Knotation: Exploring and Documenting Choreographic Processes

Marianela Ciolfi Felice **Sarah Fdili Alaoui** **Wendy E. Mackay**
LRI, Univ. Paris-Sud, CNRS,
Inria, Université Paris-Saclay
F-91400 Orsay, France
{mciolfi, saraloui, mackay}@lri.fr

ABSTRACT
Contemporary choreographers often interact directly with dancers when exploring their ideas, but lack adequate tools for capturing and documenting their work. Although our first study of choreographers and dancers revealed diverse strategies for recording choreographic fragments, we found that they *all* worked in terms of constraints, which they represented via spatial diagrams, as movement qualities or with their own personal notation system. This led to the design of *Knotation*, a mobile pen-based tool that lets choreographers sketch their own representations of choreographic ideas and render them interactive. In study two, *Knotation* served as a technology probe to support the contrasting practices of three professional choreographers. We revised *Knotation* based on their input, and ran a third structured observation study with six professional choreographers. *Knotation* easily supported both dance-then-record and record-then-dance strategies. Participants used and appropriated *Knotation*'s advanced features, including the combination of interactive timelines and floorplan diagrams, to represent and explore complex choreographic structures.

ACM Classification Keywords
H.5.2 [User Interfaces]: Evaluation/methodology, Prototyping, User-centered design

Author Keywords
Choreography; Creativity Support; Technology Probes; Sketch-based Interaction; Pen-based Interaction; Tablets

INTRODUCTION
When creating a dance piece, choreographers start from a particular stimulus, from which they develop a generative idea to explore [38]. From this point on, each path is unique, with nearly as many approaches as professional choreographers.

CHI 2018 April 21–26, 2018, Montreal, QC, Canada
 ISBN 978-1-4503-5620-6/18/046…$15.00
DOI: https://doi.org/10.1145/3173574.3174022

The choreographic creative process is both interactive and iterative: Schiphorst et al. [38] describe how each choreographer "*interacts with the idea, shaping it and being influenced by it, in a cyclic evolutionary process.*"

Our previous study [12] of contemporary choreographers found that, even though each choreographer's creative process is unique and changes over time, they all define *choreographic objects*, which represent their ideas at different levels of abstraction, and combine them with *operations*, such as reordering elements and establishing transitions. Choreographers explore these concepts in their minds and with the dancers' bodies, but also generate artefacts, including inspiring images, annotated sketches, and video clips of dance fragments.

Choreographers lack a common method for representing dance. Instead, they rely primarily on their individual and collective memory to link their ideas and document their work. Formal systems such as Laban [30] or Benesh [4] notations are used mostly by big dance companies who can afford a full-time notator. Contemporary choreographers rarely use these systems, because they are designed to document finished work and are cumbersome to deploy, thus not suitable for early exploration phases. According to Heyward [25]: "*Dance notation is arcane, and mostly inessential to the art of dance.*" Choreographers often capture intermediate phases of their work with video. However, few incorporate interactive technology as a fundamental part of their creative process, even those who use motion capture or interactive sound and visuals as part of their work.

We are interested in designing interactive digital tools that support both idea exploration and early-stage documentation for choreographic composition. We first review related work and then report results of a day-long observational study of dancers and choreographers. We introduce *Knotation v1* and present a study of three choreographers who used it as a technology probe [27]. We then describe *Knotation v2* with our findings from a structured observation of six choreographers. We conclude with directions for future research.

RELATED WORK
A variety of tools have been created to support augmented sketching for design, education and general-purpose note-taking. In the context of choreography, researchers and practitioners have introduced new technologies to augment, annotate and archive choreographers' final work.

Augmented sketching and note-taking

Among the extensive research in augmented sketching and note-taking, we focus on tools that let users add personal meaning to their sketches and notes, especially those that render sketches interactive, either through explicit actions by the user or by recognising objects from the user's strokes.

Some tools focus on helping designers specify and refine their design ideas. *SILK* [31] lets designers sketch user interface elements with a pen or a mouse, for example, drawing a scroll bar that they can then interact with. Similarly, *DENIM* [32] is a pen-based system that supports early-stage web design. Web designers can sketch different interface components and transform them into working prototypes. *DEMAIS* [1] is a pen-based desktop tool that lets designers sketch interactive behaviour and generate interactive storyboards, which they can edit with a dedicated visual language. Gross and Do's [23] pen-based system captures the vagueness and intended ambiguity in diagrams, in the context of creative design.

Moran et al.'s [33] pen-based techniques and Mynatt et al.'s *Flatland* [34] are among the earliest attempts to augment whiteboards, allowing office workers to organise notes and other information during meetings. *Livenotes* [28] was designed as a collaborative augmented note-taking tool for the classroom. A more recent example, *InkAnchor* [36], is a pen-based tool for informal note-taking with a mobile device. *InkSeine* [26] explored a pen-based approach for *active note-taking*, supporting searching and the incorporation of multimedia files.

We are particularly inspired by projects designed to support artistic practices such as contemporary music composition. For example, both *Musink* [42] and *Paper Composer* [21] let composers explore their ideas on interactive paper, using Anoto technology[1]: They can create personal musical symbols, notations and structures and link them directly to music composition software. *Knotty Gestures* [43] offers a minimalist technique for adding mathematical functions, audio and video recordings as well as other features to hand-drawn notes and sketches. Users simply draw a tiny circle or *knot* on any line, and select the desired function from a menu on an Anoto Livescribe pen. Although these and other related systems offer interesting possibilities, none are fully applicable to choreographic practice, which must capture movements of one or more dancers as they move through space over time, according to the underlying principles specified by the choreographer.

Augmenting the choreographic process

Professional choreographers and researchers explored new technologies to achieve various goals, including generating movement material and interacting with existing movement vocabularies. (See Fdili Alaoui et al. [19] for an extensive overview of systems that support choreographic composition.) One of the most well known is *LifeForms* [38, 7], designed in 1990 for the choreographer Merce Cunningham. He could select various body postures to simulate dance movements that could be combined to create new dance sequences.

More recent tools include *iDanceForms* [8], which generates new movements using a camera still frame technique, and *Scuddle* [9], which uses genetic algorithms to trigger unfamiliar and thus novel movement choices. The *Choreographic Language Agent* [11] provides a programming environment for exploring mappings between geometric visualisations and movement in the studio. Instead of prompting dancers with specific movement directions, dancers must solve generated choreographic problems by creating new movements.

Some technology supports dancers *during* performances. Hattwick et al.'s [24] family of digital musical instruments are worn as prosthetic extensions to dancers' bodies, influencing both their movements and the resulting music. Fdili Alaoui et al. [18], together with the dance company Emio Greco|PC, created an interactive installation that incorporated visualisations of movement qualities developed by the company during their *Double Skin/Double Mind* workshop. Each of these interactive technologies can serve as a stimulus during the creation phase or for the final performance. Although they offer users with new choreographic possibilities, each was designed to support a particular choreographic approach or idiosyncratic vocabulary. The challenge remains: How can we design tools that support a wide range of choreographic practices?

Annotating choreographic artefacts

Today, most choreographers rely on a combination of paper sketches and video to capture their choreographic decisions. The *Creation-Tool* [6] runs on a tablet PC and is intended for use during rehearsals. The choreographer can record video of dance sequences, and annotate them with voice and hand-written notes. *The Choreographer's Notebook* [40] offers similar functionality with a collaborative web-based tool. Choreographers and dancers can annotate video outside of rehearsals, which lets them conserve scarce resources. They can also document their choreographic process and revisit earlier choreographic choices. *Rekall* [2] is an on-line platform for the performing arts, where users can gather a variety of artefacts about a production (e.g. video, pictures, audio), organise it, annotate it, and compare it with other productions. This not only allows artists to preserve their work, but also enables researchers to identify patterns across multiple productions. Although each of these systems lets choreographers and dancers assemble and annotate their sketches, images and videos, none offers choreographers a higher level representation of the choreographic objects they develop for each piece.

Archiving Choreography

A major challenge is how to capture a choreographer's finished work, so it can be archived and performed even after the choreographer is gone. Multiple initiatives have been launched to preserve contemporary choreographic knowledge, including *Motion Bank*[2], *IMK*[3], and Siobhan Davies Dance's *Digital Archive* [17]. The *Synchronous Objects* [35] project provides on-line interactive documentation of William Forsythe's *One flat thing, reproduced*, including interactive visualisations that

[1] The Anoto pen's camera captures gestures on paper printed with a computer-readable, human-invisible dot pattern. (*www.anoto.com*)

[2] www.motionbank.org

[3] insidemovementknowledge.net

play with specific choreographic elements, such as counterpoint, that inspire choreographers to generate new material. Both *Synchronous Objects* and Forsythe's DVD *Improvisation Technologies* [20] – which includes visualisations of Forsythe's vocabulary and material – were created from annotations, with the goal of documenting and reflecting on choreographic structures, such as alignment and cues between dancers.

Emio Greco|PC's DVD *Capturing Intention* [16] documents choreographic material from the company's *Double Skin/Double Mind* workshop, using descriptions, Laban and Benesh notations, demonstrative video clips and sound material. Ribeiro et al. [37] used 3D data capture to document choreographer Joao Fiãdeiro's choreography, and worked with him to derive a set of *concepts* that later guided improvisation sessions and influenced visualisations of his creative process.

These systems focus on documenting the final outcome of a particular choreographer's work, and, sometimes, the idiosyncratic nature of the choreographer's individual creative process. We seek a more general approach that supports diverse choreographers, with diverse approaches, during early exploration and later documentation of the creative process.

STUDY 1: CHOREOGRAPHIC IDEAS ON PAPER

Before designing new tools for choreographers, we need to better understand how they explore ideas *without* interactive technology. We ran an observational study with choreographers and dancers where they captured their ideas on paper.

Participants

We recruited a professional male choreographer with 34 years of experience as the lead choreographer and four of his regular collaborators, all women, including two choreographers, one dance professor, and one dancer.

Setup

We reserved the lead choreographer's normal rehearsal theatre. He had just begun a newly commissioned work, which served as the foundation for the day's activities. We discussed the process with him, and he was free to propose specific exercises and determine the roles of the other participants. He decided that each dancer would create her own choreographic fragment individually. Together, we chose a set of activities that fit into his established work practice, while also providing data we could compare across participants.

Procedure

Each session lasts approximately four hours, including a working lunch break. The *composition* activity involves *composing* a choreographic fragment. The lead choreographer (LC) decides when to stop (approximately one hour). Participants capture the dance fragment on paper using A3 paper, coloured pens, highlighters, stickers, and post-it notes. The *transformation* activity involves *transforming* the choreographic fragment (approximately one hour). Participants choose a set of operations to apply to the fragment. We provide possible operations inspired by the framework in [12], including: *sequence*, *reorder*, *reuse*, *vary speed, rhythm, energy, or spatial patterns*, *define transitions*, *add detail*, and *abstract a choreographic object*, but LC is free to suggest alternatives. When LC asks the dancers to stop, each updates her annotations. Participants are debriefed at the end of the session, and asked for explanations of their annotations from both activities.

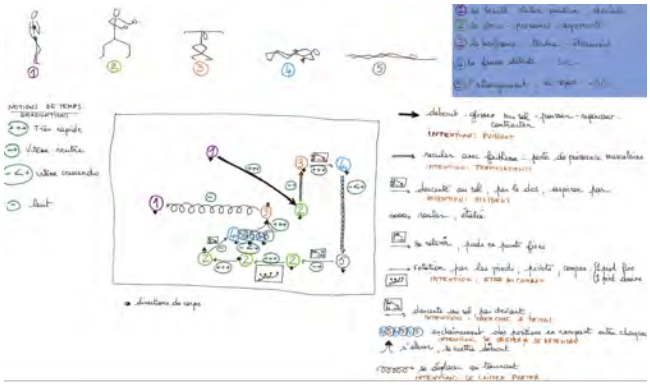

Figure 1. Study 1: Choreographic fragment captured on paper (P3).

Data collection

We recorded video and audio of the session and took pictures and hand-written notes.

Data analysis

We analysed our notes, photographs, videos, and participants' explanations of their annotations to identify which aspects of the choreographic fragments they captured and how they were represented. We looked for both common patterns and unique annotation practices.

RESULTS AND DISCUSSION

The LC brought images as a creative stimulus and showed participants a set of eight words to inspire sculpture-like body postures, with the constraint of finding linear, fluid transitions between them. He asked each participant to create her own choreographic fragment. During the *composition* activity, each participant performed her choreographic fragment in turn, based on the LC's directions. During the *transformation* activity, the LC asked participants to focus on *repetition* as a key operation for transforming their fragments. One participant joined the session late, when the others were about to annotate their fragments, so she captured hers without dancing it first. The LC remarked that writing the movement had an impact in the way she moved, *"especially in the use of space and orientations"*. Interestingly, the LC only took notes about the fragments while the participants were performing.

Choreographic objects

As in [12], we found that all participants represent their choreographic ideas by defining *choreographic objects* at different levels of abstraction and detail, which they illustrate with a combination of sketches, text, symbols, and diagrams. For example, some participants drew floorplans (diagrams that represent spatial trajectories, as seen from above), focusing on the displacement of the body with respect to the stage. They also sketched different body postures, which let them focus on the details of a particular moment of the fragment (Fig. 1).

Although LC created the higher-level choreographic object (here, the eight sculpture-like postures) the participants all

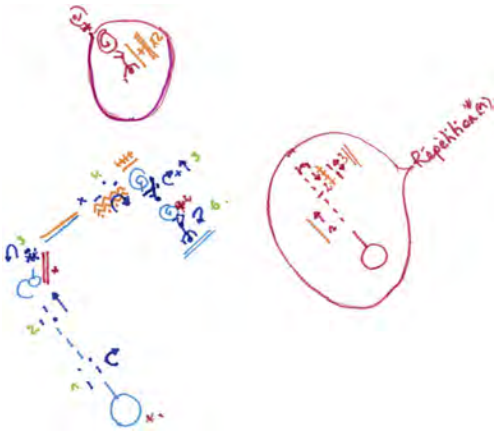

Figure 2. Study 1: P1's fragment with her personal sublanguage.

composed their own individual variations, at varying levels of detail. Their sketches each contained different subsets of choreographic elements. For example, only P2 (dancer) represented movement duration in her floorplan, and only P4 (choreographer and dancer) considered music and lights.

Personal sublanguages

One participant (P1, dance professor and dancer) had already created her own personal sublanguage, which she used to represent movement, including spins and shifts in weight or direction (Fig. 2). The other participants created their own ad-hoc sublanguages during the activity. All four participants created legends to explain their symbols.

Different representations of choreographic objects

All participants annotated movement qualities, i.e. the qualitative attributes and characteristics of movement [5]. For example, P1 and P2 mapped symbols to personally meaningful words: P1 described movements as *"tight - contracted"* whereas P2 used *"uneven"* or *"dented"*. Most participants (3/4) annotated *"movement intentions"*, with differing levels of detail and type of representation (symbols and words). All recorded transition speeds, but in idiosyncratic ways. For example, P4 used words related to speed (e.g. *"very fast"*); others assigned specific symbols. All but one participant (3/4) specified *"levels"*, i.e. the height a movement is performed with respect to the floor, and used symbols, text or both to specify rotation, body orientation, or gaze direction.

All participants created floorplan diagrams for the sculpture-like postures, with transitions among them. Each participant created different line styles to uniquely represent transitions. For example, P3 (choreographer and dancer) added complex symbols representing qualities and intentions for each transition (Fig. 1). Interestingly, although P2 drew lines to show transitions, she left trajectories *"free"*, but constrained movement qualities and *"moments of transformation"*. Her lines indicated movement duration, rather than a concrete spatial trajectory. Diverse techniques for representing postures in floorplans included: numbers (P1, P3), coloured-dot stickers (P2), and crosses (P4). Participants also found diverse ways to draw and annotate postures: P2 specified body part positions with symbols indicating the main movement quality, P3 wrote keywords, and P4 sketched minimalist postures inline with text descriptions.

Participants often created multiple representations of the same choreographic object. P1's posture sketches included a symbol for the main quality, with arrows to indicate gaze direction and the intended movement of each arm and foot. Yet her diagram marked only arm and foot positions, or sometimes a single arm for a particular posture, because she wanted to emphasise that *"it was extended"*. She produced multiple views of the same object, from different perspectives (above versus front), and at different levels of detail (position of the whole body versus arms and feet).

Diversity in annotating operations

Participants found different ways to capture repetition: P1 placed an asterisk next to each repeated part, with a more detailed view below (Fig. 2). P2 either wrote a number to specify the number of times or a symbol to indicate randomness. P3 listed movement sequences, including the number of repetitions (Fig. 1), and P4 created a new diagram that incorporated her modifications of the first fragment, making explicit the changes from her original choreographic objects.

Rules behind the movement

Most participants annotated the rules that constrain and describe the movement in their fragments, rather than the movement itself. In fact, P2 referred to her legend as a *"panel of possibilities"* from which *"it is possible to choose"*.

Summary

We observed considerable variability in how participants represent choreographic objects and operations, even given the same initial constraints (eight words to inspire eight postures, with linear transitions between them). Participants also varied greatly in their choice of which aspects to capture for each fragment. Even so, several common features emerged: All participants specified movement speed and movement qualities; all drew spatial diagrams (floorplans); and all sketched rules and constraints with respect to the movements, using a combination of sketches, personal sublanguages, diagrams, and text.

DESIGNING KNOTATION V1

In previous research [12], we argue that choreographers' tools should support free sketching, integrated images and video, and multiple representations and views of choreographic objects. Choreographers should be able to draw the overall structure of a piece, and transition easily between abstraction and detail. The results of Study 1 suggest that choreographers want to express choreographic concepts in terms of both space and time, and to represent movement in terms of constraints, through combinations of drawings, text and numbers.

Meaning should emerge during the choreographic process: Choreographers must be able to modify the meaning of particular choreographic objects, delay decisions, and freely explore different combinations. Rather than forcing choreographers to follow a particular approach or interrupting their creative flow, our goal is to help them create and interact with their own representations. This follows Shneiderman's design principles

regarding creativity support tools [39], specifically *facilitating exploratory search* and *supporting the generation of multiple alternatives*.

We introduce *Knotation*, which builds on the minimalist approach of *Knotty Gestures* [43] to add interactive functionality to the choreographer's sketches. However, instead of interactive paper, *Knotation* runs on Apple's iPad Pro™, which can be easily brought into the dance studio. Choreographers can incorporate live pictures and video, as well as pre-recorded material. They can sketch, link and interact with their own choreographic structures and notations with the Apple Pencil™. The goal is to provide an open-ended, easy-to-use system that supports the early phases of choreographic exploration and documentation.

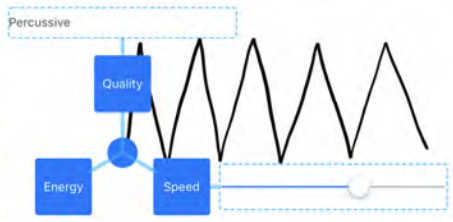

Figure 3. *Knotation v1*: Knot attached to a zigzag trajectory. Tapping the knot reveals three attributes: *quality*, *energy* and *speed*. Here, the knot defines a 'percussive' quality, with a slider to indicate speed.

Everything the user draws with the pen is considered a choreographic object. Users can add functionality to these sketches by placing the pen on the surface and dwelling, which produces a small dot or *knot*. Knots can be created in the flow of writing or drawing, at the beginning, middle or end of any pen stroke. Users can add interactive features by tapping a knot and selecting the desired function. Knots are first-class objects that can be moved, cloned, edited, or deleted.

Knots can have multiple *attributes* (*speed*, *energy*, *unison*, and *quality*), whose values are set via a *controller* (a *number*, a *slider*, or *text*). Fig. 3 shows a knot where the user assigned a text controller to the *quality* attribute and typed *"percussive"*, and added a slider controller to the *speed* attribute. To reduce visual clutter, the attributes assigned to a knot only appear when the user interacts with it.

The user can link a knot to any image or video file in the photo library. For example, a choreographer might want to sketch a floorplan and attach a rehearsal video of the corresponding section of the piece. The user adds a knot to the border of the floorplan, and links it to the video file. The user can then play the video by tapping on the knot; a second tap causes the video frame to disappear. The user can reposition both videos and images by dragging-and-dropping with the finger, and adjust the size with a pinch gesture.

Knotation v1 provides the *floorplans* identified in Study 1, where users define movement through space using trajectories, and also introduces *timelines* to let them define temporal sequences. Users define floorplans and timelines by attaching the corresponding type of knot to any type of line, including curves, circles and diagonal lines.

Users can also create *portals* that provide a link from the original choreographic object to a more detailed or more abstracted view of it. The user adds a *portal* knot and taps it to create a new canvas. The user can return to the original object by tapping on the portal knot that appears automatically at the top of the new canvas. Unlike other knots, cloning a portal does not generate a copy, but instead provides alternate access to the same object.

In summary, *Knotation v1* should let choreographers:
- compose the space, time and structure of a piece by sketching *floorplans* with trajectories and *timelines*;
- create multiple views at different levels of abstraction and link them via *portals*; and
- represent movement constraints via *attributes* and *controllers*.

STUDY 2: KNOTATION V1 AS A TECHNOLOGY PROBE

Study 1 examined how contemporary choreographers and dancers define their choreographic ideas on paper. We introduced *Knotation v1* as a technology probe [27] with three choreographers, which let us observe how they express these ideas and make them interactive. Study 2 extends our understanding by focusing on the capture of inspiring practices and cases of appropriation, as well as triggering and discussing ideas with participants.

Participants

We recruited three professional choreographers (two men, one woman), with four to 34 years of experience. All use one or more of the following to record their work: paper, video, word processing, and graphical editing tools. One participant was the lead choreographer from Study 1. One researcher is also a trained dancer/choreographer and served as a volunteer dancer.

Hardware and Software

Knotation v1, described above, runs on a 12.9" iPad Pro™ running iOS 10.2, with an Apple Pencil™ for input. *Knotation v1* is implemented in Swift 3 and uses Apple's AVKit and AVFoundation frameworks to manage video (in particular, the AVPlayer controller object). It relies on default gesture recognisers to handle user input from fingers or the pen, to recognise tap, pan, pinch, and long-press gestures. We use two ad-hoc gesture recognisers: one for panning with the pen (which generates drawn strokes) and one for long-pressing (which creates a knot).

Setup

We ran each session in a local dance studio, which had chairs, a bench and a table. Participants could use the tablet in any position, including standing up, on the floor, or on a table.

Procedure

Each session lasts approximately two hours. Participants receive a live, 2.5-minute scripted demonstration of *Knotation v1*'s basic functionality. Next, they play with the tool until they feel comfortable, up to 5 minutes. The researchers answer any questions regarding the available functionality. Activity 1 involves *composition* of a short choreographic fragment for

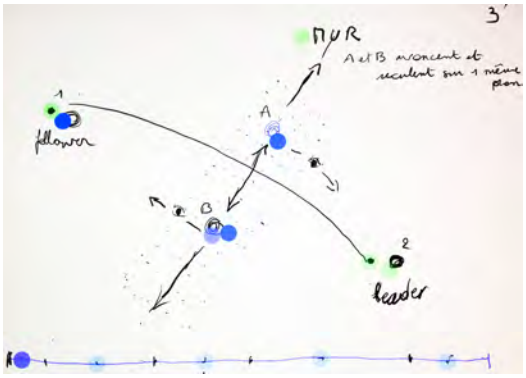

Figure 4. Study 2: Representing constraints with *Knotation v1* (P1).

about 30 minutes. Participants are asked to work on a current piece to increase engagement and to encourage recall of recent, rich details about the choreographic content. Participants choose when and how much to use *Knotation v1* and may also use paper to document their work. After a 10-minute break with healthy snacks, they begin activity 2, which involves *transformation* of the composed fragment for about 30 minutes. Participants may define transitions, reorder parts, structure the fragment, etc. The session concludes with a 15-minute debriefing session, followed by a 10-minute interview.

Data collection

We placed a camera on a tripod behind each participant to record video and audio of each session, and also took pictures, close-up videos, and written notes.

Data analysis

During the debriefing, we asked participants to explain each choreographic object. We analysed our notes, pictures, and videos, in order to find common patterns across participants, capture inspiring practices and identify examples of appropriation that might trigger new design ideas.

RESULTS AND DISCUSSION

Contrasting user strategies: Movement versus constraints

We identified two contrasting strategies among participants who focused either on concrete movements or on the rules that define them. P3 documented the particular movements he had composed, through video and textual notes. By contrast, P1 only documented and transmitted the constraints the dancers had to meet in order to perform the fragment. P2 did both: He manipulated video knots from the choreographic fragments he recorded, and played with attributes to capture the rules behind them.

During the *composition* activity, P1 asked four research team members to serve as volunteer dancers. She explained her main choreographic object: Two dancers form a *"wall"* by moving sideways along a diagonal, while the other two close their eyes and move, with the *"follower"* trying to mirror the movements of the *"leader"*. She then filmed the dancers performing the fragment. Finally she used *Knotation v1* to create an alignment relationship between the two *"wall"* dancers (Fig. 4). She drew a diagonal line with arrows to indicate the possible directions of the movement, but did not define the concrete trajectories that the dancers had to follow. She also drew a *"plane"* of dots at both sides of the diagonal, to indicate the area in which the other two dancers were allowed to move.

User strategies vary according to the type of piece

One participant adopted two distinct strategies for recording ideas, according to the type of piece. At the beginning of the session, P3 worked on a fragment of a contemporary dance piece he was revising. He used *Knotation v1* to create an *"index"* or overview of the piece, which consisted of a vertical list of textual elements corresponding to each part of the choreography. He marked[4] several phrases to help him remember the details. He created one knot per item and per transition and then filmed several elements which he linked to the knots. He considered defining his *"index"* as a timeline, but decided against it, remarking that it was more of an *"ordering"* than a timeline.

When he began annotating a tango fragment, P3 changed his approach, switching to his own formal notation and video knots to annotate the phrases. His system [41] represents each tango step as a symbol. Both partners use the same score: The leader reads the string of symbols from left to right, and the follower stands in front and reads them from right to left.

Using Knotation for improvisation and transmission

P3 appropriated *Knotation v1* in a creative way: He asked the dancer, who had never danced tango, to perform several phrases with him, holding the iPad between them. He then wrote a symbol for each step, which they read in silence as they performed, improvising the choreographic fragment.

Appropriating portals to define relationships

Instead of using portals to record additional detail about a choreographic object, P1 cloned them to establish a relationship between two dancers and indicate that they had to perform the same movement.

Triggering interaction ideas

Once their choreographic ideas became interactive, participants sought additional ways of interacting with them. For example, P3 suggested that, when attaching a video knot to a trajectory, the user could trace the trajectory with the pen to advance or rewind the video, which would link two views of the same choreographic object, one in 2D and the other in 3D. He also wanted to create his own toolbox of reusable instruments. For example, a triangular *"focus tool"* could be rotated to point in the desired direction.

Revealing the meaning of a knot

The knots in *Knotation* hid the details of their associated functionality to avoid cluttering the screen. However, participants wanted the opposite: to reveal their meaning. P1 wanted the knot to appear as an icon indicating its content, e.g. a video icon for a video knot. P2 and P3 wanted different colours for different types of knots, for easy identification.

[4] Kirsh [29] defines *marking* in dance as *"execut[ing] a dance phrase in a simplified, schematic or abstracted form"*.

Reflecting on the tool and their own practices

P1 appreciated that *"the way of representing the ideas"* in *Knotation v1* made her *"reflect on what is possible"*. P3 said that although he relies on his memory or makes long videos of his fragments, *Knotation v1* made him *"want to film [each part] and play with the videos"*. He also added that *"the tool could definitely help"* him during his creative process, for example to create a *"stable grid"* to organise his work because otherwise he is *"chaotic"*.

Summary

We observed diverse exploration and documentation strategies that captured only movement, only constraints, or a combination. *Knotation v1* successfully supported this diversity across participants and when a single choreographer used different approaches for different dance genres. Once they were able to express their choreographic ideas in *Knotation v1*, they sought additional ways to interact with them. They appropriated the available functions, and proposed specific new features. Interestingly, participants wanted knots to reveal their characteristics, rather than just encapsulate functionality, which suggests they saw knots as a way to add *personal meaning* to their sketches.

Study 2 offered three types of results:

- *Empirical*: the introduction of the concept of typed knots to define floorplans and timelines encouraged participants to explore additional possibilities for expressing movement, constraints or both;
- *Design*: in addition to suggesting specific features such as colour and knot icons, participants sought to embed interactive constraints within their choreographic objects; and
- *Technical*: we identified bugs (which lead to an autosave feature), technical challenges (e.g. optimising stroke rendering) and ways to simplify common operations (e.g. deleting objects).

ITERATING THE DESIGN: KNOTATION V2

The results of Study 2 influenced the design of *Knotation v2*: We focused on turning floorplans and timelines into first-class interactive objects, and permitting users to move or duplicate any object on the screen. We also added a number of features specifically requested by study participants.

Creating an interactive floorplan begins by drawing a closed area (within a certain tolerance) and attaching a floorplan knot. The border turns orange, indicating that the figure is now interpreted as an enclosed two-dimensional space. Any strokes within this figure are considered *trajectories*, which are also rendered in orange. Tapping on the floorplan knot animates each trajectory in the direction in which it was drawn.

Users can modify the speed of the trajectories by attaching a *speed knot* to the floorplan's border, and either entering a numeric speed value or adjusting a slider. Alternatively, users can apply a *duration knot* to specify the duration of the trajectories. *Knotation v2* calculates the speed of each trajectory in the floorplan such that they all finish at the same time. Since both speed and duration cannot be active at the same time in a given floorplan, only the attribute of the last attached knot is enabled; the others are greyed out.

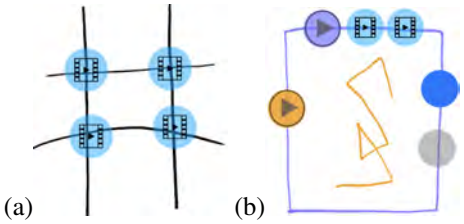

Figure 5. *Knotation v2*: Video knots can belong to multiple timelines (a). Combined floorplan (orange) and timeline (violet) (b).

Users can move floorplans, including any trajectories and knots, by dragging the border with their finger. Users can incorporate a set of strokes into a floorplan by dropping the floorplan over the strokes, which causes *Knotation v2* to interpret them as trajectories. To extract the properties of a floorplan, users can drag the border, with attached knots, with two fingers. The associated trajectories are detached from the floorplan and become normal strokes, rendered in black. Users can create a reusable floorplan template by cloning its border. *Knotation v2* clones its attached knots but not the interior trajectories.

Creating an interactive timeline consists of drawing a stroke of any shape and attaching a *timeline knot*, which turns the stroke violet. Users can then add any type of knot to the timeline. Tapping on the timeline knot displays the video knots in the order specified by the direction in which the timeline was drawn. The timeline plays the videos either at normal speed or at a speed determined by a speed knot.

Users can reorder, edit, clone, attach, detach or delete knots, even as the timeline plays. Users can create a new timeline by drawing a stroke over an existing set of knots and attaching a timeline knot to the stroke. As with floorplans, users can move timelines and their attached knots by dragging the timeline stroke.

Users can create reusable timeline templates by cloning the stroke. Users can then add new knots to the blank timeline, reusing its shape and speed. Fig. 5(a) illustrates how a single video knot can be attached to multiple timelines, which, for example, lets users explore different combinations of fragments in different orders.

Users can also combine floorplans and timelines into a single choreographic object, as shown in Fig. 5(b). Note that users are not limited to floorplans and timelines: Choreographers can create their own choreographic objects, with different characteristics. *Knotation v2* supports both finger and pen interaction: The pen draws persistent strokes, whereas the fingers move sketched objects and access associated menus, via a long press. This avoids the need for a cumbersome, moded interaction. For reasons of precision, the pen can also drag knots and invoke their menus.

The following enhancements are directly based on participants' feedback from Study 2:

- *coloured knots*, according to type;
- *icons* representing video and image knots;
- *dancer* knots, with optional names;
- *tags* for labelling knots;

- *relationship attributes* for specifying relative movement, with two examples: *mirroring*: when two groups of dancers mirror each others' movements, and *unison*: when several dancers perform a movement simultaneously; and
- *version history* to revert to previous states [39].

STUDY 3: KNOTATION V2 STRUCTURED OBSERVATION

Knotation v2 is designed to provide choreographers with a lightweight technique for quickly sketching choreographic ideas, capturing video examples, exploring constraints, and recording the result in a form that can be transmitted to dancers. We use structured observation [22], a quasi-experimental design [15] method that emphasises observing users as they perform realistic tasks in real-world settings, and making qualitative comparisons of the results. This supports ecological validity while allowing us to identify novel user behaviour and generate testable hypotheses.

Participants

We recruited six professional contemporary choreographers (5 women, 1 man), with a range of three to 47 (median 16) years of experience. P1 brought a fellow choreographer (P1C) and they worked as a team for each activity. One researcher is a trained dancer/choreographer who acted as a volunteer dancer. In their choregraphic practice, all participants sketch on paper and use video to record themselves or dance rehearsals (although the latter is rare for P1). P3 and P5 also edit their videos. We covered travel expenses for the non-local choreographer, and lunch for all participants at a local restaurant.

Hardware and Software

Each participant uses *Knotation v2*, described above, on a 12.9" iPad Pro™ running iOS 10.3, with an Apple Pencil™.

Setup

We conducted three sessions with two participants each at a local dance studio. Participants could move freely in the studio, which had a bench, chairs, and a table.

Procedure

Each session includes five activities: *training*, *composition*, *transmission*, *transformation*, and *debriefing* and lasts between two and three hours. The three middle activities are designed to reveal how *Knotation v2* supports initial creation (*composition*), documentation and communication of choreographic ideas (*transmission*), and edition of existing ideas (*transformation*).

1. Training (up to 30 minutes)
Both participants receive a live, eight-minute scripted demonstration of the main features of *Knotation v2*. Next, they play with *Knotation v2* on the iPad until they feel comfortable, asking questions as needed.

2. Composition (30 - 60 minutes)
Participants create a brief choreographic fragment for one or more dancers. They choose when and how much to interact with *Knotation v2*. The researchers and participants decide together when to transition to the next activity, after at least 30 minutes.

3. Transmission (15 minutes)
Participants take turns explaining to each other the fragments they just composed, and asking each other questions.

4. Transformation (30 - 60 minutes)
Participants are shown two artefacts that Anne Teresa de Keersmaeker uses to transmit her piece *Drumming Live*: a publically available video fragment, and a printed illustration of the golden rectangle that serves as the floorplan. Participants choose a choreographic element from the video or floorplan and modify it to match the style of the fragment they just composed, for at least 30 minutes.

5. Debriefing (15 minutes)
Participants explain the choreographic objects they created.

Data collection

We placed a camera on a tripod in the corner of the studio to record each session. We also took close-up videos, photographs and hand-written notes, and logged the participants' interaction with *Knotation v2*. We anonymised the data and refer to participants as P1-P6, and P1C.

Data analysis

We used thematic analysis [14] to code and categorise our notes, pictures, and videos. We also compared participants' practices within and across activities.

RESULTS AND DISCUSSION

Most participants (5/6) shot video of their movements with the iPad; two participants (P3 and P4) also imported images. They all left their iPads on the floor or occasionally on their laps, picking them up only when they stood to capture a dance movement. During the *transmission* activity, participants gathered around the iPad on the floor to explain their compositions to each other. They pointed to their floorplans and timelines, played videos, gestured over the iPad, and occasionally marked specific movements. Next, we present two kinds of findings: insights about participants' choreographic approaches, and insights about the use of *Knotation v2*.

Diverse choreographic approaches

Dance-then-record versus Record-then-dance
All participants successfully created a novel idea for their choreographic fragment, using personal composition strategies. For example, P1 started with two concepts – *"the sane"* and *"the crazy"* – and collaborated with P1C to write notes and sketch symbols with *Knotation v2*, as well as shoot six *"elements"*. Together, they experimented with changing the order and number of repetitions on a timeline.

We identified common approaches across participants (see Table 1). Two participants (P2, P4) used a *"dance-then-record"* approach, dancing first and then capturing the result with *Knotation v2* at the end. For example, P4 immediately started dancing and testing a variety of movements. After several minutes, she asked a researcher to record her as she danced each movement. She used *Knotation v2* only at the end to capture her fragment.

approach	id	actions	knots	attributes	TL	play TL	FP	play FP	portals	images	videos
record-then-dance	*p3*	1531	94	10	7	0	4	7	7	25	9
	p5	1142	77	21	7	0	9	53	7	0	3
mixed	*p1*	426	24	2	4	2	1	12	2	0	9
	p6	1294	41	10	9	0	10	50	3	0	0
dance-then-record	*p2*	735	26	8	1	6	3	25	3	0	2
	p4	676	29	7	2	0	4	38	2	5	3

Table 1. Study 3: Number of actions and use of key features, grouped by choreographic approach.

P3 used the opposite approach – *"record-then-dance"*. She sat on the floor thinking for several minutes, while using *Knotation v2* to plan different combinations of trajectories and movements. She then asked the volunteer dancer to perform a set of *"keyframes"*, which she recorded with *Knotation v2*. The other participants (3/6) went back and forth between dancing and using *Knotation v2*.

After watching the *Drumming Live* video during the *transformation* activity, all participants used the same approach they had adopted for the *composition* activity. However, all spent considerably more time interacting with *Knotation v2*, to check their earlier content and explore various novel transformations.

Expressing different degrees of formality

Multiple participants said they explicitly chose a particular level of formality and detail to represent their choreographic objects. P4 said she was purposely imprecise when annotating her fragment and appreciated how *Knotation v2* offered her various degrees of informality: *"For me, since I love informal things, it works, but it also works for something more formal, more precise."* P1C also noted that it permits *"being informal"*, thus *"stays open to interpretation"*.

Integrating time and space with linked choreographic objects

One participant (P5) created a complex structure with floorplans and timelines to compose time and space. She drew one floorplan and timeline per dancer (see Fig. 6), with *"properties"* (e.g. unison relationships) that are read vertically as in a *"rhythmic score"*. This served as a *"tool similar to the timeline"*, *"easily visible"*, that reveals *"what should happen at a given moment for each dancer"* (P5). She created tagged knots and attributes for each timeline that indicated the scope of specific constraints over time (e.g. the direction of the dancer's gaze). She also cloned portals to define *"shared scores"* for dancers at the proper locations on their timelines. In addition, she drew a curve over each timeline to represent the levels with respect to the floor. P5 thus created her own sophisticated structure for decomposing and combining the three spatial dimensions and time on a 2D surface.

Appropriating errors to discover interesting patterns

Some participants used errors to spark new ideas. P1 and P1C inadvertently linked several knots to the same video, which then led them to discover *"interesting patterns"* (P1C). P1C said that visualising the same element multiple times suggested new possibilities for interesting rhythms and dynamics, as well novel *"extensions"* to the element. P1C commented: *"You don't find that in the videos you shoot!"*

Assessing choices by interacting with choreographic objects

P3 and P4 emphasised the importance of expressing a range of interconnected ideas before making choreographic choices. We found that participants interacted with their choreographic objects, for example by playing or repositioning timelines and floorplans or refining their attributes, to consider alternatives. P1C described how she and P1 used timelines *"to see the available choices"* and suggested using *Knotation v2* as a way of *"validating things before testing them"* in the studio. P5 liked to *"see what were all the possibilities, because when you're trying to write [a piece] on paper, you can't pass from paper to video, or paper to duration"*.

Using Knotation v2

A quantitative analysis of the logs (see Table 1) reveals that P3, who used the *record-then-dance* approach, performed more than double the actions and created over three times as many knots as P2 and P4, the two *dance-then-record* participants. This correlation suggests a testable hypothesis: The *record-then-dance* approach is a cognitive-first strategy that favours a technology-mediated exploration of choreographic ideas, while the *dance-then-record* approach is a dance-first strategy where the technology supports documentation.

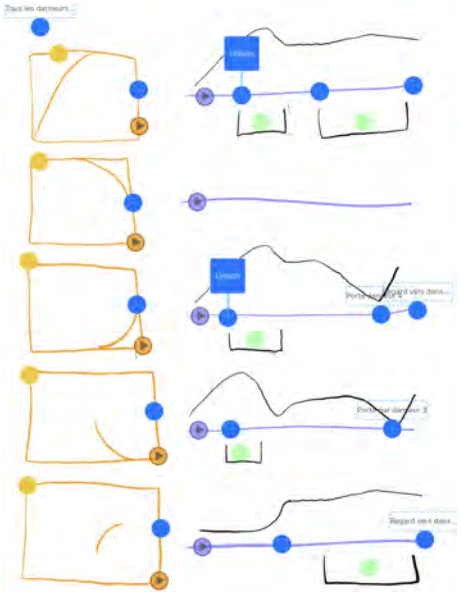

Figure 6. Study 3: P5 created pairs of floorplans and timelines, one per dancer, with progressive level changes. She also used knots to mark the scope of a particular constraint over time, and cloned portals to establish relationships among the dancers.

Most participants (5/6) imported and played video. Interestingly, P5 played one video once, and experimented instead with attributes, controllers, floorplans and timelines, which let her focus on defining higher-level structures.

All participants created at least one timeline (mean: 4.3), although the *dance-then-record* participants only created one or two. Surprisingly, most participants (4/6) did not play their timelines, even though they added and removed knots from them multiple times. This suggests that they used timelines as a grouping mechanism, obviating the need to play videos in their final order. This is similar to how designers used the *Stickylines* [13] alignment and distribution instruments to group objects while structuring graphical layouts.

All participants created at least one floorplan (mean: 5.2) and interacted with floorplans considerably more frequently than with timelines (mean: 30.8). In particular, P5 interacted repeatedly with knots to establish speed and duration. Participants created from two to seven portals each. Although P3 and P5 created slightly more, we found no differences across strategies with respect to use of portals.

Appropriating floorplans and timelines

Participants found several creative new uses for floorplans and timelines. For example, P1 and P1C overlapped clips to make them appear as a single seamless video in the timeline. P2 drew short trajectories near, but just outside the border of a floorplan, to avoid animation and indicate that the dancer began and ended the sequence off stage. P3 used floorplans to define *"keyframes"* – diagrams showing each dancer's location at a given moment as seen from above – and represented dancers with knots and transitions with lines. P6 went further, combining the concepts of floorplans and timelines: She drew a spiral-shaped timeline where the shape represented a spatial trajectory. She also redefined the meaning of trajectories within her floorplan. For example, she wrote five words with a corresponding set of symbols, one for each of five floorplans. These symbols represented trajectories *"but not in a horizontal floorplan space"* (P6).

Participants' feedback

Participants highlighted how well *Knotation v2* supported diverse choreographic processes. In particular, P3 noted that even though she and P4 used extremely different approaches, *Knotation v2* supported them both. P4 emphasised that *"it does not impose a method"*, which she liked very much.

Participants liked *Knotation v2*'s ability to gather diverse material about a project. P1C said it was: *"really interesting to be able to gather imagery easily, that is instantly playable, with your hypothesis of time and space"*, and finds *Knotation v2 "a file easy to rework, to be brought up again"*. P1 liked that *"instead of having fifteen thousand notes, you have it here all assembled"*. P3 explained that, for her, there is a *"time of creation"* and a *"time of technology"*, and that *"a tool like this allows you to join those times"*. Interestingly, P4 suggested a new name (*"Knowtation"*) to highlight its ability to collect knowledge about a piece. By contrast, P1 felt that having *"so many possibilities"* constantly *"triggered new ideas"* before he could process his previous ideas, so he *"got entangled"*.

Participants suggested a number of possible features, such as grouping timelines and floorplans. They also noted several limitations. P2 mentioned she wanted *"to keep everything visible"* but the screen size was an issue, although she noted *"I have the same problem with the computer"*. P3 wanted to use portals to visualise the tree-like structure of a piece, which we leave for future work.

Summary

Knotation v2 successfully supported participants with diverse choreographic approaches, including *dance-then-record*, *record-then-dance* or a combination of the two, without imposing a particular process. Participants could assign personal meanings to both their input and the system's feedback, and change their minds over time. They could also choose their desired level of formality, from informal sketches to formal notations. The structured observation approach generated a testable hypothesis: A *record-then-dance* approach most enhances exploration of choreographic ideas, while a *dance-then-record* approach favours documentation.

Participants combined timelines and floorplans to represent their choreographic objects, including both simple and complex temporal and spatial structures. Interestingly, they appropriated their errors to explore novel choreographic patterns. Study 3 demonstrates the potential of *Knotation v2* as a mobile tool for exploring and documenting choreographic ideas in a studio setting, and offers new insights into the choreographic creative process.

CONCLUSION AND FUTURE WORK

Our goal is to design interactive digital tools that support exploration and documentation of choreographic ideas, without enforcing a particular creative process. We began by observing a professional choreographer and several dancers, which highlighted both the diversity in how they represent choreographic fragments, as well as the need for capturing and annotating movement constraints. We designed *Knotation*, a mobile pen-based tool that offers a lightweight method for sketching choreographic ideas with embedded images and video. Users can sketch their own personal representations of the dance, and add various forms of interaction to further explore their ideas.

Using *Knotation v1* as a technology probe revealed contrasting strategies for capturing movement, constraints, or both. *Knotation v2* explicitly supports interactive timelines and floorplans, as well as incorporates participants' suggestions. We then demonstrated how *Knotation v2* successfully supported opposite choreographic approaches (*dance-then-record* and *record-then-dance*), and allowed users a wide range of expression, at varying levels of formality. In future, we plan to explore the collaborative potential of *Knotation*. Other promising directions include extending support for personal sublanguages; letting users create their own instrument palettes [3]; and assessing results with the Creativity Support Index [10].

ACKNOWLEDGMENTS

This work was partially supported by European Research Council (ERC) grant n° 321135 CREATIV: Creating Co-Adaptive Human-Computer Partnerships.

REFERENCES

1. Brian P. Bailey, Joseph A. Konstan, and John V. Carlis. 2001. DEMAIS: Designing Multimedia Applications with Interactive Storyboards. In *Proceedings of the Ninth ACM International Conference on Multimedia (MULTIMEDIA '01)*. ACM, New York, NY, USA, 241–250.
2. Clarisse Bardiot. 2015. Rekall: An environment for notation/annotation/denotation. *Performance Research* 20, 6 (2015), 82–86.
3. Michel Beaudouin-Lafon. 2000. Instrumental Interaction: An Interaction Model for Designing post-WIMP User Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '00)*. ACM, 446–453.
4. Rudolf Benesh and Joan Benesh. 1977. *Reading dance: The birth of choreology*. International Specialized Book Services.
5. Lynne Anne Blom and L Tarin Chaplin. 1982. *The intimate act of choreography*. University of Pittsburgh Pre.
6. Diogo Cabral, João Valente, João Silva, Urândia Aragão, Carla Fernandes, and Nuno Correia. 2011. A Creation-tool for Contemporary Dance Using Multimodal Video Annotation. In *Proceedings of the 19th ACM International Conference on Multimedia (MM '11)*. ACM, New York, NY, USA, 905–908.
7. Tom W Calvert, Armin Bruderlin, Sang Mah, Thecla Schiphorst, and Chris Welman. 1993. The evolution of an interface for choreographers. In *Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*. ACM, 115–122.
8. Kristin Carlson, Thecla Schiphorst, Karen Cochrane, Jordon Phillips, Herbert H. Tsang, and Tom Calvert. 2015. Moment by Moment: Creating Movement Sketches with Camera Stillframes. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (C&C '15)*. ACM, New York, NY, USA, 131–140.
9. Kristin Carlson, Thecla Schiphorst, and Philippe Pasquier. 2011. Scuddle: Generating movement catalysts for computer-aided choreography. In *Proceedings of the Second International Conference on Computational Creativity*. 123–128.
10. Erin Cherry and Celine Latulipe. 2014. Quantifying the Creativity Support of Digital Tools Through the Creativity Support Index. *ACM Trans. Comput.-Hum. Interact.* 21, 4, Article 21 (June 2014), 25 pages.
11. Luke Church, Nick Rothwell, Marc Downie, S. delahunta, and Alan F Blackwell. 2012. Sketching by programming in the Choreographic Language Agent. In *Proceedings of the Psychology of Programming Interest Group Annual Conference.(PPIG 2012)*. 163–174.
12. Marianela Ciolfi Felice, Sarah Fdili Alaoui, and Wendy E. Mackay. 2016a. How Do Choreographers Craft Dance?: Designing for a Choreographer-Technology Partnership. In *Proceedings of the 3rd International Symposium on Movement and Computing (MOCO '16)*. ACM, New York, NY, USA, Article 20, 8 pages.
13. Marianela Ciolfi Felice, Nolwenn Maudet, Wendy E. Mackay, and Michel Beaudouin-Lafon. 2016b. Beyond Snapping: Persistent, Tweakable Alignment and Distribution with StickyLines. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 133–144.
14. Victoria Clarke and Virginia Braun. 2014. Thematic Analysis. In *Encyclopedia of Critical Psychology*. Springer, 1947–1952.
15. T.D. Cook and D.T. Campbell. 1979. *Quasi-experimentation: design & analysis issues for field settings*. Houghton Mifflin.
16. Scott deLaHunta. 2007. *(Capturing intention): documentation, analysis and notation research based on the work of Emilio Greco*. Amsterdamse Hogeschool voor de Kunsten.
17. Scott delaHunta and Norah Zuniga Shaw. 2008. Choreographic resources agents, archives, scores and installations. *Performance Research* 13, 1 (2008), 131–133.
18. Sarah Fdili Alaoui, Frédéric Bevilacqua, Bertha Bermudez Pascual, and Christian Jacquemin. 2013. Dance interaction with physical model visuals based on movement qualities. *International Journal of Arts and Technology* 6, 4 (2013), 357–387.
19. Sarah Fdili Alaoui, Kristin Carlson, and Thecla Schiphorst. 2014. Choreography as Mediated through Compositional Tools for Movement: Constructing A Historical Perspective. In *Proceedings of the 2014 International Workshop on Movement and Computing*. ACM, 1.
20. William Forsythe. 2012. *Improvisation technologies: a tool for the analytical dance eye*. Hatje Cantz.
21. Jérémie Garcia, Theophanis Tsandilas, Carlos Agon, and Wendy Mackay. 2012. Interactive Paper Substrates to Support Musical Creation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, 1825–1828.
22. Jérémie Garcia, Theophanis Tsandilas, Carlos Agon, and Wendy E. Mackay. 2014. Structured Observation with Polyphony: A Multifaceted Tool for Studying Music Composition. In *Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14)*. ACM, 199–208.
23. Mark D. Gross and Ellen Yi-Luen Do. 1996. Ambiguous Intentions: A Paper-like Interface for Creative Design. In *Proceedings of the 9th Annual ACM Symposium on User Interface Software and Technology (UIST '96)*. ACM, New York, NY, USA, 183–192.

24. Ian Hattwick, Joseph Malloch, and Marcelo M Wanderley. 2014. Forming Shapes to Bodies: Design for Manufacturing in the Prosthetic Instruments. In *NIME'14 The International Conference on New Interfaces for Musical Expression*. 443–448.

25. Anna Heyward. 2015. How to Write a Dance: Remy Charlip and the problems of dance notation. *The Paris Review* (2015).

26. Ken Hinckley, Shengdong Zhao, Raman Sarin, Patrick Baudisch, Edward Cutrell, Michael Shilman, and Desney Tan. 2007. InkSeine: In Situ Search for Active Note Taking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. ACM, New York, NY, USA, 251–260.

27. Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B. Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, Heiko Hansen, Nicolas Roussel, and Björn Eiderbäck. 2003. Technology Probes: Inspiring Design for and with Families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03)*. ACM, New York, NY, USA, 17–24.

28. Matthew Kam, Jingtao Wang, Alastair Iles, Eric Tse, Jane Chiu, Daniel Glaser, Orna Tarshish, and John Canny. 2005. Livenotes: A System for Cooperative and Augmented Note-taking in Lectures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05)*. ACM, New York, NY, USA, 531–540.

29. David Kirsh. 2011. How marking in dance constitutes thinking with the body. (2011).

30. Rudolf Laban. 1975. Laban's Principles of Dance and Movement Notation. *Lange. London: MacDonald and Evans* (1975).

31. James A Landay and Brad A Myers. 2001. Sketching interfaces: Toward more human interface design. *Computer* 34, 3 (2001), 56–64.

32. James Lin, Mark W Newman, Jason I Hong, and James A Landay. 2000. DENIM: finding a tighter fit between tools and practice for Web site design. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, 510–517.

33. Thomas P. Moran, Patrick Chiu, and William van Melle. 1997. Pen-based Interaction Techniques for Organizing Material on an Electronic Whiteboard. In *Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology (UIST '97)*. ACM, New York, NY, USA, 45–54.

34. Elizabeth D. Mynatt, Takeo Igarashi, W. Keith Edwards, and Anthony LaMarca. 1999. Flatland: New Dimensions in Office Whiteboards. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, USA, 346–353.

35. Maria Palazzi and Norah Zuniga Shaw. 2009. Synchronous Objects for One Flat Thing, Reproduced. In *SIGGRAPH 2009: Talks (SIGGRAPH '09)*. ACM, New York, NY, USA, Article 2, 1 pages.

36. Yi Ren, Yang Li, and Edward Lank. 2014. InkAnchor: Enhancing Informal Ink-based Note Taking on Touchscreen Mobile Phones. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 1123–1132.

37. Claudia Ribeiro, Rafael Kuffner dos Anjos, and Carla Fernandes. 2017. Capturing and Documenting Creative Processes in Contemporary Dance. In *Proceedings of the 4th International Conference on Movement Computing (MOCO '17)*. ACM, New York, NY, USA, Article 7, 7 pages.

38. Thecla Schiphorst, Tom Calvert, Catherine Lee, Christopher Welman, and Severin Gaudet. 1990. Tools for interaction with the creative process of composition. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 167–174.

39. Ben Shneiderman. 2007. Creativity support tools: Accelerating discovery and innovation. *Commun. ACM* 50, 12 (2007), 20–32.

40. Vikash Singh, Celine Latulipe, Erin Carroll, and Danielle Lottridge. 2011. The choreographer's notebook: a video annotation system for dancers and choreographers. In *Proceedings of the 8th ACM conference on Creativity and cognition*. ACM, 197–206.

41. Matías Alberto Trípodi. 2017. *Essai de Système de Notation du Mouvement pour le Tango*. Self-published.

42. Theophanis Tsandilas, Catherine Letondal, and Wendy E. Mackay. 2009. Musink: Composing Music Through Augmented Drawing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 819–828.

43. Theophanis Tsandilas and Wendy E. Mackay. 2010. Knotty Gestures: Subtle Traces to Support Interactive Use of Paper. In *Proceedings of the International Conference on Advanced Visual Interfaces (AVI '10)*. ACM, 147–154.