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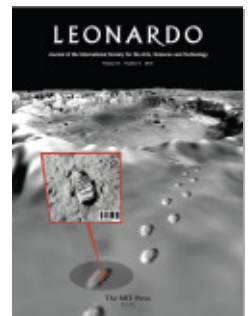
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A Novel Use of 3D Motion Capture: Creating Conceptual Links between Technology and Representation of Human Gesture in the Visual Arts

Gongbing Shan
Peter Visentin
Tanya Harnett

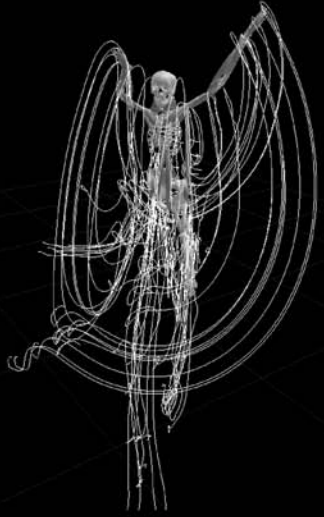
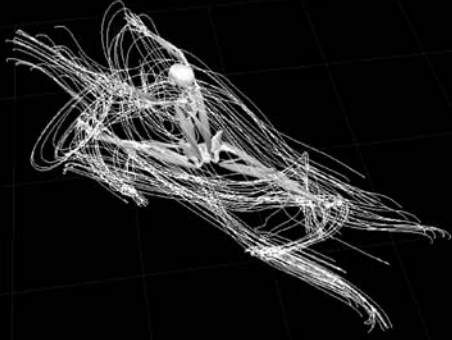
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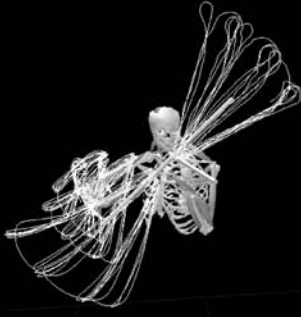
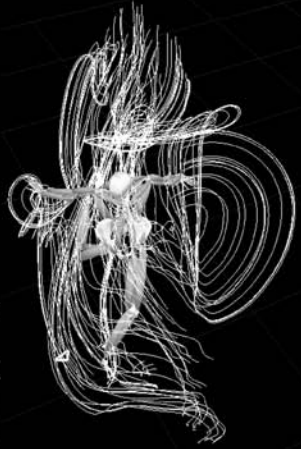
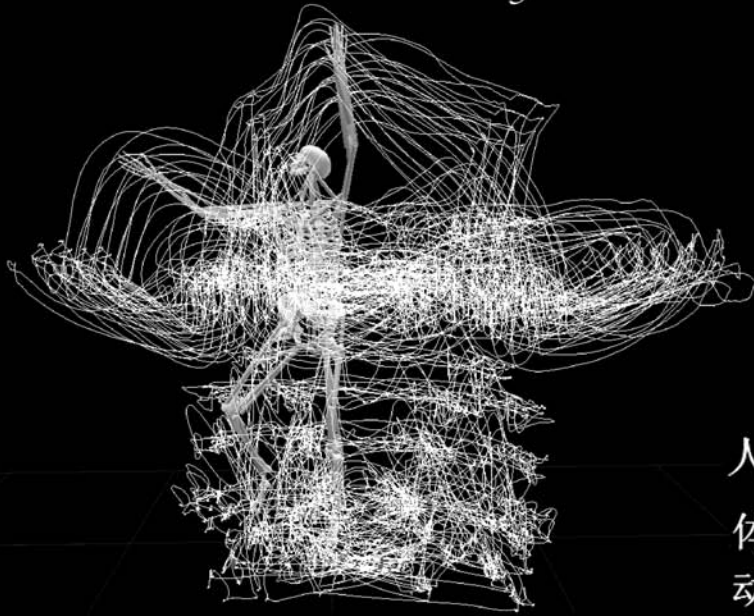
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Signatures des mouvements humains

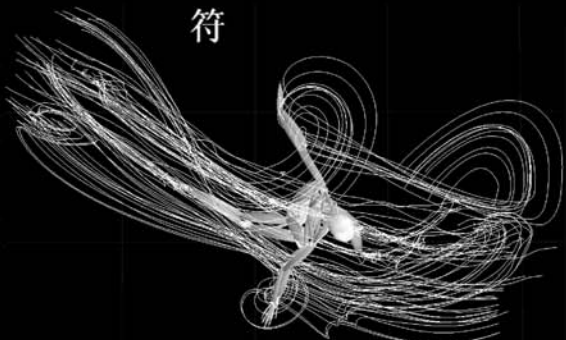
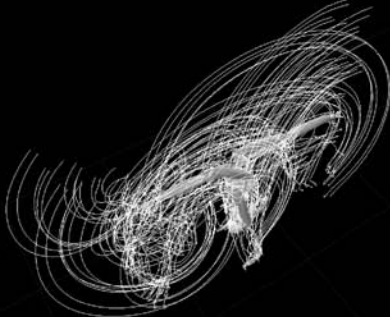


Unterschriften der menschlichen Bewegungen



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Signatures of Human Movements



A Novel Use of 3D Motion Capture: Creating Conceptual Links between Technology and Representation of Human Gesture in the Visual Arts

Gongbing Shan,
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Innovation is a driving force in both science and art. In science, technological innovation is typically synonymous with improvements in accuracy of measurement and, seemingly, objectivity of data. In art, innovation mainly focuses on individuality and the subjective interpretation of that which the artist perceives. The human experience is contingent on both art and science; the latter provides a means of ordering our perception of the world and the former serves as a moderator between perception, understanding and representation. To integrate the two, conceptual interfaces are needed, because, frequently, technology carries potential beyond its primary intended application. The purpose of this paper is to provide discussion on one such link: between the understanding of human movement and the technologies that have influenced the representation of it.

Historically, depictions of human movement have had the particular challenge of representing time-based events in a single image. Prior to the development of photography, movement could be represented by capturing a visual affect defined at a critical point during the unfolding of a gesture—essentially, stop-action. When used to suggest the essence of motion, stop-action representations need not be anthropokinetically accurate (anthropokinetics refers to movement efficiency as it relates to the human anatomical structure). Their effectiveness as images may be merely representational, relying on exaggeration, iconography, cultural connotations and/or the experiential knowledge of the viewer. For example, Myron's classical representation of a discus thrower (ca.

460 BC) is, from an anthropokinetic standpoint, hardly realistic. Yet its representation of athleticism and dynamism is widely understood; the contorted, unnatural body position has become an iconic portrayal of power and effort (Fig. 1).

What work is there which is as distorted and elaborate as that *Diskobolos* of Myron? But if anyone should criticize this work because it was not sufficiently upright, would he not reveal a lack of understanding of the art, in which the most praiseworthy quality is this very novelty and difficulty? [1]

Prior to the 20th century, affective representations of human movement using stop-action were clearly the norm. In images alluding to movement, representation involved artistic synthesis and interpretation of the latent content of the human form, that is, a mood or expression of feeling associated with a physical action. For example, in 19th-century Romantic imagery, movement might be alluded to in various ways using formal structure, brush-stroke quality, painterly techniques, color or other culturally/stylistically loaded techniques.

Some of the most profound changes in representing dynamic events on a 2D plane are attributable to technological developments in photography. In addition to having a fundamental impact on post-19th-century realism in still image-making, photography made possible the use of multiple exposure, time exposure and multi-frame stop-action imaging techniques to evoke the unfolding of movement. These techniques were employed by both scientists and artists, but with fundamentally different motivations. The photographs of Eadweard James Muybridge sparked a huge controversy in the art world as realist painters became conscious that their works were not so true to life as they imagined, and his work using human subjects and multi-camera stop action photography initiated a scientific approach to human-movement studies [2,3]. Further developments using photography to capture and analyze human movement can be traced to the following: (1) Etienne-Jules Marey, a French physiologist working with high-speed photography at the same time as Muybridge, who captured multiple images with one camera on one photo plate [4]; (2) Wilhelm Braune and Otto Fischer, who per-

ABSTRACT

As an unfolding of time-based events, gesture is intrinsically integrated with the aesthetic experience and function of the human form. In historical and contemporary visual culture, various approaches have been used to communicate the substance of human movement, including use of science and technology. This paper links the understanding of human gesture with technologies influencing its representation. Three-dimensional motion capture permits the accurate recording of movement in 3D computer space and provides a new means of analyzing movement qualities and characteristics. Movement signatures can be related to the human form by virtue of trajectory qualities and experientially and/or culturally dependent interactions.

Gongbing Shan (educator, researcher), Faculty of Arts and Science, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta, Canada T1K 3M4. E-mail: <g.shan@uleth.ca>.

Peter Visentin (educator), Faculty of Fine Arts, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta, Canada T1K 3M4. E-mail: <visentin@uleth.ca>.

Tanya Harnett (educator), Faculty of Fine Arts, Faculty of Arts and Science, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta, Canada T1K 3M4. E-mail: <tanya.harnett@uleth.ca>.

Article Frontispiece. Movement trajectories of selected artistic and athletic activities recorded using 3D motion capture.
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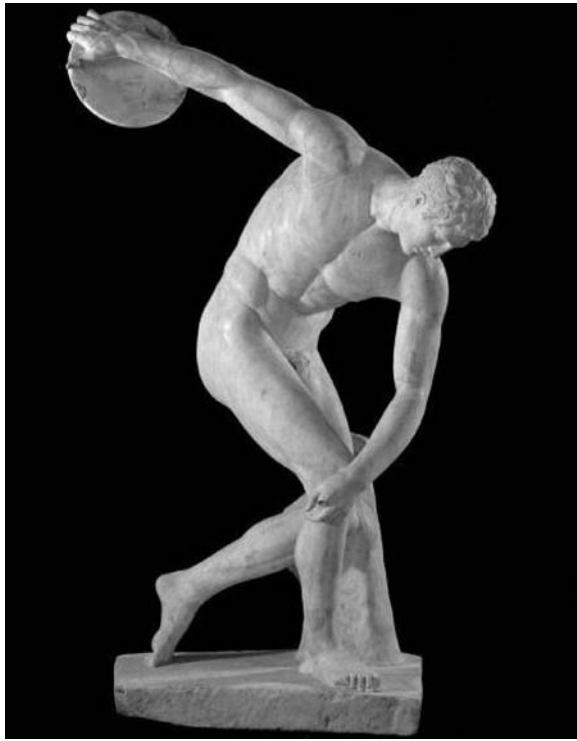


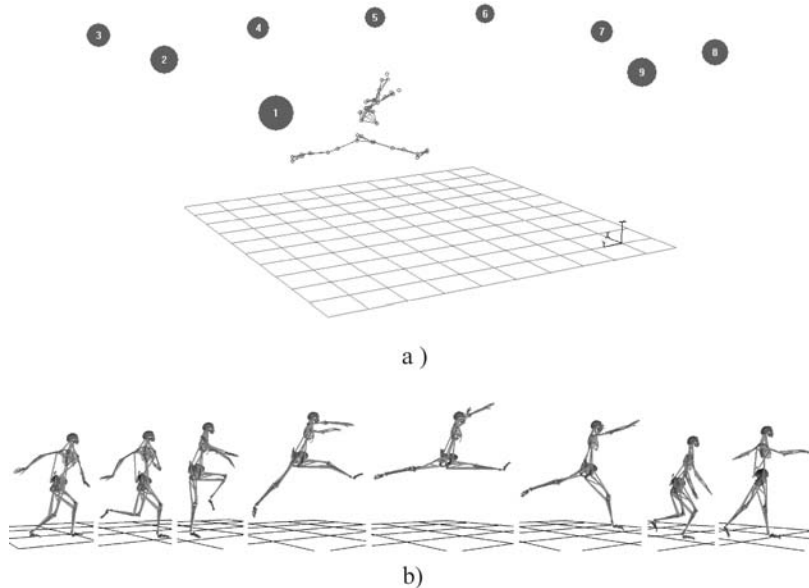
Fig. 1. Myron, *Diskobolos*, ca. 460 BC.

formed extremely thorough analyses of gait using four cameras without shutters and subjects marked with Geissler tubes, which emitted current that could then be seen on film [5]; (3) Nikolaj Bernstein, who in the 1920s and 1930s developed precise kinematic procedures using cyclography, a technique employing film slowly moving through a camera with a

mirror placed at a 45° angle to the optical axis, thereby creating a picture that gave a frontal and lateral view of the subject [6]; and many others, using techniques such as strobes and multiple and time exposure [7].

Directly influenced by photography, early 20th-century Futurist painters such as Umberto Boccioni and Gino Severini

Fig. 2. (a) 3D motion capture reconstruction showing multiple camera placements (numbered 1–9) and a wire frame reproduction of the apogee of a Grand Jeté ballet leap. (b) Sequential stop-frame reconstruction of the movement. (© Gongbing Shan)



began to experiment with these ideas, creating works (e.g. *States of Mind: The Farewells* [1911] and *Dynamism of a Dancer* [1912], respectively) that compressed the principle of multiple exposure imagery into “kaleidoscope art of force lines, vectored shapes and mobile patterns” [8]. Displaying multiple fragmented essences in a single visual image, these artworks approach an expression of time and position designed to represent a perception of the human experience by combining the traditional idea of stop-action affective representation with Muybridge’s multiple exposure techniques.

In each of these instances, the creation of art can be understood as a sequential expression of how we experience our current existence, one in which advancements in technology have influenced our existential perception of the world. Conceptual extremes of this process can be seen when the technology effectively becomes “transparent.” For example, the works of modernist American artist Franz Kline condense gesture onto a single two-dimensional canvas—one that may not be anthropokinetically accurate but is physically expressive; contemporary artist (and present co-author) Tanya Harnett develops the dynamics of a 3D space through layered subject matter, portrayal of gesture and historical reference, using them as a stage for a photographic image that compresses time, x-y-z dimensionality and cultural reference into a flat-surface gestural work. Harnett’s *Nude Descending a Staircase* (Color Plate A) is a direct reference to the work of the same title by Marcel Duchamp, who acknowledged the influence of Etienne-Jules Marey’s studies. The motivations of such artists are partially rooted in the representation of human movement. When we view such works, we understand them as a metaphor of the human experience.

FRAMING THE QUESTION

If photographic techniques tested the liminality of visual culture in the early 20th century, film, video and more recent developments with computers (3D motion capture, virtual reality, etc.) do so in ours. Cognition in these dynamic environments relies upon viewers to subliminally compress information from multiple images and events into a summative experience. Even remembrance of the experience remains a time-based phenomenon. These newer tools are relatively easy to use and diminish demands formerly made on content creators to synthesize when representing movement qualities. Simply because video media

unfolds sequentially, its verisimilitude is easily established. With respect to motion-capture technology as an extension of video media, four fundamental and consequential questions arise: Can 3D motion capture trajectory data be effectively used to communicate key characteristics of human movement in a single still 2D image? If so, does it also facilitate analysis and categorization of dynamic, time-based motions? If the answer to this question is also “yes,” how much representative information is needed in order to evoke an event’s unfolding over time (effects of human movement)? Can we begin to speculate about cultural context as a factor influencing gesture? This study initiates discussion on the utility of motion capture as a tool to aid description and analysis of the characteristics of human movement and identify activity dependent element combinations that may be unique—essentially amounting to movement signatures.

THEORETICAL CONSIDERATIONS

In her seminal book *Grids*, Rosalind Krauss discusses the history of the grid and places it in the context of 20th-century Modernist art, consistent with Greenbergian philosophy. Krauss finds that the grid, if it maps anything, maps the surface of the painting. Further, the material and aesthetic aspects of art are demonstrated using the same 2D flat surface.

There are two ways in which the grid functions to declare the modernity of modern art. One is spatial, the other is temporal. . . . In the spatial sense, the grid states the absolute autonomy of the realm of art . . . it is anti-natural, and anti-mimetic and anti-real. . . . In the temporal dimension, the grid is an emblem of modernity [9].

Thus the grid functions as an analogy for a form of cultural inertia that gives birth to 20th-century modernism. This thinking is not temporal in the classical sense. Rather, it is a “staircase to the universal and they [artists] are not interested in what happens below in the Concrete” [10]. This use of the term “temporal” connotes stasis, a condition necessary for the grid to serve as both an emblem and a cultural myth related to a time/place/period in art history. In short, the grid is a 2D concept, one that embodies the mythos and storytelling of the Modernist period. In the 21st century there is a need to re-evaluate the functional and cultural context of the grid.

This need seems to be a continuing

Fig. 3. Front view of tae kwon do side kick with body trajectory lines included (above). Sequential stop-frame reconstruction of the movement (below). (© Gongbing Shan)



challenge, no matter the artistic genre. Still reminding us of an x-y plane, Brian Hayes, in his review of technologies and modes of graphic representation, speculates that some of the alternatives to pixel-based digital imaging “could give hints about the way the brain stores and interprets images” [11]. Photographic representations can use techniques that require time-based processes to capture static images, but without reference to dynamic intent or representation of 3-dimensional space, they can sometimes leave no sense of the temporal in the image itself. For example, Kiki Smith’s *My Blue Lake* (1995) uses a peripheral (time-based) photographic process. Although physicality is a central subject for this feminist image, the gestural and temporal are not. In such instances, a dimension seems missing—one that links 2D imaging to time-based 3D phenomena and their perception.

In terms of gestural communication and its representation, a more “classical” view of the temporal may be necessary. Gesture communicates information, the meaning of which is driven by empirical experience. Perceptions of gesture as an unfolding of time-based events are intrinsically integrated with the form and function of human movement. Since the viewer of a 2D image has experienced the phenomenon of gesture as a time-based event, interpretation of the image should also be a time-based phenomenon. When attempting to present the dynamic content of human gesture in a single still image, synthesis must occur; both time and

embodiment must be represented. This synthesis is key to the aesthetic experience and understanding of a visual imagery that is both spatial and temporal. Informed by this, visual communication should be linked to the culture of the viewer, so that iconography, visual analogy and/or personal experience can play a role.

This paper explores the use of 3D motion capture as a means to extract the dynamic trajectory content and temporal nature of specific human movements. Motion capture provides the means to accurately record movement in 3D computer space. This technique differs from photography in two fundamental ways: (1) the information gathered is not an actual image; rather it is a collection of trajectories generated by predefined, user-determined points; and (2) the viewer’s choice of perspective is not controlled by camera placement, since it can be altered after the motion has been captured. We speculate that images synthesized from motion-capture trajectories may be used to generate signatures of human movement (see Article Frontispiece) that are objectively representational of time and bodiliness. In order to initiate dialogue on this issue, we supply several examples of movement signatures generated using motion-capture technology.

METHOD

We used a 3D motion-capture system to record full or partial body movement. Multiple reflective markers were placed

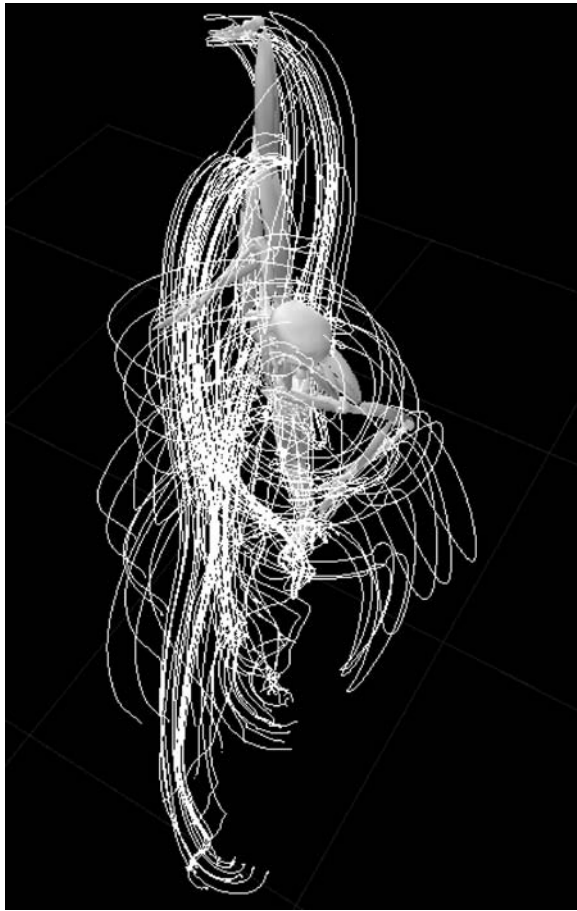


Fig. 4. Tae kwon do side kick (top view) with body trajectory lines. (© Gongbing Shan)

on subjects to identify body segments and joints—points normally thought to be anatomically significant for human movements. The movements of these markers resulted in trajectories recorded in 3D computer space. Once captured, trajectories could be displayed and other information, such as computer-generated musculoskeletal models to represent the human subjects, could be added (Fig. 2).

A nine-camera VICON v8i motion-capture system [12] was employed to track markers (9 mm in diameter) at a rate of 120 frames/sec. Marker tracking was accurate within 1.5 mm. We placed markers on subjects as follows: (1) four on the head; (2) one trunk marker on each of the sternal end of the clavicle, the xiphoid process of the sternum, the C7 and T10 vertebrae, each scapula, left and right anterior superior iliac and the posterior superior iliac; (3) upper-extremity markers on the right and left acromion, lateral side of upper arm, lateral epicondyle, lateral side of forearm, styloid processes of radius and ulna and distal end of the 3rd metacarpal bones; and (4) lower extremities markers on left and right lateral sides of thigh and shank, lateral tibial condyle, lateral malleolus, distal end of 5th metatarsal, calcaneus

Fig. 5. Baseball pitcher’s movement (back view from above) with body trajectory lines. (© Gongbing Shan)

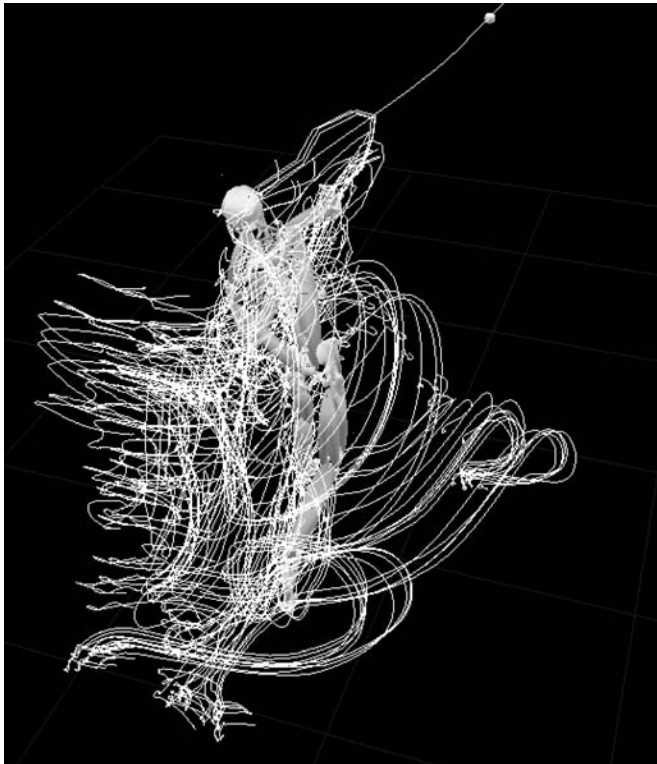
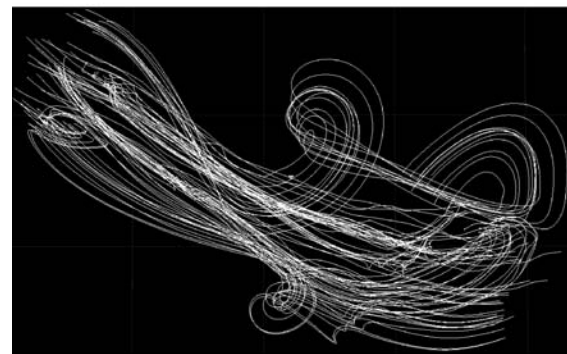


Fig. 6. Soccer maximal instep kick (top view): (a) with body trajectory lines and (b) without human form model. (© Gongbing Shao)



a)



b)

and big toe. Model segments were identified as follows: head, upper trunk, lower trunk, upper arms, lower arms, hands, thighs, shanks and feet.

We examined human movement activities from the following fields of sport and the performing arts: taekwon do, baseball, soccer, classical ballet, classical Indian dance and music performance. In each of these, movements of the subjects were driven by specific desired outcomes. As such, movements were found to be repeatable to a high degree of precision, a characteristic that was enhanced by the high degrees of training and experi-

ence of the participants. Thus, we found the movements to have identifiable, outcome-driven signatures.

EXEMPLARY EXPERIMENTS

Notwithstanding type of activity, trajectory-based images generated using motion capture suggested qualities that might be aids to establishing movement signatures; even the language intuitively used to describe them seems naturally rooted in “perceptual” experience. The uniqueness of each activity could be understood by considering its rela-

tive emphasis on factors such as stability (balance, body position/posture), athleticism (weight, speed, power/vigor), quality of movement (control, smoothness/abruptness) and dimensionality of the movement (excursion/range of movement). Selected examples, described below, showed how motion capture could aid discourse about perceptual characteristics of human movement.

Example 1 showed trajectories associated with a basic taekwon do skill—the side kick. Its main characteristics were as follows:

Stability: Trunk trajectories had relatively small, near-linear excursions (Fig. 3) and they tended to be clumped in one area of the image. The largest trajectories (legs and feet) visibly occurred on a plane rather than in a volume. Clear presence of a center, circled by rotational trunk trajectories, suggested weight, balance and centripetality (Fig. 4).

Athleticism: Long trajectory lines of the legs, particularly the feet, contrasted with the “low-energy,” shorter lines of the trunk, lending the impression of a speed differential and of directed power. Orientation of the foot and leg trajectories was in contrast to those of the rest of the image, showing dynamism (see Fig. 3).

Quality of movement: Continuities of trajectories were smooth, showing controlled gestures, except for acute-angle structures that occurred at the apex of the foot excursion. Abrupt changes of direction indicated thresholds of the activity or bodily limits where energy of the movement was released.

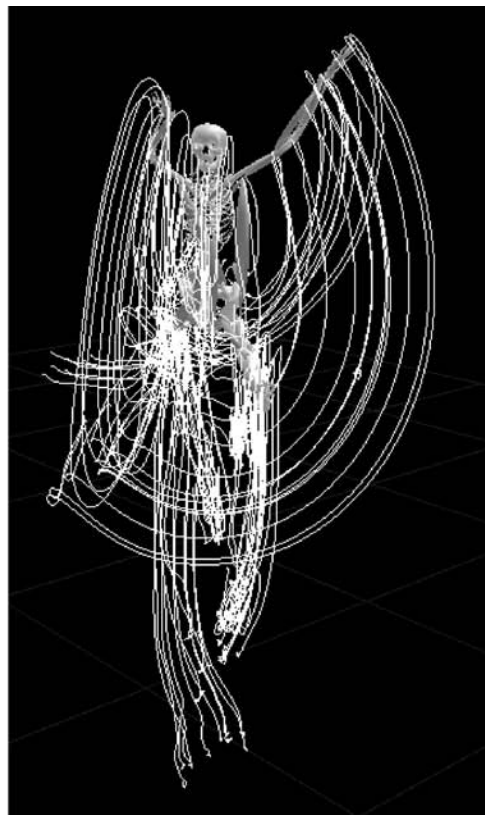
Dimensionality: Generally, compact excursions of trajectory lines showed movement to be occurring in a limited space, suggesting bodily control.

Example 2 was a signature generated from a baseball pitch (Fig. 5), which had similar visual features to those described above. Core stability could be seen in trunk trajectories and dynamism/athleticism in those of the limbs. Points of energy buildup and release were apparent.

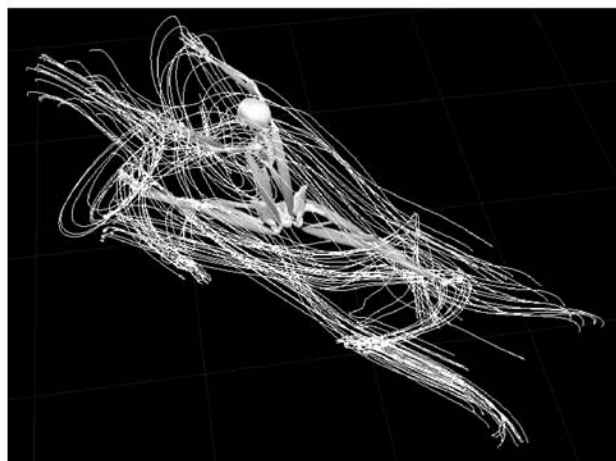
Example 3 represented a soccer kick pictured from above (Fig. 6a). Its key characteristics were as follows:

Stability: Most trajectories appeared to be aligned in one general direction and had similar lengths. Relatively parallel to one another, trajectories (particularly trunk and head) showed a state of controlled balance.

Athleticism and dimensionality: Swirling trajectories of the arms were related to energy and athleticism. The double structure of these swirls indicated building and release phases of the movement.



a)



b)

Fig. 7. Ballet Grand Jeté with body trajectory lines: (a) front view and (b) top-left-back view. © Gongbing Shan

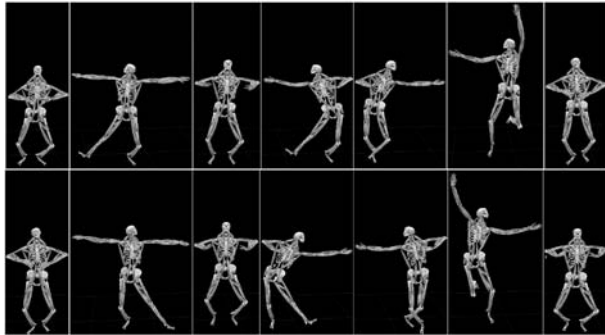
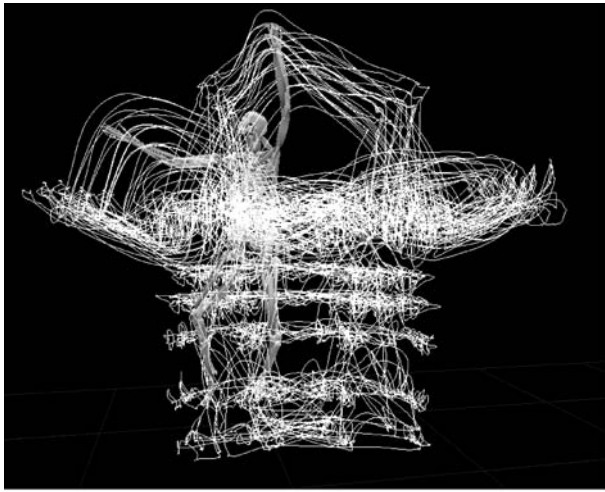


Fig. 8. Indian classical dance I: (top) front view showing body trajectory lines. (bottom) sequential stop-frame reconstruction of the movement. (© Gongbing Shan)

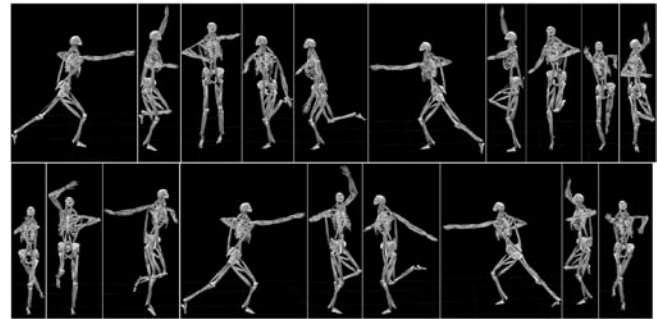
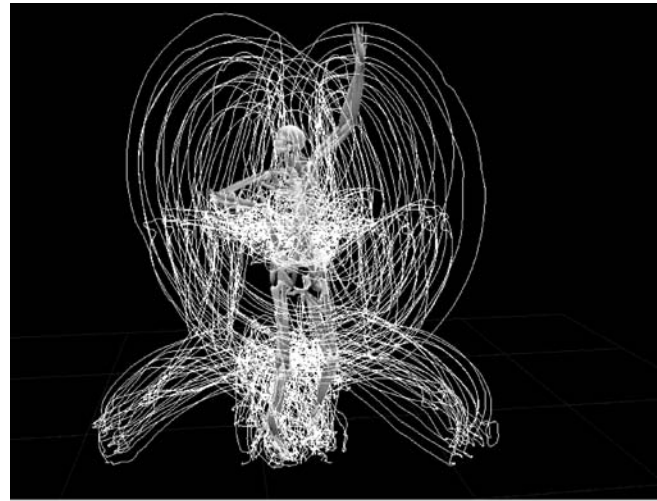


Fig. 9. Indian classical dance II: (top) front view showing body trajectory lines. (bottom) sequential stop-frame reconstruction of the movement. (© Gongbing Shan)

It also imparted scale to the overall gesture—a larger movement dimension as a whole.

Quality of movement: Abrupt changes in trajectory direction (points of curvilinear discontinuity) showed the release of pent-up power, a quality related to dynamism. Even with the referential human form removed from the trajectory image, the essential characteristics of the resultant signature were clear (Fig. 6b).

Example 4 was a signature generated by a *Grand Jeté* from classical ballet and had signature characteristics of balancing (Fig. 7a).

Stability and quality: A dense mass of trajectories and a planar orientation in the central trajectories of the image (trunk) were evidence of balance and control. These contrasted with trajectories (e.g. of the arm) whose excursions had a rotational focal point (i.e. the shoulder), and the regularity of the curvilinear path clearly indicated fluidity and speed.

Athleticism, dynamism and dimensionality: A top view of the activity emphasized athleticism and dimensionality of the movement (Fig. 7b). Building and release of energy was obviously apparent in angular trajectory lines and in swirls that occurred toward the end of trajectory lines.

Quality of movement: Continuity of trajectories indicated smooth, controlled gestures, except for an acute-angle structure occurring at the apex of the foot excursion—again indicating physical thresholds of the participant and a point of energy release.

Example 5 showed fundamental skills of classical Indian dance (Figs 8–10). In this art form, hand gestures and steps were executed according to highly codified traditions. In Indian dance, different combinations of gestures and movements provide a huge vocabulary through which stories can be depicted in surprising detail, perhaps intended to surpass the spoken word. The theatrical aspect of Indian dance is combined with purely aesthetic movement.

Stability and control: The clearly formal structure of trajectory lines showed controlled movement. Layered densities of line showed elements of architectural symmetry, balance and regularity and consistency of movement. The center of gravity was virtually fixed in a horizontal plane. Arch-shaped trajectories (arms) revealed weight, rhythm and smoothness. Such characteristics, particularly the symmetrical, architectural references that were the result of highly codified

training, could perhaps be seen to be cultural indicators.

Athleticism and quality: Continuous gesture trajectories, along with no obvious points of curvilinear irregularity, indicated dynamism to be relatively unimportant. Energy expenditure was directed toward control rather than athleticism, which would have had more indications of gathering and release.

Dimensionality: Generally compact excursions of trajectory lines suggested movements in a limited space.

DISCUSSION

Attempts to compress the spatial and temporal into single-frame images must necessarily be connected to the original structure—as an analogy for a story. Two-dimensional images are not necessarily limited to an explicit rejection of narrative. We agree with Krauss that “the sequential progress of the story does not achieve resolution but rather, repression. . . . That is, for a given culture, the contradiction [between image and narrative] is a powerful one, one that will not go away, but will only go, so to speak, underground” [13]. For human movement, the experiential nature of bodily

ness is a link connecting the spatial and the temporal. Activities such as sports, dance and performance are loaded with cultural myths, whether it is the embodiment of the warrior class, religious symbolism or the inertia of cultural fashion. Movement signatures necessarily play a role in storytelling.

This assertion acknowledges important differences between the concepts of *history* and *etiology*. Whereas history is often viewed as developmental, which should not be conflated with eschatological, etiology investigates the conditions needed for historical change to take place. In the creation of an image, the image itself develops both “[in] an immediate and obvious way a supplementary message, in addition to the analogical context itself . . . and whose signified, whether aesthetic or ideological, refers to a certain ‘culture’ of the society receiving the message” [14]. Change occurs within the context of culture—whether biologically or philosophically motivated.

Examining sports, the tradition (etiology), as a surrogate for warrior-class activities, emphasizes power and speed, with sublimated elements such as control and balance. These are signature elements of activities derived from a tradition of battle. Accuracy may also be revealed through repeatability demonstrated in successive trials. Culturally, armies (and sports teams) are an extension of the concept of championing, whereby selected representatives of the group pit their skills against opponents in proxy

for the group as a whole. The signatures of exemplary activities 1–3 (above) reveal the identified characteristics.

Performing arts activities such as dance represent traditions that can also be understood as a proxy; one for the *values* of the group heritage—whether religious or secular. In the case of Example 4, the Grand Jeté, cultural references are rooted in the court of Louis XIV, where the foundations of classical ballet originated and dance was used as a political tool. As a matter of note, when he took power after reaching the age of majority, Louis the XIV, a virtuoso dancer, performed in an allegorical ballet, dressed as the Sun God Apollo, “which depicted the glorious rising of the sun following the events of the night. The rising symbolized the rising of the King, le Roi Soleil, who was surrounded by dancers representing Honor, Grace, Love, Courage, Victory, Favor, Renown, and Peace” [15]. From this time forward, Louis XIV’s noble class devoted much of their efforts to learning ballet in order to imitate the noble bearing of the King. Hence, fundamental signature elements—upright bearing, control, naturalness, harmony and order, and demonstrated strength through elegant fluidity—became highly codified; controlled symmetrical dance structures and steps were analogous with the nobility of the King and his natural, god-given place in the universe. These elements are still present in the fundamentals of ballet today (Example 4).

Clearly, many activities can be viewed

as culturally weighted. The East Indian dance figures associated with Example 5 are visually distinctive, with characteristics that display cultural implications. In highly codified dance traditions, stylization is meant to capture something that is meaningful to or representative of the culture. Thus the movement signatures can be seen to embody aesthetic qualities and values of that culture. In East Indian dance, iconography is very direct [16]. Much of it is related to storytelling (religious or historical) through gesture. Formal, architectural structures, stability and control can be attributed to the rhetorical cohesion needed to tell these stories. Although it is beyond the scope of this current research, we speculate that such information could be used in sociological and/or anthropological studies. Furthermore, it might also be used as a bridge in the exchange of cross-cultural ideas.

In summary, we have examined five human movement activities from the fields of sport and dance. In each of these, movement was outcome driven. As such, the movements were repeatable, a characteristic that is emphasized by training, and had gestural form and aesthetic qualities that were related to desired outcomes rooted in the cultural psyche.

Two-dimensional images that trace movement trajectories communicate something of bodiliness to the extent that, as abstractions, they present tangible qualities that capitalize on the viewer’s familiarity with the human condition.

Fig. 10. Indian classical dance III: (top) front view showing body trajectory lines. (bottom) sequential stop-frame reconstruction of the movement. (© Gongbing Shan)

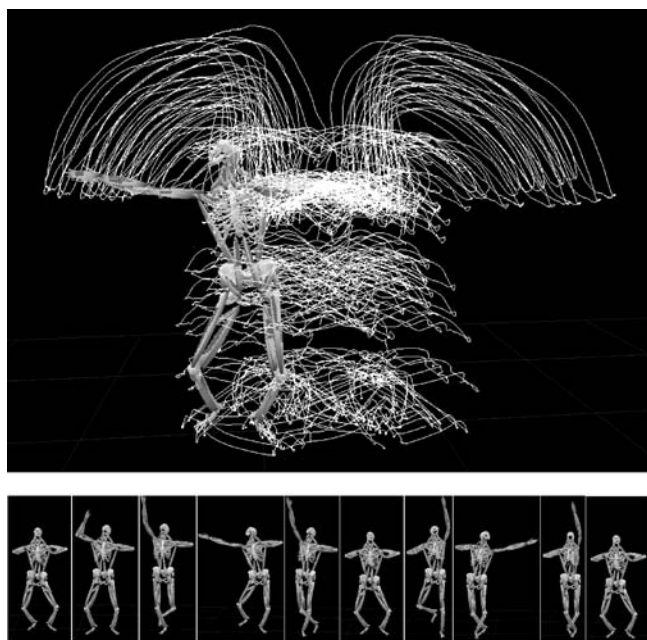
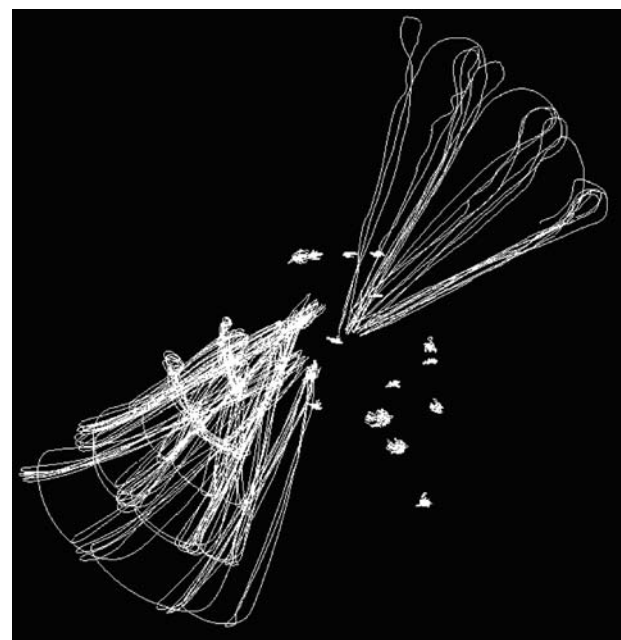


Fig. 11. Activity for readers to identify. (© Gongbing Shan)



Clearly differing from signatures of motions that are less bodily dependent, this quality is distinctive. The experience of the viewer bridges any gaps between perception and understanding of trajectory-based images as representative of human movement. This experience imbues trajectory data with meaning, providing a third dimension to a still image, even without the inclusion of a human form (see Fig. 6b).

In Fig. 11, we further extended this thesis to an activity that included the use of a tool. Trajectory images showed characteristics that could clearly be understood as both bodily and mechanical.

Stability and control: The clearly repetitive structure of trajectory lines showed controlled movement. Consistent and linear elements in the center of the image expressed the mechanistic, while curvilinear trajectories at the proximal and distal ends of these lines showed an element of bodiliness. Stability was further made clear by the 13 near-static trajectory “blobs” in the center of the image. There was a clear asymmetry in the image trajectories, a quality that reinforced the impression of a bodily function being connected to the use of a tool in the service of mechanism.

Athleticism and Quality: Continuous gesture trajectories with no obvious points of curvilinear irregularity indicated dynamism to be relatively unimportant. Energy expenditure was directed toward control.

Dimensionality: Generally compact excursions of trajectory lines suggested movements in a limited space.

Readers are challenged to identify the activity depicted in Fig. 11. The answer is revealed in Note [17].

Sensitivity to movement signatures creates conceptual links between bodiliness and our experience with it as a temporal medium. This provides an additional dimension for still imagery, one that sometimes can have additional layers of meaning associated with cultural mythos. Data obtained through the use of many different technologies has similar potential. For example, filmmakers and animators have already incorporated such concepts in their work. However, this work is too literal, and viewers’ access to ideas is limited by content creators’ narratives. Simply put, the film/animation’s appearance of objectivity effectively hinders the possibilities of conceiving of the information as merely another kind of metaphor for the human experience. “There is . . . no filmed scene whose objectivity is not finally read as the very sign

of objectivity” [18]. Synthetic interpretation and objective representation may be two sides of the same coin, but the conceptual interface between the two is a way of thinking.

CONCLUSION

Motion-capture technology is specifically designed for time-based 3D recreation of movement. The current study shows motion-capture technology to be an effective tool for synthesizing time-based trajectory information into single-frame, time-independent images that contain useful information about movements and gestures. Since the technology was designed to effect time-based analysis, it may appear counterintuitive to use it in such a manner, that is, in single images. However, our discussion shows that these images can be an effective metaphor for the human experience, since they provide objective representations (measured trajectories) that inform human perception and stimulate interpretations (through visual suggestions of key characteristics related to human movement). They do so in a manner that is both objective and faithful to the nature of the movements. Images generated in this manner can be related to the human form by interpreting the qualities of and relationships among trajectory lines. Effectively, such images can be understood as signatures of human movement containing latent and communicative content related to bodiliness—gestural representations that may be understood in a manner that is experientially or culturally dependent.

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17. These descriptors are consistent with Fig. 11’s representation of the activity of violin performance.

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Gongbing Shan obtained his Ph.D. (1998) in biomechanics from the University of Münster, Germany. He is the founder of Biomechanics Lab at the University of Lethbridge, Canada, and an associate professor in the Department of Kinesiology of the same university. His research interests include biomechanics of human locomotion and performance. Two of his artworks created using biomechanics technology were exhibited in New York and New Jersey.

Peter Visentin received his master’s degree in music performance (violin) from the University of Toronto in 1986. He performs on both modern and baroque violins and has given hundreds of performances in North America, Europe, China, Japan and Australia. He uses motion capture to study human movement and gesture as they pertain to music performance, conducting, non-verbal communication and repetitive stress injuries.

Tanya Harnett is an assistant professor at University of Lethbridge, Canada, with teaching responsibilities in Native American Studies and in Art. Using the manipulation and reprocessing of photography, and digital imagery combined with painting and drawing, she explores gesture, materiality, feminism, spirituality, hierarchy of media, technological modes of representation and organic contrasts.