Self-awareness and Self-expression: Inspiration from Psychology

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Chapter 2
Self-awareness and Self-expression: Inspiration from Psychology

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Abstract Self-awareness concepts from psychology are inspiring new approaches for engineering computing systems which operate in complex dynamic environments. There has been a broad and long-standing interest in self-awareness for computing, but only recently has a systematic understanding of self-awareness and how it can be used and evaluated been developed. In this chapter, we take inspiration from human self-awareness to develop new notions of computational self-awareness and self-expression. We translate concepts from psychology to the domain of computing, introducing key ideas in self-aware computing. In doing so, this chapter therefore paves the way for subsequent work in this book.

2.1 Introduction to Self-awareness

The *Oxford English Dictionary* defines *awareness* as "knowledge or perception of a situation or fact." Informally, we might typically consider that humans build up knowledge, or become aware of things, by perceiving the world around them. We observe interactions, listen to other people, watch television, read books, and, particularly in early life, learn through play. When considering awareness in humans, it is common to consider that all the knowledge we possess, all of our awareness, is acquired through perception. This idea was first postulated by Hume [187], who argued that all human knowledge is induced from experience. What then does it mean for a human to be *self*-aware? For Hume, the "self" is not a defined physical entity, but instead describes the bundle of experiences or perceptions unique to an

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individual. A Humean form of self-awareness might then be considered to consist of an individual's knowledge of its experiences. Kant [210] criticised Hume's view, extending the scope of the self significantly, arguing that there is some entity which is the subject of these experiences, and is common through space and time. This Kantian self synthesises information from experiences with concepts held in the mind and with the imagination. Kant further argued that as an individual performs actions within the world, since its actions are based on its synthesised knowledge, they represent its self, giving rise to the self also as an object. This object in turn is something which can be perceived and experienced.

Though there is a long history of analysis of the nature of the self in philosophy, more recently, psychology has made a more pragmatic attempt to develop an understanding of the varieties of knowledge individuals possess concerning themselves. The notion of self-awareness first appears in the literature around the turn of the twentieth century [25, 382], perhaps most importantly with James [197] making the distinction between two forms of self based on the differences between the Humean and Kantian views described above. First, the *implicit* self, often referred to as the self-as-subject, or the "I", is the self which is the subject of experiences. These experiences are unique to the individual, and they are from the individual's own point of view, determined by factors such as their sensing apparatus, their situation within the world, and other factors associated with their own state. Second, the *explicit* self, or self-as-object, can be discerned. Here the self is an object of knowledge. It is a thing which can be recognised, modelled and reasoned about, including in relation to other objects in the world. An individual's awareness of its explicit self is often considered the more advanced form of self-awareness in this distinction, building on implicit self-awareness. Indeed, implicit self-awareness emerges much earlier in the lives of human infants than its explicit counterpart does [231].

One commonly considered form of self-awareness is that as measured by the so-called *mirror test* [140]. A subject being evaluated is presented with a mirror, to which it is then allowed to get accustomed. The subject is then distracted and, without its knowledge, a visible change is made to its appearance. This is usually done by marking its face, e.g., putting a spot on its cheek or forehead. The subject is then presented with the mirror again. Any behaviour directed towards this marker by the subject implies self-recognition, which is seen as being enabled by a mental representation of oneself (also known as a secondary representation). As Asendorpf et al. [18] put it:

> *"[secondary representation] is not a perception of oneself but rather a constructed mental model of oneself that can be manipulated in fantasy. Therefore, the ability to recognise oneself in a mirror that requires linking a mirror image (a primary representation) with one's self marks the capacity for secondary representation."*

Explicit self-awareness requires a subject to possess the capacity to construct such a secondary conceptual representation of itself. What then does the mirror test tell us about self-awareness? Humans, primates and some other animals have "passed" the mirror test [140, 18], however, Haikonen [155] showed that very little sophistication in computing machinery can enable a computational system with visual sensors to also pass. Haikonen therefore goes on to suggest that the ability or inability to self-recognise may not prove the presence or absence of self-awareness more generally at all. Since a computing system can specifically and easily be designed to pass the mirror test, using the test as a yardstick by which to tell whether or not the system is self-aware may thus be a misleading notion. Indeed, even if we accept Asendorpf's [18] claim that self-recognition requires some form of secondary representation (i.e., a conceptual model) of oneself, it is clear that the mirror test is concerned with a quite specific aspect of what might be considered self-awareness, based on a conceptual model of one's appearance. As this chapter will go on to discuss, we are concerned in this book with a broader treatment of self-awareness.

As should now be apparent, and is highlighted in recent work (e.g., by Morin [275], Legrain et al. [231] and Rochat [344]), there is much ongoing discussion about what might and what might not constitute self-awareness and various observed forms of it. In some cases, more "primitive" aspects of self-awareness are stated to fall instead into consciousness, upon which self-awareness builds. For example, Morin's definition considers self-awareness as distinct from, but building upon consciousness, as *"the capacity to become the object of one's own attention."* Further, he also addresses the conceptualisation of subjective experience, describing a self-aware organism as one that *"becomes aware that it is awake and actually experiencing specific mental events."*

In other cases, this perceptual (or pre-conceptual) subjective experience is itself also included in the scope, effectively presenting self-awareness and consciousness as overlapping concepts. In this chapter, our concern is not with attempting to settle these debates, but instead with understanding theories of self-awareness as presented in the literature, with the aim of developing concepts inspired by self-awareness to benefit the design of computing systems. Therefore, some of what is presented and discussed here is considered by some literature, but not all, to be forms of consciousness rather than self-awareness proper.

2.2 Key Concepts for Self-aware Systems

In drawing inspiration from psychology, in this book we utilise three key concepts which appear prominently in the self-awareness literature, and which have shown promise as useful concepts in the design of self-aware computing systems. These three key concepts are (i) public and private self-awareness, (ii) the extent of self-awareness capabilities can be characterised by various levels, and (iii) self-awareness can be a property of collective systems, where knowledge need not be present in a single central source, and may instead be distributed. Further, we argue that self-awareness properties alone are of limited value in computational systems, or indeed any system at all, unless accompanied by associated behaviour. In this book we use the term *self-expression* to refer to *behaviour based on self-awareness*. The remainder of this section introduces these key concepts.

2.2.1 Public and Private Self-awareness

As discussed above, Morin's definitional introduction to self-awareness contains two aspects. His first is centred on the idea of being the *"object of one's own attention"*, and establishes a subject-object view of self-awareness, where aspects of oneself are objects within a conceptual mental model. This *explicit* self-awareness (as presented, e.g., by Legrain et al. [231]) permits an individual to focus its attention on itself, to consider itself as an object within the world, and to observe and consider its own behaviour. However, Morin's second passage, that the individual *"becomes aware that it is awake and actually experiencing specific mental events"* reveals another facet of self-awareness, that which is *implicit*. This is concerned not with the self-as-object "me", but rather with "I", the self-as-subject of experiences. Here, the individual is aware of its experiences within the world, and that these are its own experiences, subjective and unique.

This distinction was first expounded in detail by Duval [111], who defined two classes of self-awareness: *subjective* and *objective*. Objective self-awareness is described as being *"focused exclusively upon the self and consequently the individual attends to his conscious state, his personal history, his body, or any other personal aspects of himself"* [111]. Subjective self-awareness by contrast is described as *"a state of consciousness in which attention is focused on events external to the individual's consciousness, personal history, or body"* [111].

Many authors have since developed this distinction further [131, 55, 58, 137, 147], in whose literature a slightly different distinction between *public* and *private* self-awareness develops. Private self-awareness is concerned with obtaining knowledge of internal phenomena, typically externally unobservable and accessible only to the individual. Such knowledge might include, for example, being hungry or having a headache. More complex private self-awareness might include an individual's knowledge of its values, opinions, goals or thought processes. Public self-awareness, on the other hand, is more concerned with how the individual can be (or is) perceived externally. This might include knowledge of how the individual appears to others, its social relationships or the effects of its interactions with the physical environment. Froming et al. [137] describe this as awareness of oneself as a *social object*.

In a minimal form, we may consider public self-awareness only insofar as it is present in individuals capable of implicit (or subjective) self-awareness. In this case, the individual would be capable of subjective perception of its environment. Given the unique situated nature of the individual, these experiences are themselves uniquely related to itself. However, in an explicit (or objective) form, public self-awareness may include knowledge of how the individual itself is or could be perceived by others, for example, how it looks (recalling the mirror test discussed above), whether it is a member of a particular group, or whether it has impacted on a shared environment. This requires knowledge not only of its environment, but also of itself as an object within that environment, an object of which others may be aware.

In summary, an individual's public self-awareness is concerned with knowledge obtained from experiences of the perceived environment in which the individual is situated. This knowledge may include both social aspects (e.g., other individuals, its own appearance) and purely physical aspects (e.g., the world). An individual's private self-awareness is by contrast concerned with knowledge obtained by experiences solely concerning the individual. This knowledge is obtained internally and is typically not available to others, unless the individual communicates it. An individual which is self-aware in both the public and private senses therefore has the capability to acquire and possess knowledge of its external environment and its internal state.

In taking inspiration from self-awareness for computing systems, we could choose (and some have previously chosen) to consider self-awareness only in its explicit, private sense, as the ability to build conceptual models of (part of) its own internals. Alternatively, we can broaden this further, to include the consideration that a system's sensing of its environment and itself provides a unique subjective experience, which can be modelled and reasoned about. Regardless of how we choose to draw the boundary around a definition of self-awareness, the literature does agree that self-awareness even within both its implicit and explicit forms is a multi-level phenomenon, where increasingly complex levels describe an individual's self-awareness capabilities.

In considering the self-awareness capabilities of systems in general and computing systems in particular, we are interested in the benefits (or not) of increased self-awareness, relative to current state-of-the-art systems. For example, to what extent can endowing a system with conceptual models of itself, its interactions, its goals, its past and its future enable more effective self-expression? Can this provide increased potential for adaptation? How important is a system's ability to learn such models for itself? What are the costs of maintaining and learning such models? And can a self-aware system build models of these costs too, taking account of them when deciding how to best conceptualise itself and its world? On the implicit side, what are the benefits of considering the subjective nature of a system's sensory input? To what extent does the consideration of a system's own state affect how that input is collected, stored, and reasoned about? Is there a benefit to considering differences between systems' own subjective experiences of a shared environment, or does this simply add complexity to a system's description, for little gain? These questions give a flavour of the reasons why, in this book, we take a broad view of self-awareness, including both implicit and explicit, and public and private forms. The chapters throughout the book engage with different aspects of self-awareness, from runtime learning and trade-off modelling, to exploring the heterogeneity of different systems' sensed experiences in a shared problem domain.

2.2.2 Levels of Self-awareness

As noted in much of the self-awareness literature (e.g., [231, 275]), it is widely believed that self-awareness is not a singular, *all or nothing* phenomenon, rather it can be thought of as a spectrum, where the capabilities of an individual are associated with one or more levels of self-awareness. Accordingly, several attempts have been made to define levels of self-awareness. Morin [275] provides a review of several of these classifications, highlighting similarities and differences between them. Some sets of levels, such as those by Rochat [344], focus on classifying self-awareness capabilities according to the way in which they are observed to develop in human children. Legrain et al. [231] provide a classification of three levels, considering only explicit self-awareness. One classification, due to Neisser [284], describes five levels which offer what is perhaps one of the most broad treatments of self-awareness, from the most minimal to the most advanced. Importantly from our perspective, Neisser's model also includes aspects of implicit self-awareness. In line with our approach of taking a broad view of self-awareness in our mission to translate concepts from psychology to computing, we have focussed on Neisser's levels as a concrete source of inspiration. These five levels now follow.

1. **Ecological self**
   The ecological self is the most minimal form of self-awareness. It permits sufficient knowledge only for basic stimulus-response behaviour, as the individual has a basic awareness of stimuli. The ecological self can be thought of as the minimum requirement for the individual to not be unconscious.
2. **Interpersonal self**
   The interpersonal self enables the individual to possess a simple awareness of its external interactions, permitting limited adaptation to others in the performance of tasks.
3. **Extended self**
   The extended self extends the interpersonal self to permit reflection of interactions over time. The individual is aware of the existence of past and future interactions.
4. **Private self**
   The private self allows the individual to process more advanced information concerning itself, such as thoughts, feelings and intentions.
5. **Conceptual self**
   The conceptual self, or self-concept, is the most advanced form of self-awareness, representing that the individual is capable of constructing and reasoning about an abstract representation of itself.

This final, most advanced level of self-awareness also permits what is sometimes termed **meta-self-awareness** [276, 366]. This is an awareness on the part of the individual that it is itself self-aware. Meta-self-awareness may consist of complex analysis and reasoning of both public and private self-awareness processes at any of the preceding levels. Examples of meta-self-awareness might include the individual's being aware that it is angry about something, or that it has recently learnt a lot about a particular topic. Smallwood et al. [366] discuss awareness at the meta level extensively, arguing that a lack of such a capability can lead to excessive mind-wandering in humans. They argue that the absence of meta level awareness leads to an individual being unable to direct its attention, thus exhibiting a lack of awareness more generally.

2.2.3 Self-awareness in Collective Systems

So far, we have just considered self-awareness in the context of a single individual. However, Mitchell [272] notes that self-awareness can also be observed in collective systems, where there is no central point at which such self-knowledge is located. Examples of these collective systems include those comprised of individuals that might normally be considered either organisms in their own right (e.g., ants in a colony) or constituent cells of a larger organism (e.g., neurons in the brain). In these cases, it appears from an external perspective that such biological collective systems are self-aware at the level of the collective, even though this property may not be present at the level of the individual component. This awareness, Mitchell describes as being concerned with

> *"information about the global state of the system, which feeds back to adaptively control the actions of the system's low-level components. This* ***information about the global state is distributed*** *and statistical in nature, and thus is difficult for observers to tease out. However, the system's components are able, collectively, to use this information in such a way that* ***the entire system appears*** *to have a coherent and useful sense of its own state."* [272]

We have added the emphasis here, in order to highlight that a system which behaves as if it were self-aware is not necessarily required to possess a single "mind-like" component[1]. Indeed, in many cases, the entire system appears self-aware, despite only local knowledge being present at constituent parts of the collective. Self-awareness might be considered the product of emergence.

This is a key observation which can contribute to the design of self-aware systems: one need not require that such a system possess a global omniscient controller. Indeed, many natural systems appear to have been favoured by evolution which do not have such a central point of control, and rely upon relevant knowledge being available at appropriate locations within the system. It is highly likely that this idea can improve the robustness and adaptability of such systems; these are desirable properties for natural and artificial systems alike.

2.2.4 Self-expression

As we have seen, self-awareness is concerned with knowledge synthesised and held by an individual about itself and its experiences. This knowledge may be centrally held, or else distributed in nature. However, in studying the self-awareness properties of natural and computational systems, we have found it advantageous to explicitly and separately consider the related process of an individual determining its behaviour as a result of this knowledge. This process we call self-expression. In

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[1] Indeed, while the brain has long been known to be a collective system composed of neurons, consciousness in the human mind is itself thought by some [98] to also be a distributed phenomenon, with nothing like what we might call global knowledge.

social psychology, self-expression has been defined as *"the assertion of one's individual traits"* [217]. Similarly, Chen et al. [66] define self-expressive individuals as ones which behave *"in line with their states and traits,"* where a trait is *"a genetically determined characteristic or condition"*,[2] which may be either physical or behavioural.

In this book, we therefore distinguish between self-awareness, which is the property concerned with an individual's knowledge, and self-expression, which is the property concerned with an individual's resulting behaviour, behaviour based on or informed by its knowledge and characteristics. This also helps to highlight that action or behaviour is not a requirement for self-awareness. It is, however, typically highly useful, especially in purposeful systems such as those which are engineered. For this reason, we typically consider self-awareness and self-expression together.

2.3 Computational Self-awareness

In this section, we propose that human self-awareness can serve as a source of inspiration for a new notion of *computational self-awareness* and associated *self-expression*. We introduce a general framework for the description of the self-awareness properties of computing systems. In later chapters of this book, this framework is developed into a reference architecture (Chapter 4) and a series of derived architectural patterns (Chapter 5). Together, these can be used to determine whether, how, and to what extent to build self-awareness capabilities into a system. This framework provides a common, principled basis on which researchers and practitioners can structure their work, and indeed is used throughout this book. The psychological foundations, while not strictly necessary, can provide a means of channelling a wide range of ideas – which would perhaps otherwise not have occurred to engineers – acting to inspire the design of future computing systems.

While the concepts of public and private self-awareness transfer in a fairly straightforward manner to computing systems, Neisser's [284] five levels of self-awareness lend themselves to being easily misinterpreted if discussed only in their psychological context. Therefore, we have found it useful to make these psychological concepts tangible from an engineering perspective. We do this by expressing these concepts in computational terms or processes, as part of our proposed notion of computational self-awareness.

2.3.1 Private and Public Computational Self-awareness

The first key idea of public and private self-awareness can be summarised as follows:

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[2] *American Heritage Science Dictionary*, Houghton Mifflin Harcourt, 2005

- **Private self-awareness**: This is a system's ability to obtain knowledge based on phenomena that are internal to itself. A system needs internal sensors to achieve this.

- **Public self-awareness**: This is a system's ability to obtain knowledge based on phenomena external to itself. Such knowledge depends on how the system itself senses/observes/measures aspects of the environment it is situated in, and includes knowledge of its situation and context, as well as (potential) impact and role within its environment.

Some prior work in self-aware computing has considered only private self-awareness, i.e., a system's awareness of its own internal state. However, the importance of the availability of external sources of information to self-awareness processes should be emphasised: self-awareness is not only concerned with sources of information internal to the individual. We argue that a full consideration of computational self-awareness also includes public aspects, where a system's knowledge of itself in relation to its social and physical environment can be synthesised with private self-awareness, in order to produce integrated conceptual models. In this book, we hope to demonstrate that the distinction, inclusion and synthesis of both public and private self-awareness raise many important questions for engineers of self-aware computing systems.

2.3.2 Levels of Computational Self-awareness

We now describe our computational framing of the levels of self-awareness, which were first presented by Faniyi et al. [127] and elaborated upon by Lewis et al. [236]. It is possible to relate the levels of self-awareness to the concepts of private and public self-awareness, and hence the sources of the relevant knowledge (i.e., based on internal or external sensors). The relevance of each level to these concepts is also described. The relationship provides an indication of the architecture that will be required in order to realise each of the levels. In each case, Neisser's level of self-awareness is given on the left, and our corresponding level of computational self-awareness is on the right.

1. **Ecological self $\longrightarrow$ Stimulus-aware**
   A system is stimulus-aware if it is able to obtain knowledge of stimuli acting upon it, enabling the ability to respond to events. It does not have knowledge of past/future stimuli. Since stimuli may originate both internally and externally, stimulus-awareness can be **private**, **public** or **both**.

2. **Interpersonal self $\longrightarrow$ Interaction-aware**
   A system is interaction-aware if it can obtain knowledge that stimuli and its own actions constitute interactions with other systems and the environment. It is able to obtain knowledge via feedback loops that its actions can provoke or cause

specific reactions from the social or physical environment. Simple interaction-awareness may just enable a system to reason about individual interactions. More advanced interaction-awareness may involve the system obtaining knowledge of social structures such as communities or network topology. Interaction-awareness is typically based on external phenomena, whereby it is a form of **public** self-awareness. However, a system which learns about causality in internal interactions with itself would constitute a form of **private** self-awareness.

3. **Extended self $\longrightarrow$ Time-aware**
   A system is time-aware if it can obtain knowledge of historical and/or likely future phenomena. Implementing time-awareness may involve the system using explicit memory, time series modelling and/or anticipation. Since time-awareness can apply to both internal and external phenomena, it can be **private**, **public** or **both**.

4. **Private self $\longrightarrow$ Goal-aware**
   A system is goal-aware if it can obtain knowledge of current goals, objectives, preferences and constraints. It is important to note the difference between goals existing implicitly in the design of a system, and the system having access to its goals such that it can reason about or manipulate them. The former does not describe goal-awareness; the latter does. Example implementations of goal-awareness include state-based goals (i.e., knowing what may or may not be a goal state) and utility-based goals (i.e., ability to obtain a utility or objective function). Goal-awareness permits adaptation to changes in goals. When coupled with interaction-awareness or time-awareness, goal-awareness permits the ability to reason about goals in relation to other individuals or likely future goals, respectively. Since goals may exist privately to the system, or collectively as a shared or externally imposed goal, goal-awareness can be **private**, **public** or **both**.

5. **Conceptual self $\longrightarrow$ Meta-self-aware**
   A system is meta-self-aware if it is able to obtain knowledge of its own level(s) of awareness and how the level(s) are exercised. Such awareness permits metacognitive processes [84] to reason about the benefits and costs of maintaining a certain level of awareness. It further allows the system to adapt the way in which the levels of self-awareness are realised (e.g., by changing algorithms realising the levels), thus changing the degree of complexity of realisation of the levels). Since meta-self-awareness is concerned only with knowledge of internal processes, it is a form of **private** self-awareness.

Figure 2.1 shows an illustration of the relationship between private and public self-awareness concepts and these levels.

Although possession of (self-)knowledge is important to achieve computational self-awareness, we argue that it is the *ability to obtain this knowledge on an ongoing*

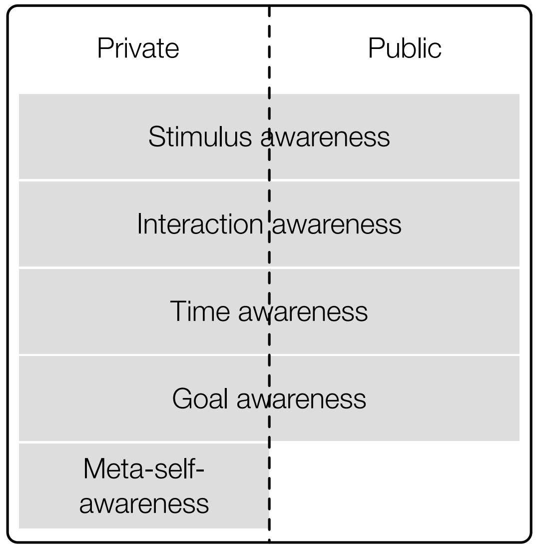

Fig. 2.1 Levels of computational self-awareness, and how they relate to private and public aspects in this framework. While the first four levels can involve perception and conceptualisation of either internal (private) or external (public) factors, meta-self-awareness is concerned with awareness of other self-aware processes, which are private to the individual.

basis throughout the system's lifetime that enables self-awareness. We do not consider a system with knowledge but no means to update or add to that knowledge during its lifetime to be computationally self-aware: it has instead been programmed by a domain expert. While the levels are considered from an architectural perspective in Chapters 4 and 5, Chapters 6 and 7 consider how online learning and knowledge representation techniques can realise these characteristics of self-aware systems on an ongoing basis.

2.3.3 Collective and Emergent Computational Self-aware Systems

Finally, self-awareness can be, and indeed is often, found in complex systems composed of many interacting subsystems. This is important for the design of self-aware computing systems. In building self-aware systems, we do not need to require a global "knowledge base" or common awareness mediator. Indeed, in many natural systems, such components are absent [272]. Whether a self-aware system is organised in a centralised or a decentralised manner is, we argue, not a conceptual difference, but an architectural one. We anticipate that, and indeed several of the examples given in this book show that, decentralised self-awareness can provide increased robustness and adaptability in the face of change.

The third key concept inspiring our framework is therefore the notion that self-awareness can be a property of a collective system, possibly even emerging from interactions within the collective. Systems within a collective that interact with each other only locally as part of a bigger system might not individually possess knowledge about the system as a whole (i.e., the global state). Global knowledge is instead distributed [272], but the system is able to collectively use this information such that it has a sense of its own state and thus be self-aware at one or more of the aforementioned levels. Figure 2.2 illustrates that, from the conceptual point of view, a collective system comprising several self-aware systems may itself be viewed as a self-aware system, and considered using the computational self-awareness framework introduced in this book.

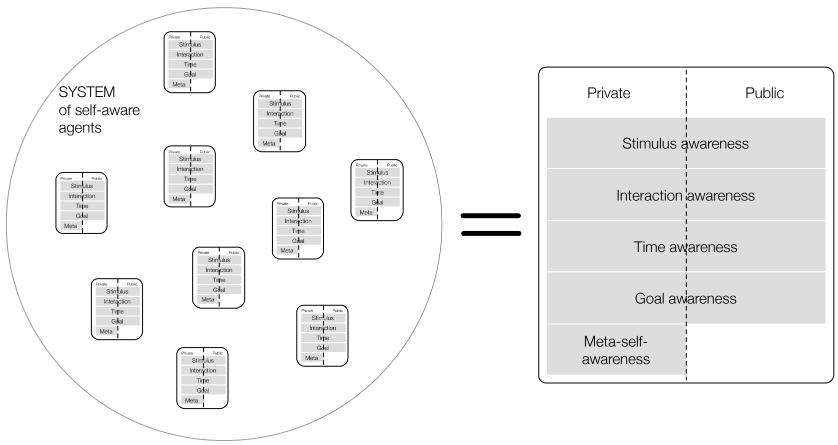

Fig. 2.2 Aspects of computational self-awareness can be considered when taking a single system view, and at subsystem level when composing a collective system. The relationship between these two may be complex, and exhibit emergent self-awareness properties.

When we talk of self-aware computing systems, we may therefore be referring to several different types of self. First, it should by now be clear that self-awareness may be a property of an autonomous agent, which is capable of obtaining and representing knowledge concerning itself and its experiences. Indeed, much of the literature on autonomous and intelligent agents is concerned with techniques for agent learning, knowledge acquisition and representation, and architectures to support these capabilities. Second, according to this third key idea of collective self-awareness, the boundary of a self-aware entity, indeed the “self”, is not limited to a single agent. Chapter 4 revisits this idea, in the context of architecture, and considers both centralised and decentralised approaches.

2.4 Summary

This chapter presented a brief introduction to self-awareness concepts as they are understood in humans. Further, we have begun to consider how such concepts can be translated to the domain of computing systems. The new notion of *computational self-awareness* is proposed, based on three key concepts:

- Public and private self-awareness: A self-aware system can have the ability to obtain knowledge based on phenomena that are external and internal to itself, respectively.

- Levels of self-awareness: The self-awareness of a system can be described in terms of one or more levels of self-awareness, which characterise self-awareness capabilities. We presented a set of levels inspired by psychology, comprising stimulus-awareness, interaction-awareness, time-awareness, goal-awareness and meta-self-awareness.

- Collective self-awareness: Self-awareness may be present at the level of a single system, or at the level of a collective system, where interactions between components provide distributed learning.

Additionally, we introduced the notion of *self-expression*, behaviour based on self-awareness. Self-expression typically provides highly dynamic behaviour, able to adapt to a system's changing self-awareness as it learns. Self-expression may include behaviours considered "normal" functional system behaviour, as well as self-adaptation, self-reconfiguration, self-explanation, or any other forms of individual or collective behaviour informed by a system's self-awareness.

These concepts are used as the basis for much of the work in subsequent chapters in this book, where architectures, algorithms, platforms and case studies expand on and demonstrate their use.

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