 29) the **interplay between persons' social behaviors** and their **interactions with computing technologies** (Dryer et al., 1999) **Current interpretations** (different definitions used in literature) ● *Computational facilitation of social studies and human social dynamics as well as the design and use of information and communication technologies that consider social context.* (Parameswaran & Whinston, 2007; Wang et al., 2007) ● *a multi-disciplinary approach in analyzing and modeling social behaviors on different media and platforms to produce intelligent applications* (King et al., 2009; Li et al., 2008; Wang et al., 2007) ● *an umbrella term for all computer science research that analyzes content and activity on social networks* (Manovich, 2018) ● *Information processing that occurs as a consequence of human social interaction, usually assumed to occur in an online medium.* (Michelucci, 2013c) ● Note: there is some debate in the field about how to classify systems in which behaviour relies upon social knowledge or judgment but does not involve social interaction among participants.
Social Informatics / Social Network Analysis	**Original definition** The interdisciplinary **study of the design, uses, and consequences of information, and ICTs**, and their **interactions** with institutional and cultural contexts." (Kling et al., 1998). **Current interpretations** (agreement on definition in literature, based on the original definition) ● *The fields studies the relationship between ICTs and the larger cultural context they're used in, studying the social aspects of computerization* (Kling, 2007) ● Other names used for it: the social analysis of computing, human-centered computing, social studies of information technology and the sociology of computing Social computing among other fields, relies on **social network analysis** (Wang et al., 2007), which is: ● (1) a method for analysing the volume and patterns of social relations linking individual actors to each other and (2) a way of theorising social structure and its effects on behaviour. (Scott & Carrington, 2011) ● *Studying the structure of relationships among social entities, as well as the impact of said structure on other social phenomena* (Butts, 2008) ● *The use of big data to understand social behavior; in Social Network Analysis the "big data" is presumed to originate from behavioral data derived from technology-mediated social systems*. (Lerman, 2013)
Superorganism	**Original definition** The term was first proposed by William Morton Wheeler describe ant colony members appearing to operate as a single functional unit (Wheeler, 1911) It was originally mainly used ecology, a buzzword used by biologists in the 20th century "to describe the then novel idea that a **collection of agents could act in concert to produce phenomena governed by the collective**. Like a slime mold that assembled itself from moldy spots into a thrusting blob […]" (Kelly, 1994) This then started to get used in describing human behavior and cognition, computation processes, and in AI. **Current interpretations** The term is used in different fields with similar definitions. Current interpretations based on Hölldobler & Wilson, 2009 (biology) "a group of individuals self-organized by division of labour and united by a closed system of communication" Biology: ● *highly integrated societies have evolved group-level phenotypes analogous to those of individual organisms* (Sasaki & Pratt, 2018) ● *Highly cooperative and socially integrated animal groups, acting like an organism despite each*

	animal's physical individuality. The features of a superorganism can be extended to humans, who can display superorganismic properties. These are: (1) mechanisms to integrate individual units (2) mechanisms to achieve unity of action (3) low levels of heritable within-group variation (4) a common fate (5) mechanisms to resolve conflicts of interest in the collective's (Kesebir, 2012) Human behavior and cognition ● *individual agents self-organizing their collective activities to achieve goals, as if they were part of a single organism* (Zambonelli, 2014 and 2015). ; it is the group, rather than the individual organism, that functions as an integrated unit, having many of the properties that individual organisms possess (Wilson, 2001) ● Individual organisms functioning together to support the objectives of the collective as a whole ○ **Superorganismic computation** can be achieved, when human computation takes on superorganismic qualities; then computations become decentralized and some human participants of these computations may specialize at particular tasks, but their participation in different projects will be self guided." (Pavlic & Pratt, 2013) ● *a large ensemble of individual organisms capable of behaving in a collectively orchestrated way to serve the good of the ensemble itself. In particular, closing the sensing, computing, and actuating capabilities in a loop, and making such activities collaborative ones, realizing coherent collective behaviours* (Zambonelli, 2014)

Additional

Hybrid Intelligence	**Original definition** Originates from Lomov and Venda, who describe 11 characteristics of hybrid intelligence systems. They are **human-centered systems with dynamic interaction, active exchange of information, flexibility of hierarchical structure executing joint collection and analysis of information** (For longer description see Lomov & Venda, 1977) And more recently by (Rahimi & Hancock, 1986) *systems in which both human and machine interact, each as a c**ooperative intelligent entity**.* The three key elements of this definition are the terms **interaction, cooperation, and intelligence**. It specifies collaborative actions directed toward a common goal of perceived or implied utility. Later modified it to: *systems in which human and machine engage in some form of collaborative action in order to achieve a defined goal* (Hancock, 1993) **Current interpretations** Mostly defined as: *"the ability to achieve complex goals by combining human and artificial intelligence, thereby reaching superior results to those each of them could have accomplished separately, and continuously improve by learning from each other"* (Dellermann et al., 2019 and also: Kamar, 2016; Pan, 2016; Zheng et al., 2017; Raouzaiou et al., 2002 etc.) Zheng et al., 2017 distinguish between two types of HI: Human-in-the-loop hybrid-augmented intelligence: an intelligent model that requires human interaction. In this type of intelligent system, human is always part of the system and consequently influences the outcome in such a way that human gives further judgment if a low confident result is given by a computer. Cognitive computing based hybrid-augmented intelligence: new software and/or hardware that mimics the function of the human brain and improves computer's capabilities of perception, reasoning, and decision-making. In that sense, CC based hybrid-augmented intelligence is a new framework of

	computing with the goal of more accurate models of how the human brain/mind senses, reasons, and responds to stimulus, especially how to build causal models, intuitive reasoning models, and associative memories in an intelligent system. In another meaning of the term, the involvement of humans is not necessary: has also been defined as *any system that combine at least two intelligent technologies* (eg. Ch. Sanjay & Ch. Prithvi, 2014) *Software system comprising a combination of methods and techniques from AI subfields that operate in parallel* (Eberhart et al., 2015) The term **hybrid-augmented intelligence** is sometimes used as a synonym (eg. Pan, 2016
Complex problem solving	**Original definition** ● Previously: (Edwards, 1962) used the term "***dynamic decision making***": *"In dynamic situations, a new complication not found in the static situations arises. The environment in which the decision is set may be changing, either as a function of the sequence of decisions, or independently of them, or both."* (p. 60) ● CPS introduced in Germany by Dörner and colleagues in the mid-1970s CPS consisted of the identification and control of dynamic task environments that were previously unknown to the participants. (Dörner & Funke, 2017) ● Funke then defines CPS with: (a) **Complexity**: Elements relevant to the solution process are large, many identification and regulation processes are involved (b) **Connectivity** between a huge number of variables, difficult to anticipate all outcomes (c) **Dynamic** nature: changes over time, can change decrementally (d) I**ntransparency** (opaqueness) of the scenarios required the systematic collection of information, neither structure nor dynamics are disclosed; only some variable can be observed (e) **Polytely**: the existence of multiple (sometimes even conflicting) goals (Funke, 1991) **Current interpretations** Generic term; no widely accepted definition. Most definitions refer to the ability to overcome barriers in order to achieve a target state within a **complex, not fully known and dynamically changing** environment Used in at least three different ways: (1) as a paradigm to study cognition under real-life conditions (2) as a descriptor of behavior exhibited while dealing with a certain class of problems usually presented on a computer, and (3) as an ability construct that is related to intelligence. (Funke, 2010) (Paper on CPS taxonomy - Quesada et al., 2005) ● In CPS the given state, goal state, and barriers are complex, change dynamically during problem solving, and are intransparent, the exact properties of the given state, goal state, and barriers are unknown to the solver. For complex problem solving, a problem must be (a) novel, (b) complex, (c) dynamically changing over time, and (d) intransparent before we can legitimately call our dealings with the problem CPS, thus, is not a straightforward extension of "simple" problem solving (SPS), but qualitatively different (Frensch & Funke, 1995) ● *Complex problem solving (CPS) is the successful interaction with task environments that are dynamic (i.e., change as a function of user's intervention and/or as a function of time) and in which some, if not all, of the environment's regularities can only be revealed by successful exploration and integration of the information gained in that process* (Buchner, 1995). ● *goal-state and initial-state are clearly described, and there is (a) no precise definition of the problem space (not complete) and/or (b) no precise definition of the operators available (what can be done).* (Krems, 1995)

Citizen Science Focused

Citizen	**Original definition:**

Cyberscience / Citizen Cyber-science (CCS)	First mention: David Anderson 2008 https://www.planetary.org/blogs/guest-blogs/amir-alexander/setiathome_20080115.html, but not actually defined (Alexander, 2008). **Other prominent uses and current interpretations:** Term mostly attributed to: Francois Grey 2009 https://cerncourier.com/a/viewpoint-the-age-of-citizen-cyberscience, but again, no actual definition (Grey, 2009) Citizen Cyberscience equated to distributed-thinking projects (Hand, 2010) Dissertation: When Scientists Meet the Public: An Investigation into Citizen Cyberscience (Darch, 2011) "These projects utilise the abilities of personal computers, GPS receivers and mobile phones to double as scientific instruments. Within citizen cyberscience, it is possible to identify three subcategories: volunteered computing, volunteered thinking and participatory sensing. " (Haklay, 2013) "In citizen cyberscience, professional scientists collaborate with volunteers (citizens) to conduct scientific research via the Internet" (Jennett et al., 2013) "...citizen cyberscience is online participation in scientific research by members of the public. The key here is to see the diverse approaches this phenomenon employs and the enormous variety of topics it addresses, yet also recognize that the narrow focus includes only those activities conducted, at least partly, online." (Newman, 2014) Citizen science projects that utilize technology — online citizen science projects, also known as "citizen cyberscience"—enable researchers to tackle research questions that otherwise could not be addressed (Jennett et al., 2016) "Existing CCS projects are mainly categorised as volunteer computing (VC) or volunteer thinking (VT) projects" and "We therefore believe that integrating VT and VC into a single project can help to make interesting and engaging use cases for CCS projects" (Yadav et al., 2017)
Volunteer Computing (VC) (distributed computing projects)	**Original definition:** "This paper presents and discusses the idea of Web-based volunteer computing, which allows people to cooperate in solving a large parallel problem by using standard Web browsers to volunteer their computers' processing power." and "The idea behind volunteer computing is to allow users from anywhere on the Internet to join in the solving of a parallel problem by simply using a Java-capable browser and visiting a web site. Because it requires no prior human contact and very little technical knowledge on the part of the client user, volunteer computing makes it possible to build very large parallel computing networks very easily." (Sarmenta, 1998) **First project** The first volunteer computing project was GIMPS (Great Internet Mersenne Prime Search), which started in 1996 and is still ongoing. (https://www.mersenne.org/various/history.php) **Other prominent uses and current interpretations:** "...define it as a new form of parallel computing that focuses on maximizing the ease with which people can volunteer their machines". and "Volunteer computing is a variation on the idea of metacomputing – using a network of many separate computers as if they were one large parallel machine, or metacomputer" (Sarmenta, 2001) "Volunteer computing" uses Internet-connected computers, volunteered by their owners, as a source of computing power and storage (Anderson & Fedak, 2006) Projects utilise the unused processing capacity that exists in personal computers and uses the Internet to send and receive 'work packages' that are analysed automatically and set back to the main server (Haklay, 2013) Generally it is a non-interactive process for those contributing computing resources to a project

	https://arxiv.org/pdf/1707.09566.pdf “Volunteer computing is based on two pillars: the first is computational - allocating and managing large computing tasks; the second is participative - making large numbers of individuals volunteer their computer resources to a project.” and “Our findings highlight the differences between volunteer computing and other forms of community-based projects, and reveal the intricate relationship between individual motivations, social affiliation, tenure in the project, and resource contribution” Differences: “(a) self-oriented motivations - enjoyment and reputation - not having a significant impact on contribution, (b) the importance of the project-related enhancement motivational factor, (c) and the moderating effect of team affiliation on the (negative) relationship between tenure and contribution.” (Nov et al., 2010) “Volunteer computing, also known as public-resource computing, is a form of distributed computing that relies on members of the public donating the processing power, Internet connection, and storage capabilities of their home computers.” (Korpela, 2012) ‘Crowdsourcing’ (Citizens as sensors; Volunteered Computing), Level 1 in Haklay’s typology of CS projects. “At the most basic level, participation is limited to the provision of resources, and the cognitive engagement is minimal. Volunteered computing relies on many participants that are engaged at this level and, following (Howe, 2006), this can be termed ‘crowdsourcing’.” (Haklay, 2013)
Volunteer Thinking (VT) (distributed thinking) / Virtual Citizen Science	**Original definition:** **Other prominent uses and current interpretations:** 2008: “‘volunteer thinking’. This is a recent evolution of distributed computing, in which volunteers on the web contribute to scientific data analysis — examples include projects such as GalaxyZoo and Herbaria@home.” (https://www.researchgate.net/profile/Tobias_Blanke/publication/228619770_No_claims_for_universal_solutions-possible_lessons_from_current_e-humanities_practices_in_germany_and_the_uk/links/02e7e5336fbe99e053000000/No-claims-for-universal-solutions-possible-lessons-from-current-e-humanities-practices-in-germany-and-the-uk.pdf) Virtual citizen science in their typology: “In the science-oriented Virtual projects, all project activities are ICT-mediated with no physical elements whatsoever” (Wiggins & Crowston, 2011). ‘Distributed Intelligence’ (Citizens as basic interpreters; Volunteered thinking), Level 2 in Haklay’s typology of CS projects. “The second level is ‘distributed intelligence’ in which the cognitive ability of the participants is the resource that is being used.” (Haklay, 2013) In volunteer thinking, the volunteers are engaged at a more active and cognitive level In these projects, the participants are asked to use a website in which information or an image is presented to them. When they register on the system, they are trained in the task of classifying the information. After training, they are exposed to information that has not been analysed and are asked to carry out classification work. Besides science research, volunteer thinking projects can also be found within humanities research. VT allows volunteers to participate interactively in citizen cyber-science projects to solve human computational tasks.
Volunteer Sensing / Participatory Sensing / Crowdsensing	“In participatory sensing, the implementation of a similar level of engagement will have participants asked to carry sensors around and bring them back to the experiment organiser.” (Haklay, 2013), meaning ‘similar level’ as volunteer computing/crowdsourcing. Capabilities of mobile phones are used to sense the environment. In addition they can link to external sensors.
Mobile Crowdsensing / Mobile Crowd Sensing and Computing (MCSC)	Mobile crowdsensing belongs to three main types: environmental (such as monitoring pollution), infrastructure (such as locating potholes), and social (such as tracking exercise data within a community) (Ganti et al., 2011) “MCSC extends the vision of participatory sensing by leveraging both participatory sensory data from mobile devices (offline) and user-contributed data from mobile social networking services (online). Further,

	it explores the complementary roles and presents the fusion/collaboration of machine and human intelligence in the crowd sensing and computing processes." (Guo et al., 2015)
Volunteer Gaming	Seemingly not defined. Used in (Kloetzer et al., 2013) as a type of Virtual CS (along with VC and VT) Used in (Abu-Amsha et al., 2016) as type of CCS (SAH also referenced in publication)

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