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A modeling approach to introduce haptic feedback in multimodal awareness for groupware systems

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Abstract The key to effective collaboration is awareness; traditional groupware systems have relied on visual cues to achieve it. Audio has been used to complement and overcome the limitations of graphical displays to maintain awareness. However, the emergence of alternative user interface strategies, such as haptic feedback, presents new opportunities to promote awareness. Yet, designing effective haptic awareness mechanisms is challenging due to the lack of documented experience. Therefore, we suggest using flexible prototyping and evaluation tools to facilitate an exploratory design process. We also propose that the design of awareness features should consider modalities to be used and the relationships between them from the outset. To support this idea, we introduce a modeling language and supporting tools to express haptic awareness features. We show how the language can be used in the context of model-driven development of groupware.

Keywords: *haptic interfaces, awareness, groupware, model driven development.*

1 Introduction

In groupware systems, users are informed regarding the actions that the other users perform and how these actions affect the work environment Gutwin and Greenberg (2002); Gutwin et al. (1996). This information provided by the system is known as awareness. According to Dourish and Bly (1992), awareness is the perception or knowledge of the group and of the activities performed by others that provides context for your own activities. In particular, awareness information allows users to coordinate their work based on knowledge of what others are doing or have done Collazos et al. (2019). Supporting awareness has important if subtle, benefits, such as increasing the effectiveness of collaborative work, fostering social relationships, and improving the general well-being of individuals Gutwin and Greenberg (1998).

Most literature about the design of groupware systems assumes that users interact with the system via traditional GUI elements displayed on the screen. Providing awareness information only through a visual display has limitations. For example, visual awareness does not work if the display is outside the user's field of view, or if the display becomes so cluttered that visual cues cannot be recognized, or if the user is not paying attention Gutwin et al. (2011).

Sound cues are frequently used to attract the user's attention, and audio has been used to help maintain awareness in groupware Gaver (1991); Gaver et al. (1991). Audio has various advantages as a channel to communicate awareness. Audio does not take screen space and therefore does not contribute to display cluttering. Audio does not require visual attention and is not affected by the user's orientation. Audio can complement visual inputs and can be processed in parallel.

Audio also has limitations as a means to maintain awareness. Although it is not affected by display cluttering, its effectiveness is reduced in noisy environments (the equivalent form of cluttering for audio). The bandwidth of audio is limited in comparison to visual display, in particular, due to limitations in our ability to recognize and tell sounds apart. Sound cues are hard to recognize when they overlap or when they are not different enough. To increase the bandwidth, some systems resort to spoken messages (e.g., AOL's "you've got mail" message). Although spoken messages and alerts are common in conversational UIs, they can distract and overwhelm the user if overused to provide awareness when the main task is cognitively demanding Edwards et al. (2019).

Over the last decade, multimodal-multimedia interfaces have become the dominant computer interface worldwide Oviatt et al. (2017). A multimodal interface provides several different sensory channels for data input and output Stivers and Sidnell (2005). One of the main reasons is their flexibility as they allow users to select a suitable input mode, or to switch between modalities as needed for different physical contexts. Multimodal interfaces also contribute to improved cognition and performance because they allow users to self-manage and minimize their own cognitive load. Based on Gestalt's theory, working memory and activity theories support the conception and design of multimodal interactions Oviatt (2017). Within this wave, the growth of haptic interfaces that actively stimulate the sense of touch stands out Parisi (2018). In Computer Supported Cooperative Work (CSCW) and Computer Supported Cooperative Learning (CSCL) domains in particular, the literature reports case studies, prototypes, and experiments fundamentally based on vibrotactile feedback, either through the creation of new wearable devices or the exploitation of hardware and software available in mass consumer products such as smartphones or smartwatches.

Considering haptic feedback as a means to communicate awareness information, one realizes the existence of at least three complementing interaction modalities, namely the visual modality (the GUI), the audio modality, and the haptic modality. In practice, this means that groupware designers should be able to express not only the awareness feature they want to attach to an event but also the mode (or combination of modes) in which that feature is to be implemented. There is evidence that touch increases compliance with a request, touch is associated with significantly higher request compliance, and there was evidence of a difference in the touch condition between subjects who had noticed tactile contact and those who had not Joule and Guéguen (2007).

Hapticians (haptics designers) follow an observable process to design haptic interaction. A set of four basic design activities has been identified for the process: browsing, sketching, refining, and sharing MacLean et al. (2017). This process is similar to the one defined by Collazos et al Collazos et al. (2019), where a set of 5 activities have been proposed to support awareness: (1) Awareness Goals to support; (2) Awareness Information Identification; (3) Modeling, which is needed to integrate Awareness support in software systems developed through model-based methodologies (MDD); (4) Distribution; and (5) Awareness User Interfaces. The possibility of establishing a conceptual infrastructure, like haptic design languages, has been mentioned among the main challenges for haptic experience design Schneider et al. (2017). Such languages, for example, as a formal lexicon of terms, are especially needed in multidisciplinary teams, where experts and novices in haptic design work together.

In this article, we argue that the design of awareness functions should consider multimodality from the outset, as recommended in multimodal and multisensory design literature (e.g. Oviatt et al. (2017)). To support the discussion, we present a language of haptic stimuli inspired by the notion of Haptemes and Haptices Lahtinen (2008) that support two of the three categories into which the tactile experience can be organized (discriminative, affective and social Linden (2016)). This language includes four vibrotactile icons and a pause element that allow a wide variety of haptic stimuli to be expressed for providing awareness. We further show how the language can be used in the context of model-based collaborative software development, with a demo based on a Hybrid Classroom scenario.

The rest of the article is organized as follows: Section 3 discusses related works on using haptic interfaces and Model Driven Development (MDD) in the development of collaborative systems; Sections 4 and 5 introduce our language for haptic awareness features based on the haptices and haptemes concepts by Lathtinen Lahtinen (2008), and its use in an MDD approach for designing CSCL. Section 6 presents an Evaluation of our proposal with a Demonstration approach after Ledo et al. (2018); finally, Section 7 presents Conclusions and further works.

2 Background

In groupware systems, the awareness mechanism is a medium that provides contextual information about the past activities, present state, and future options of a virtual environment, triggering the cognitive process described above Sohlenkamp (1999), so that group members can perceive the state and changes of their virtual shared space. The provided contextual information answers questions such as who does/did an action, what is/was done, where are/were the individuals/objects, when did an event occur, and why did an event occur Gutwin and Greenberg (2002); Abowd and Mynatt (2000).

Since Bolt's "Put That There" prototype Bolt (1980), multimodal interface systems have grown steadily. Oviatt Oviatt et al. (2017) presents a complete overview of the field and defines multimodal interfaces as "systems that process two or more combined user input modes - such as speech, pen, touch, manual gestures, gaze, and head and body movements in a coordinated manner with multimedia system output." This implies two main aspects of multimodal interfaces: developing modes of interaction and developing techniques to combine or integrate the modes that enable more flexible, expressive, powerful, and natural interfaces. Stivers and Sidnell (2005). The most common interface combines a visual modality (e.g., display, keyboard, and mouse) with a voice modality (speech recognition for input, speech synthesis, and recorded audio for output). However, other modalities can be used, such as pen-based input or haptic input/output. Proposed advantages of a multimodal output system include synergy and redundancy. Information presented through multiple modalities is merged and refers to several aspects of the same process. Currently, multimodal output is primarily used to improve the match between a communication medium and content and to support care management in data-rich environments where operators face considerable visual attention demands Sarter (2006).

The use of the sense of touch as a form of communication with technology has a long history. Unlike vision and hearing, the two traditional senses used in HCI, the sense of touch is proximal: it perceives objects that are in contact with the body, and it is bidirectional, allowing both perceiving and acting on the environment. In the early 1920s, Robert Gault designed the Teletactor with the intention of helping hearing-impaired people understand spoken language. When the operator spoke into the telephone handset, the device transformed speech sounds into precisely controlled vibrations that were sent through the reed Parisi (2018). In 1957, Frank Geldard developed Vibratese, a vibrational representation of an alphabet through five actuators on the body Geldard (1957). In 1959, the movie The Tingler provided vibrational feedback in cinema seats IJsselsteijn (2003). The goal of those tactile displays was to convey information as clearly as possible rather than to provide physical realism. Enriquez and MacLean presented the notion of haptic icons (*hapticons*) as "brief programmed forces applied to a user through a haptic interface, with the role of communicating a simple idea in a manner similar to visual or auditory icons" Enriquez and MacLean (2003). Later, Brewster and Brown introduced an approach to designing structured vibrotactile information displays in their research on *tactons* or tactile icons (a subclass of hapticon) Brewster and Brown (2004). *Tactons* have been used for systems as diverse as emotion induction Huisman et al. (2013) or spatial orientation in mobile systems Pielot et al. (2009). Subsequent research focused on the efficiency of information transfer Brown et al. (2005), usability aspects such as the number of icons that could be learned Ternes and MacLean (2008), and added value to the user experience Maggioni et al. (2017). In this type of research, key design parameters such as frequency, amplitude, waveform, and timing (e.g., duration, number of beats, rhythm) are identified.

The literature shows different approaches to the use of tactile mechanisms for awareness in collaborative systems. Taking into account the Awareness taxonomy presented by Collazos et al. (2019), the use of People as a source of awareness is the most frequently reported.

Some initial examples focused on sets of icons to facilitate turn-taking. For example, Chan et al Chan et al. (2008) designed a protocol that allows users to express varying levels of urgency in their request for control to a collaborator. Control status and requests are communicated by touch, with the intention of offloading visual attention. To support this, they developed a set of haptic icons, tangible stimuli that have been assigned specific meanings. They found that the haptic icons could be learned with a high degree of accuracy in less than 3 minutes and remained identifiable even under a significant cognitive workload. In an exploratory observational study comparing haptic, visual, and combined haptic and visual support for their protocol, participants generally preferred combined multimodal support and, in particular, haptic support for control changes and visual support for state display.

Comado Yamamura et al. (2021) is a device that aims to explore co-presence between remote users during a video call. To achieve that, Comado adds a blur effect “outside of conversation”, as well as a transmission of haptic feedback to the desk of the remote participant.

People emotional state has been explored by Ju et al. Ju et al. (2021) and Frey et al. Frey et al. (2018). Ju et al. present an experiment where 28 vibration sample sets for 4 different emotions were recorded and then replayed to test how well they could be recognized. The results support the hypothesis that people can use vibration feedback as a medium for expressing specific subjective feelings. Frey et al. describe the effectiveness of conveying a physiological signal often overlooked for communication: breathing. They present the design and development of digital breathing patterns and their evaluation along three output modalities: visual, audio, and haptic. They found that experiment participants intentionally modified their own breathing to match the biofeedback. In e-learning scenarios, affective tactile stimulation can be applied to reinvigorate the learner’s interest when she or he is bored, frustrated, or angry Huang et al. (2010). Gaffary et al. Gaffary et al. (2014) address expressing spontaneous emotions. In the context of a game application that involves haptic interaction, a suitable scenario and context were designed to elicit a spontaneous stressed affective state. This study investigated spontaneous haptic behaviors occurring during stressed affective states. Chen et al. Chen et al. (2010) used haptic technology for floor control in a conversation. Subjects can express their emotions by changing the ball’s color and radius, as well as its speed. With observational experiments, the authors verified the effect that haptic interaction brings about. Results implied that online negotiation involving haptic interaction could increase the sense of presence and is also helpful for expressing one’s emotions.

3 Related work

The use of touch modality to communicate situational awareness and socio-affective has been reported in literature. Several studies show how remote touch enhances the sense of presence and awareness of the other and how people can construct or use affective tactile symbols Haans et al. (2007). Smith Smith and MacLean (2007) shows the importance of dyadic relationships, the type of contexts, and the level of presence awareness (for example, the perceived distance between them). Contexts (social versus functional) seemed to have an impact; comparing a handshake and a ping-pong touch showed that the emotion conveyed by a handshake was easier to recognize. Hanss Haans and IJsselsteijn (2006) points out that these works assume that digital touch is the same as physical touch. To further investigate this assumption, Zhang et al Zhang et al. (2021) explores digital touch greetings in co-located work meetings during Covid-19. Other works focused on capturing and communicating users’ emotions to support self-understanding instead of human-human two-way communication, away from our focus.

Stephanie Wong et al. Wong et al. (2017) show the use of haptics to improve communication among the members of a flight crew. The paper presents a prototype called “Smart Crew”: a smartwatch application that allows flight attendants to maintain an awareness of each other and communicate through messaging with haptic feedback. It is designed with an emphasis on real-time information access and direct communication between flight attendants, regardless of their location.

Bailenson et al. Bailenson et al. (2007) proposed the concept of Virtual Interpersonal Touch (VIT), people touching one another via force-feedback haptic devices. Participants used a Grounded Force Feedback joystick to express emotions and attempted to recognize the recordings of emotions generated in the previous experiments. Results indicated that humans were above chance when recognizing emotions via VIT but not as accurate as people expressing emotions through non-mediated handshakes.

In relation to modeling visual techniques, Mobile Collaboration Modelling (MCM) Jang et al. (2002) is a visual language to represent mobile collaborative work. MCM focuses on the representation of computer-mediated interactions between users but does not provide elements to specify awareness information. CSRML (Collaborative Systems Requirements Modelling Language) Teruel et al. (2012) is an extension of the i* language to model groupware system requirements that includes support to represent artifacts that enable the users to be aware of other user’s presence/actions. Computer-Supported Interaction Modelling Notation (CI-

MoN) Canché and Ochoa (2018) is a visual modeling language that allows designers to represent autonomous agents that can provide awareness information. Notwithstanding, CIMoN notation does not provide support to describe and characterize awareness information that should manage these agents.

In the case of modeling collaborative systems, some works propose software engineering resources to model groupware systemsGallardo et al. (2011); Kamoun et al. (2012). However, initiatives that combine models with transformation to code, such as Model Driven Software Development approaches (MDD) Brambilla et al. (2012); Stahl et al. (2006), that propose to improve the quality and efficiency of the software construction processes are more appropriate. In this paradigm, models assume a leading role in the software development process, going from being contemplative entities to becoming productive entities from which implementations are automatically derived. In this context, the inclusion of haptic technologies in the design of awareness applied to collaborative systems must be addressed.

CSSL 2.0 (Collaborative Software System Language) Bibbo et al. (2022); Bibbo (2022) is an extension of UML to support Model-Driven Software Development of collaborative applications. Among other design decisions, CSSL lets the designer model awareness features attached to activities, tools, and workspaces. A CSSL model indicates which events trigger the Awareness update.

To provide more flexibility and readability to CSSL, different concrete syntax are offered, each of them supported by a specific editor (called CSSL Tool Bibbo (2022)). The CSSL Tool offers different views of the same model. Each of them is graphically edited with a specific editor. All the editors were built using the Sirius project from Eclipse [1]. Sirius is composed of a set of Eclipse editors (diagrams, tables and trees) which allow the users to create, edit and visualize models (CSSL language in this case) [2]. Based on a viewpoint approach, Sirius allows the user to work with different approaches to the same design. All these tools are useful to describe different aspects of the same system from different points of view, for example the structure, the dynamics or the awareness design and so on. Both, the CSSL language metamodel and the editors are available on GitHub Bibbo (2023).

The **System Structure Editor** allows the designer to create and connect the main components of the system (Activities, Roles, Tools, and Spaces). **The System Roles Editor** allows the designer to configure the roles involved in the system and which operations are assigned to them. The **Process Diagram editor** is used to describe collaborative activities that make up each process and in what order they are executed are displayed. Finally, the **Activity Diagram Editor** allows the designer to specify the states through which a collaborative activity goes (Activity Protocol).

All these editors can display different types of awareness that are updated by events that occur in the system. Transformation tools then interpret the models created with CSSL, and as a result, executable applications are obtained. The work described in the present article extends CSSL and CSSL Tool to support multimodality in awareness.

[1] https://www.eclipse.org/sirius/SiriusTool

[2] https://www.eclipse.org/modeling/emf/

4 A language for haptic awareness features

The tactile experience can be organized into three categories: discriminative, affective, and social Linden (2016). Discriminative touch refers to the ability to perceive and distinguish different tactile characteristics, such as the shape, size, and texture, among others, of the objects we touch. This information is processed by the sensory areas of the cerebral cortex and allows us to identify and recognize objects through physical contact with them. Affective touch refers to the ability to experience emotional sensations related to physical contact with other people or objects. For example, hugging a pet or holding a loved object can be perceived as comforting, trigger pleasant or unpleasant emotions, produce comfortable sensations in other parts of our body, etc. Social touch, on the other hand, refers to the social and cultural importance of physical contact in interpersonal relationships. The ways in which we touch ourselves and the ways in which we allow ourselves to be touched can be influenced by cultural norms and values and can have a significant impact on our relationships with others. For example, in some cultures, physical touch may be seen as a way of demonstrating affection or intimacy, while in others, it may be seen as inappropriate.

The kind of tactile experience the user can experiment with by getting the awareness information through the tactile modality is much closer to affective and social touch than to the discriminative category Eid and Al Osman (2015). For example, in the scenario of a hybrid classroom environment Triyason et al. (2020) (see Section 6 for details), it will be important for the teacher to be able to feel and recognize the stimuli received but fundamentally to associate them in a meaningful way with the type of social communication that is to be transmitted (“Hi Prof, I want to log in”; “Goodbye Prof, I’m leaving the class”; “Prof, I’d like to ask a question”; “Hey prof, I’m still waiting to ask”).

Looking for inspiration in using the affective and social touch for collaboration, we will rely on the work by Lahtinen Lahtinen (2008). Lathinen describes how to convey and describe the transmission of messages on the body of another person by touch based on two constructs: haptemes and haptices.

Hapteme refers to the smallest distinguishable unit of touch information. It is similar in concept to a phoneme in verbal language, which is the smallest unit of sound that can change the meaning of a word. In haptics, haptemes can be considered the building blocks of touch, combining to create more complex and nuanced touch experiences. For example, different haptemes can be used to convey different emotions or sensations through touch, such as warmth, pressure, and vibration.

Haptices are defined as messages shared by touch on the body. A haptice consists of one or more haptemes. For example, a vibration hapteme can be recognized by its duration, frequency, amplitude, etc. Haptices include sharing a personal body space, meaningful tactile contact, context and the use of different communication channels. Social body space includes the areas of the body involved in sending and receiving haptices. Haptices can be used to share multidimensional meanings. With the training in the use of haptices, the areas of the body used for perception become larger, and the perceivable movements become smaller. Haptices are divided into categories, which include: confirmation system, rapid social messages, body drawing, contact with people and environment, guiding and sharing artistic experiences through movements Lahtinen (2008).

Therefore, our language proposes using haptices for each awareness event that the designer proposes through the tactile modality. To design each haptice you have two type of elements: a set of predefined haptemes that the designer can customize both on design time or implementation time, and pauses. The haptemes are inspired by the proposals of tactons or tactile icons Brown et al. (2005); Hoggan and Brewster (2007). That is, each one of them corresponds to a specific vibrotactile pattern easily differentiated by its envelope and that can be adjusted in one or more parameters. The envelope of a signal is the imaginary curve that delimits it. This envelope contains useful information for the hapticians. It conveys affective meanings (an ascending ramp is associated with greater urgency or increasing arousal, a peak with confirmation of actions, etc.)Yoo et al. (2015). A pause is the time that elapses between the execution of one hapteme and the next.

Haptic rendering is the modeling and presentation of tactile stimuli to the user. Three approaches are commonly used for rendering: a mathematical and physical model of a real phenomenon Salisbury et al. (2004), the extraction of patterns from a large data set Kuchenbecker et al. (2011) or the design of effects perceptually meaningful for users Seifi et al. (2015). The proposal presented in this work is based on the latter approach.

In this initial version of the language for haptic awareness, our extension to CSSL includes four simple haptemes that can be combined together into different haptices to deliver awareness of task, presence, and people (state or location). Haptic actuators, usually available in mobile devices, game controllers, etc. are Eccentric Rotating Mass DC Motors (ERM). However, they are progressively being replaced by Linear Resonant Actuators (LRA) or Piezoelectric devices (see Basdogan et al. (2020), for a review). ERM devices usually offer a low resolution of an effect, among other things, because it is impossible to manipulate the amplitude and frequency of vibration separately. However, this resolution is enough to provide a basic catalog of distinguishable patterns Poyraz and Tamer (2019). Several studies have shown that up to seven vibrotactile icons can be easily recognized and learned even in the presence of other modalities Chan et al. (2008). Therefore we have decided to include in this first version of our language only four clearly distinguishable haptemes to facilitate modeling with low-cost prototypes.

The haptemes available in this version and their parameters are presented in Table 1. Plateau provides a ”flattened” stimulus, with a vibrotactile pattern of constant intensity from start to finish. Hill is a short stimulus with a vibrotactile pattern that starts and ends with the same intensity (extreme intensity) and peaks in half the time (top intensity) with a symmetrically curved envelope. Downward Slope provided a pattern with a envelope of decreasing intensity, it starts with the maximum power to be reached (max intensity) and decreases until it ends (min intensity). The Upward Slope provides the reverse pattern of the previous one, the intensity increases until it reaches the maximum in the specified duration. As the table indicates, each hapteme can be parameterized in terms of its duration, the type of curve (for Down/Up), and the number of repetitions (the number of times the pattern should be executed in loop).

The Pause element makes it easy to create haptices that are not just a juxtaposition of haptemes. A Pause represents the time that elapses between the completion of one hapteme and the beginning of the next. This lapse can be expressed in negative terms, whose semantics is that there is a temporary overlap in the execution of two successive haptemes. This inclusion provides two options to the designer: build richer haptemes and define haptemes of haptemes. First, using these negative pauses, an haptician can define much richer envelopes, adjusted to the design need (see Figure 1). Also, the possibility of establishing perceptible positive Pauses between sets of haptemes allows the elaboration of ”longer tactile utterances” and increases the semantic potentiality of the language.

5 Introducing haptic awareness in groupware models

Developing groupware is not an easy task Grudin (1988). Traditional approaches in software development processes, mainly based on coding, do not facilitate the modeling and development of this kind of system. Often, there is no clear documentation of design decisions taken during the coding phase, making the evolution and maintenance of the systems difficult. Also, models and diagrams created in the early stages quickly lose their value as coding progresses. Model Driven Development (MDD) paradigm seems to be a good fit Molina et al. (2014, 2016). Here we use the CSSL language that adheres to the MDD paradigm. In this way, graphical models of the system can be created and then used as a source to obtain executable versions. In this case, the models guide the development and future improvements to be made to the system.

CSSL allows modeling the system in both its static and dynamic aspects with different integrated views so that any modification in one of them triggers corresponding changes in the others. For example, the Structure Model Editor allows displaying the relationship between the main components of the system, such as workspaces, activities, roles, and collaborative tools. The dynamic aspects of collaborative systems are modeled with the Process Model Editor and the Protocol Model Editor. These allow describing how the system will behave when users are collaborating. With the first, the order in which the activities are executed is described, and with the second, the actions that the roles can perform at each moment are modeled. In this way, the states through which the activity passes and which operation (or event) triggers the state change are described.

Let’s imagine a Hybrid College Classroom scenario (see

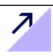
Hapteme	**Plateau**	**DownwardSlope**	**UpwardSlope**	**Hill**
Envelope	Square	Downward slope	Upward slope	Symmetric
Parameters	Duration, intensity, repetitions	Duration, Max/min intensities, repetitions	Duration, Min/max intensities, repetitions	Duration, top intensity, extremes intensity, repetitions
Icons				

Table 1. Haptemes included in this work

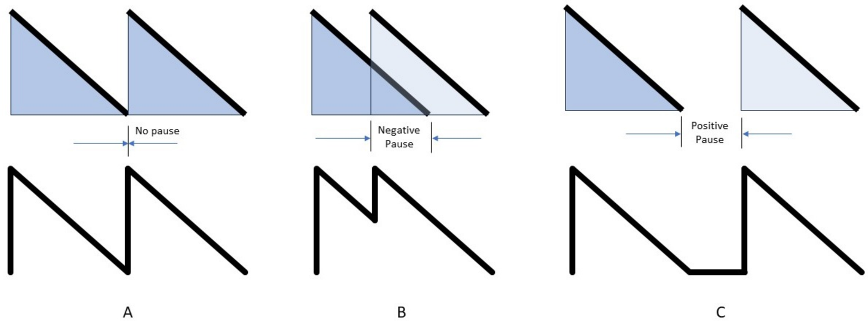


Figure 1. Haptemes composed of two Downward Slopes: a) With no Pause between them; b) With a negative Pause duration that allows the second Slope to be executed before the end of the first one and generates two close stimulation peaks within a continuous envelope; c) With a positive pause, that moves the stimulation peaks away and allows each haptice to be clearly perceived

Figure 2). Slides are projected onto a screen from a local computer. At the same time, that computer (or another one) allows the teacher to open the video conference call, give access to remote students and share the presentation with them. A microphone system sends the audio to the videoconferencing system to facilitate listening to the remote students. The remote attendees' camera window is viewed on a second computer monitor or, if available, can be projected onto another screen.

Figure 3 depicts a System Structure model in CSSL. Gray squares (a) represent collaborative activities; there is only one activity in the model: Class. Green squares (b) represent groupware collaboration tools (audio-visual). Pink Squares (c) represents collaboration tools with a haptic display; there is one tool with this display. Blue circles (d) represent Roles. Orange circles (e) represent spaces; there is one space in the model: HybridClassroom.

To specify awareness functionality, the designer connects the events of interest to the collaborative element in which the occurrence of those events should be depicted. This is done via the awareness functionality boxes in the model. A box (f) representing an awareness element has two areas. The top of the box provides a name for the awareness functionality. The lower part of the box lists the events of interest. The arrow connecting an awareness functionality box to a tool, space, or activity indicates where such awareness should be communicated.

Awareness functionality boxes can be decorated to express additional conditions for providing awareness. A satellite dish decorator, for example, indicates that the awareness is online. A datastore decorator indicates that the given awareness functionality should be made persistent. A cloud decorator indicates that the awareness is volatile.

A special editor to configure the awareness also allows specifying the order in which the haptemes and pauses are chained. The haptemes and pauses are added graphically to the awareness configuration as shown in the Figure 4. In the lower part of the figure you can see how the duration and intensity of the repetition of the ”Plateau” hapteme is configured.

By designing dynamic aspects with CSSL, such as processes or protocols, we can include awareness configuration. For example, Figure 5 shows the specification of an interaction protocol for the “Class” activity. The class is divided into two states. First, when the teacher makes a “presentation” of the topic and then when the students can discuss (discussion) using the chat and the shared whiteboard. Operations that the roles can execute allow switching between these states. The example shows the “DiscussionTime” awareness that is triggered by the onStart and onFinish events of the “Discussion” state. This awareness will be displayed in the “classroom” as shown in Figure 8 at the end of Section 6.2.

CSSL was extended to model haptic awareness by following the language proposed in Section 4. To introduce haptic awareness in a model, the designer has to specify that the target device has support for displaying haptic effects. The bottom panel of Figure 3 shows how to configure the haptic display of the tool. The purple rectangle labeled HapticBracelet in the figure represents a haptic feedback tool, the haptic bracelet, and it is an abstraction of a concrete hardware device. The haptic bracelet in this model can later be implemented as an ad-hoc bracelet or as a smartwatch with haptic feedback functionality.

Besides indicating which events should trigger haptic feedback in a haptic tool, the designer can express the nature of the expected haptic stimuli. The designer can do so via decorators and specific configurations. Currently, the available decorators correspond to the four atomic haptices presented in Section 4. In addition, each haptic decorator offers certain configuration possibilities (e.g., the plateau decorator can be

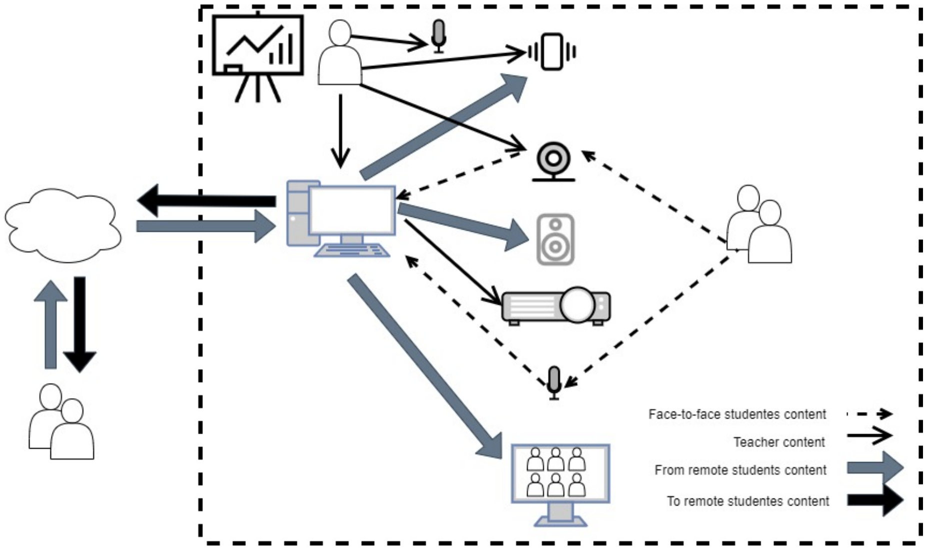


Figure 2. Hybrid classroom layout, based on Triyason et al. (2020), including haptic interaction modality for the teacher

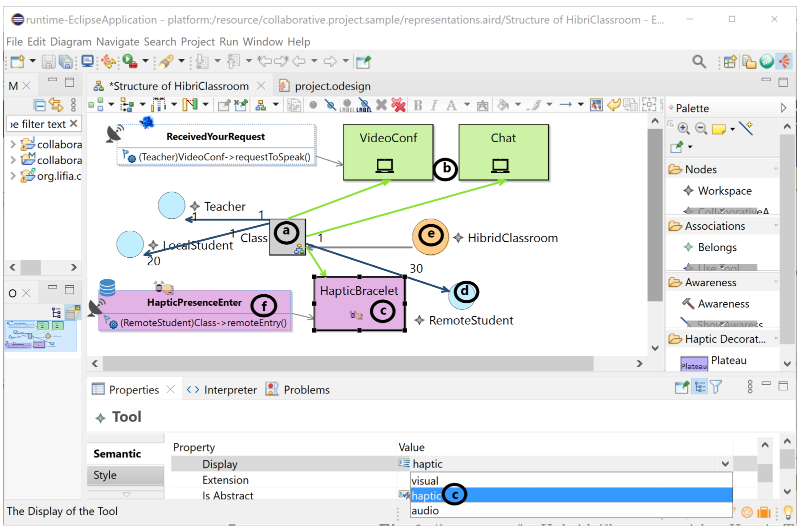


Figure 3. Structure of a Hybrid Classroom with a Haptic Tool

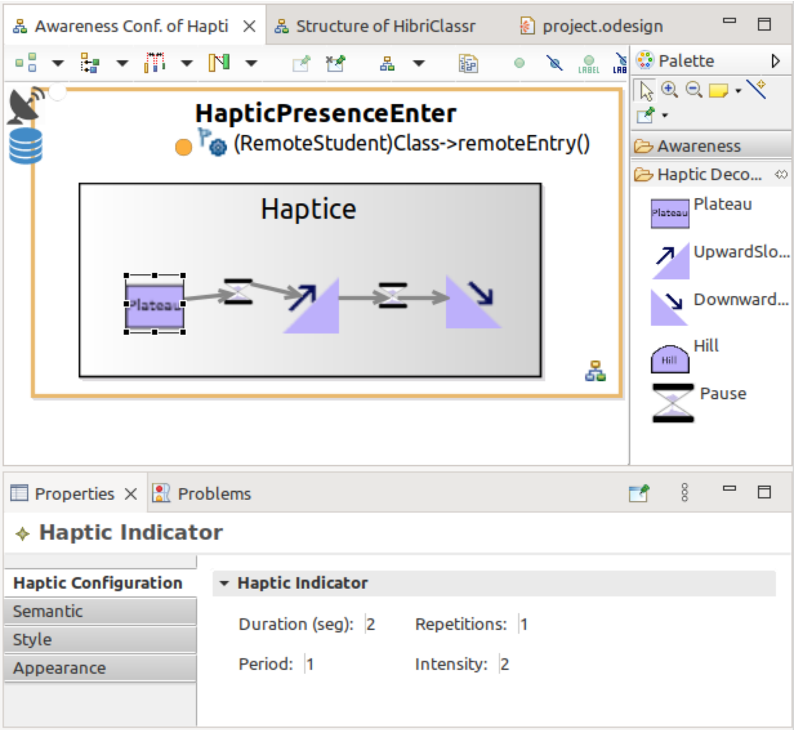


Figure 4. Haptice Configurator for Awareness

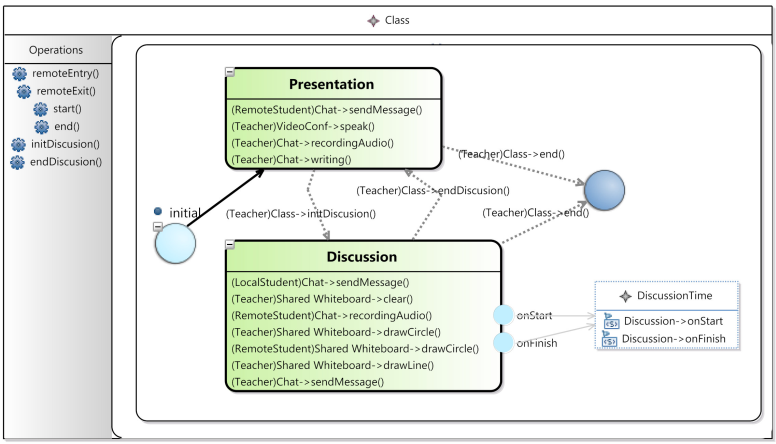


Figure 5. Model of Activity Protocol with Awareness

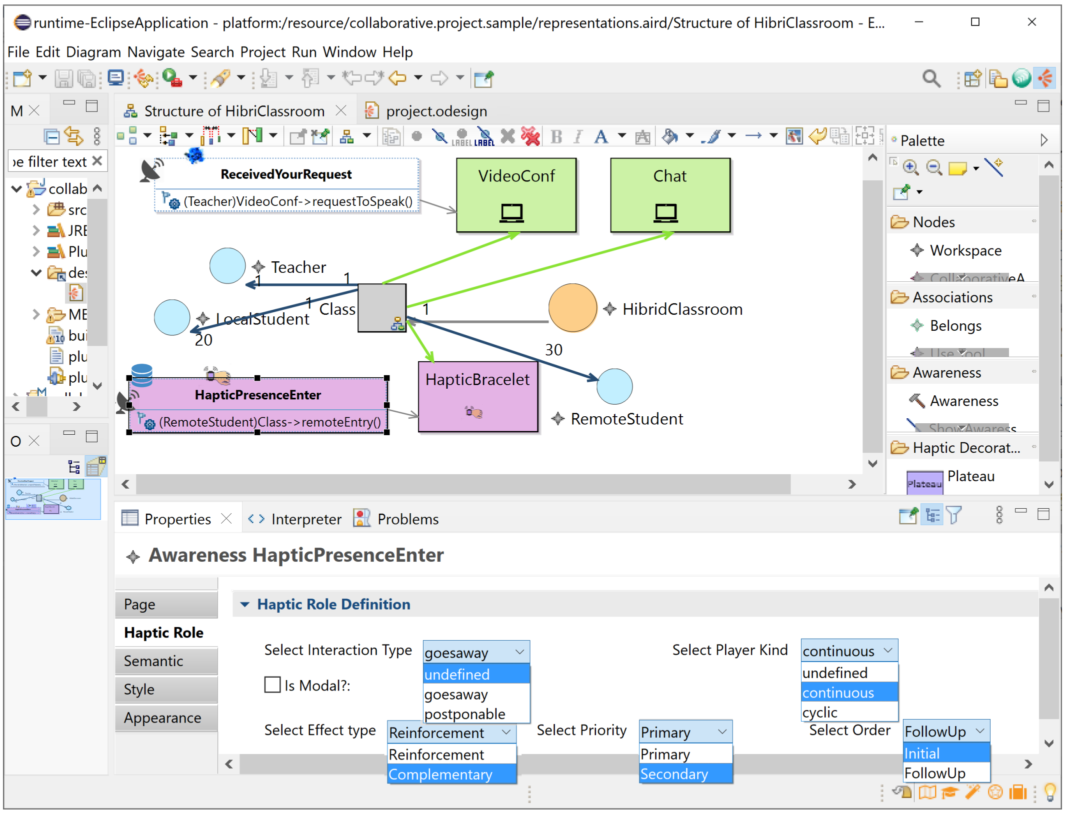


Figure 6. Adding Haptic Awareness to the Model

configured with duration, intensity, and repetition), which can be set via configuration forms.

Haptic decorators can be combined with other decorators to indicate whether the awareness is synchronous or not and whether it is persistent or transient. Moreover, you can define whether the awareness is modal or not. In addition, you can define the type of interaction of the haptic awareness (undefined or goesaway or postponable), which means describing how the recipient of the awareness notification should react. When awareness is defined as *"postponable"* it means that the user can postpone the notification. If the awareness is defined as *"goesaway"* it means that the user does not have to do anything for the notification to go away. In addition, it is possible to describe characteristics of the awareness reproduction (undefined or continuous or cyclic); if it is *"cyclic"*, it means that the awareness is repeated every certain period of time, while if it is defined as *"continuous"* the awareness will be reproduced until the user decides to stop it. All haptic awareness configurations are shown in Figure 6.

In multimodal interfaces, haptics can play different roles in relation to the other modalities in the device MacLean et al. (2017). There are three possible groups of roles for haptics to be included in multimodal interactions: firstly, a haptic signal can work with other senses to provide reinforcing information about the same concept or complementary information about another (effect type); haptics can also be defined as the primary stimulus or secondary to another signal (priority); finally, a haptic signal can present an easy-to-process initial notification with low information density, then the user can continue to refer to a visual modality for more details at a better time. Alternatively, the action can be followed by a confirmation (order) (see Properties panel at Figure 6).

6 Evaluation

Ledo et al.Ledo et al. (2018) surveyed the evaluation methods employed by researchers for design toolkits in HCI and found that the most reported method is "Demonstrations". A demonstration shows what the toolkit can support and how users can work with it. The goal is to use examples and scenarios to clarify how the toolkit's capabilities facilitate the proposed applications. Demonstrations can use individual examples (new or replicated), collections (case studies, design space explorations), or "how to" scenarios.

The goal of our work is to streamline the inclusion of the haptic modality in the MDD toolbox for CSCL with awareness. Therefore, we approach the validation of our proposal by demonstrating the design space it enables. For the demonstration, we structure the design space by two dimensions. One dimension is the taxonomy of awareness presented by Collazos et al.Collazos et al. (2019). They define three basic components for getting awareness information in collaborative systems: people, tasks, and resources. For the scope of this article, we will concentrate on the people component. The other dimension is composed of the different roles that haptics can take in multimodal interaction MacLean et al. (2017): Effect type (complement or reinforce), priority (primary or secondary signal), order (initial or follow-up). We base the exploration of the design space on the "hybrid college classroom" scenario strongly driven by the COVID-19 pandemic, as presented by Triyason et al.Triyason et al. (2020).

6.1 The Hybrid College Classroom Scenario

We introduced the Hybrid College Classroom scenario in Section 5. In this context, the teacher must be attentive to the activity of the student in the room, to the projection of their slides, and, in addition, to the information coming from the video-conference system (images and audios of remote students, their arrivals and departures, as well as requests for participation). The teacher could wear a device (i.e. a bracelet) that generates vibrotactile signals to fill specific needs for awareness. Therefore, we can consider the following Use Cases (UC):

- **UC1 - Remote login:** When a student enters the physical classroom, the teacher can see him walking through the door. For remote students, he may enable the waiting room and may need a strong "student-in-waiting" alert to enable him access to the class (for example, for late-coming students).
- **UC2 - Remote leaving:** Similar to Remote login, but for the case that a student leaves the virtual session (what can be purposeful or just due to connectivity issues)
- **UC3 - Raised hand:** When a student in the classroom wishes to speak, it is not difficult for a glance at the teacher to be sufficient to do so. On the other hand, those who are remote can use the "raise hand" functionality but require the teacher to be watching the projection to detect it.
- **UC4 - Chat comment:** When a remote student sends a chat message, only a constant visualization of the screen allows that message to be detected at the moment.

Following, we discuss each use case in turn, showing how the proposed approach supports the designer. These four user cases offer adequate coverage of the design space. As depicted in Figure 7, they cover the people dimension of awareness and also offer adequate coverage in terms of the haptic roles they enable.

6.2 Discussion of the use cases

The next paragraphs discuss, for each use case, the modifications that the designer introduces to the System Structure model. Figure 8 presents the resulting model.

UC1 - Remote login: This case requires obtaining Person-Location (remote) and Person-Activity (requires login) information. The disruptive ability of the haptic modality to immediately capture attention Zhang et al. (2016) can be useful in support of visual information, especially for cases where students enter with the class already started. The use of vibrotactile effects, immediately perceptible to the teacher, without the general distracting effect of an audible alert, can facilitate the necessary response. In this case, the designer adds a class called HapticBracelet and decorates it with an haptice (HapticPresenceEnter) integrated by two haptemes: an UpwardSlope followed by a Plateau. The haptice initiates when the student requests entry and works as a reinforcement of the alert box on the screen (visual modality).

UC2 - Remote leaving: This second use case is very similar to the previous one, requiring the same awareness information sources. Now, the designer decided to use the same combination of modalities, so he added a new decorator to the HapticBracelet called HapticPresenceExit. However, the haptice will start with a Plateau, ending with a DownwardSlope (usually associated with an event completion Seifi et al. (2015)). The haptice will be included as a secondary signal of the alert box that stays on the screen until the teacher closes it.

UC3 - Raised hand: This use case primarily involves Person-location and Person-activity information. Face-to-face students that are present in the classroom can be introduced to the dialogue with the teacher in several ways. Sometimes, they may raise their hands and wait to be allowed to speak. But in many cases, the teacher's nonverbal language or silence will implicitly enable a quick intervention. This case is not so simple to handle for the case of remote students when transmission delay can cause silence in the classroom to be perceived by remote students when someone has already begun to speak. Therefore, it is common to use the "raise your hand" protocol indicated by a command in the videoconferencing platform. It is often the case that more than one student requests the floor. Then the designer decides to use the haptic modality in conjunction with the visual icon on the screen of the raised hand, but now as a complement to that information. The pattern decided upon can be a chain of Hills, which will not cease unless the teacher deactivates them and whose frequency and/or duration will grow proportionally to the number of students requesting to speak. Therefore, a third decorator for the HapticBracelet, called HapticRaisedHand, is added with the haptice described. In this way, the teacher will have at his disposal the information by visual modality. Still, the haptic modality will complement it with a signal that not only indicates that someone is requesting to speak but, in a way, associated with its intensity or pattern also indicates that others have joined that request.

UC4 - Chat comment: This last use case involves knowledge of People-location (remote), the People-action (writes in the chat), and the Task-status (persists). Chat is a form of a conversation held in parallel to the lecture, one-to-one or one-to-all. The use of the haptic modality, in this case, can help facilitate the directed conversation between teacher and learner. The designer then adds a fourth decorator (HapticNewChatMessage) with the haptice used for the previous case. Still, now it will be issued after the presence of the message in the chat box (secondary signal), complementing the visual modality to follow up on the request.

7 Conclusions and future work

Multimodal interfaces have become the dominant computer interface worldwide. Increasing developments in haptic interfaces, both in available hardware and in the necessary software infrastructure, have facilitated the entry of this modality into new UIs.

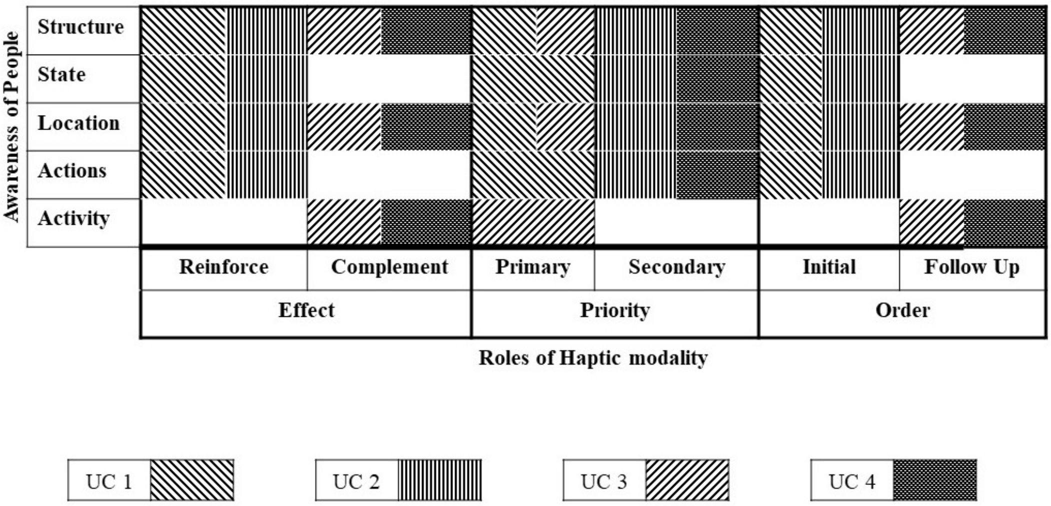


Figure 7. Design space (Haptics modality role vs Awareness of People) and coverage provided by the Use Cases

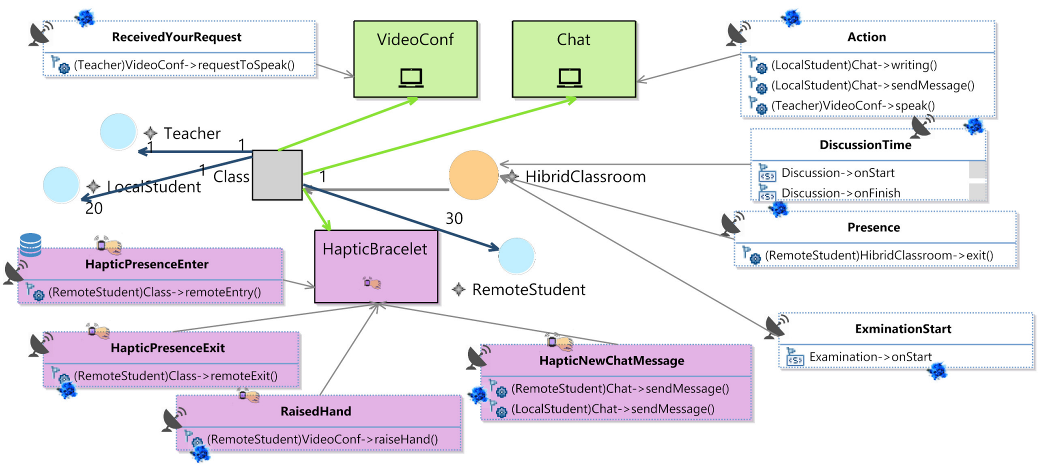


Figure 8. Model of Hybrid Classroom with haptic awareness

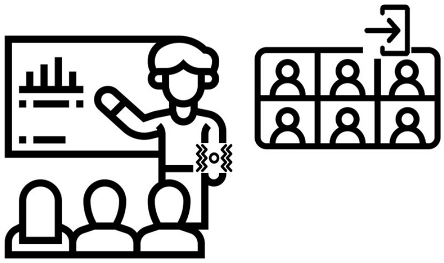


Figure 9. Use Case 1. Remote login

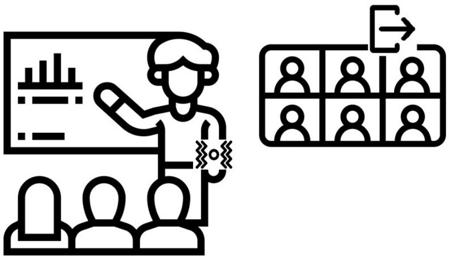


Figure 10. Use Case 2. Remote leaving

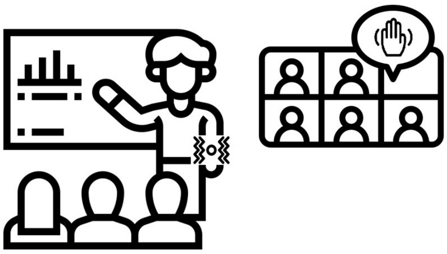


Figure 11. Use Case 3. Raised hand

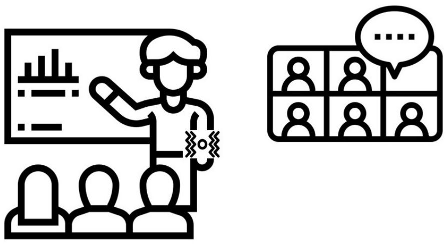


Figure 12. Use Case 4. Chat comment

To contribute to the incorporation of haptics in this multimodal scenario, in this paper, we have presented a tactile event language as an extension of the CSSL language that allows the inclusion of haptic awareness events in Collaborative Systems. Our language is based on the idea of haptices and haptemes Lahtinen (2008) and takes advantage of the MDD paradigm to facilitate the conception of awareness events at design time, considering the best contributions of the available modalities as appropriate.

As an extension of CSSL, Section 6 presented the demonstration of four use cases for a feasible hybrid classroom scenario that can be satisfied with our extension. Using the presented haptices and haptemes language, the practitioner can manage at design time the flow of modalities according to the convenience of each use case, establishing the characteristics of the appropriate vibrotactile stimulus and the role of this modality in relation to the other intervening ones. As it has been stated among the requirements of haptic experience design Schneider et al. (2017), the subsequent work at derivation and implementation time will allow adjusting the stimulus parameters to the technology actually available, distributing among multiple actuators, etc.

As future work, we plan to extend the catalog of haptices included in the language, conduct user experiments to fine-tune the parameterization of the included stimuli, and extend the CSSL editing tool to extend the options for integrating modalities into an application. Moreover, to better understand the applicability and particularities of haptic feedback to provide awareness, we will conduct a study focused on frequently used awareness displays such as the radar view, the participant's list, and the telepointer.

CSSL is a groupware modeling language for groupware motivated by model-driven design. This motivation impacts the granularity and specificity of the models. Collaboration engineering is an approach to the design of collaboration processes. It works at a higher abstraction level than CSSL. The core construct of collaboration engineering is the Thinklet, which is a reusable collaborative activity. Thinklets are combined and connected to conform processes that can be graphically represented. It remains a question for future work if (and how) the strategy we propose in this article to model multi-modal awareness can be combined with collaboration engineering. Moreover, it is also a question for future work if, and how, the models proposed in this work can be used without the support of specific editors (for example, in pen and paper based design workshops).

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