Is Walking Just a Boring Dance?

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A talk on how ideas from ballroom dancing can help us design a high-level architecture for whole-body motion control of robots
What’s wrong with robot (humanoid) motion?

- too compartmentalized
- motions are too discrete and too prescribed
- lack of smooth, efficient transitions
- repertoire too small
- too much emphasis on cyclic motion and not enough on variety
- no coherent unifying theory
What about Khatib’s operational–space formalism?

+ best formalism we currently have for *instantaneous* whole–body motion

- but it needs to be extended into the 4th dimension (time)

We need a formalism that works with *atomic motion activities* in the same way that Khatib’s formalism works with instantaneous acceleration and force.
What is an atomic motion activity?

(a vague idea that needs to be refined through a programme of robot motion research)

definition: (first attempt)

- a single use of a subset of a robot’s motion freedom (such as a single limb) for a single elementary purpose over a single period of time
Some tentative examples (for a single leg)

- flight phase for energy-efficient walk
- high-clearance (obstacle avoiding) flight phase
- landing for a walking step
- landing for a jogging step
- careful landing for a slippery surface
- quiet landing for stealthy creep
- walking stance phase, constant velocity
- walking stance phase, strong acceleration
How can we build a Khatib–like formalism from atomic motion activities?

1. Raibert–style hopping/running control systems prove that a controller can execute multiple activities simultaneously, even if they interfere slightly with each other.

2. A big enough repertoire of atomic activities will contain redundancies, and therefore also a null space, allowing Khatib’s methods to be applied (in principle).
A redundancy example

two implementations of an accelerative stance for a Raibert–style monopod
A redundancy example

two implementations of an accelerative stance for a Raibert–style monopod
A redundancy example

two implementations of an accelerative stance for a Raibert–style monopod

- foot force acts along line of leg
- foot force is servoed to achieve zero moment of impulse about CG
Why is a formalism based on motion activity better than one based on instantaneous motion?

1. It introduces an element of *anticipation*
   - synchronise slow and fast actuators
   - increase peak performance
   - reduce time delays

2. Motion activities can incorporate knowledge of a particular robot mechanism
   - energy–optimal atomic motions
   - possibility to adapt and improve
   - ... and communicate those improvements to another robot
What does (ballroom) dancing have to offer?

- dancing is organised motion
- dancing is quality motion
- dancing is non-cyclic motion
- dancing incorporates a huge variety of motion, including:
  - vigorous, energetic motion
  - motions requiring a high degree of skill
  - physical interaction with a partner
- dancing can be codified
Dance steps

- a dance step is a short sequence of footsteps, possibly accompanied by other movements
- dance steps are the *atomic units* of a dance
- a dance is a collection of dance steps — if you know the steps then you know the dance

Here’s an example . . .
Whisk (Waltz)

Wall

line of dance

sequence of steps
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Whisk (Waltz)

Wall

line of dance

more details
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Whisk (Waltz)

Wall

- Line of dance
- Closed
- Promenade
- Yet more details
Dance routines

- a dance routine is a sequence of dance steps
- there are rules on how to sequence dance steps, which depend on
  - which foot is free
  - the orientation of the couple
  - their dance position
Variability

- a dance step is *atomic* because it is indivisible

- but a dance step is also *elastic* because it can be modified to suit the circumstances

Things that can be modified include:

- speed (usually dictated by the music)
- amount of turn
- amount of travel
Smoothness and flow

- novice dancers execute dance steps discretely, causing a stop–start effect at the end of each dance step
- experienced dancers learn to modify the end of each dance step so as to make it flow smoothly into the next step

Robots should copy this strategy.
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Is this a useful analogy?
Sequencing atomic motion activities

We need to think about

- the range of acceptable initial conditions
- the range of achievable final conditions
- the error margin due to uncertainties and environmental disturbances
- resources (actuators) required by an activity
- compatibility with other concurrent activities
Sequencing atomic motion activities

range of acceptable initial conditions

atomic motion activity

range of achievable final conditions

error margin

target

time
Sequencing atomic motion activities

A sequence like this meets all entry/exit conditions, and therefore should execute correctly.

Planning a sequence like this looks like an AI constraint satisfaction problem.
Summary

- notions from the world of dancing might help us design a better robot motion control architecture
- the idea of an atomic motion activity needs to be fleshed out
- this approach could bring AI more closely involved in high-performance motion control
- there is a lot of work still to do