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

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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

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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.

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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
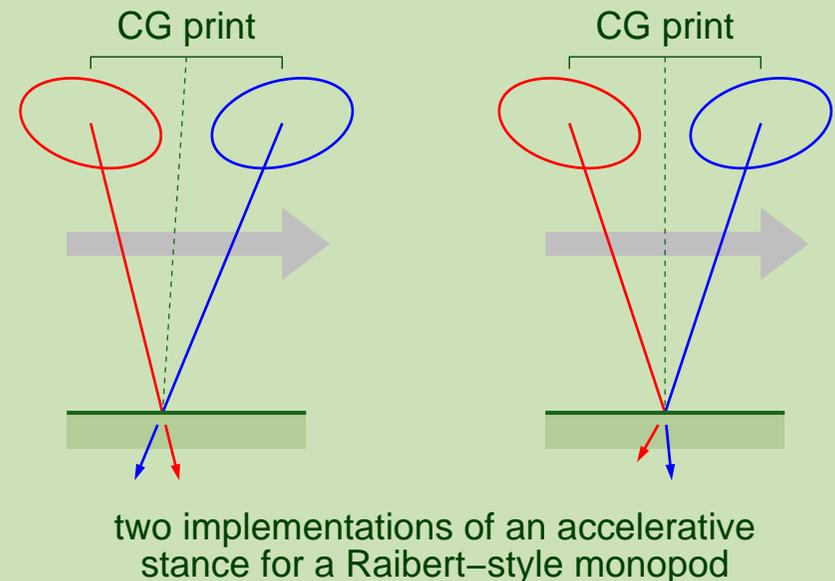
Some tentative examples (for a single leg)

- 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
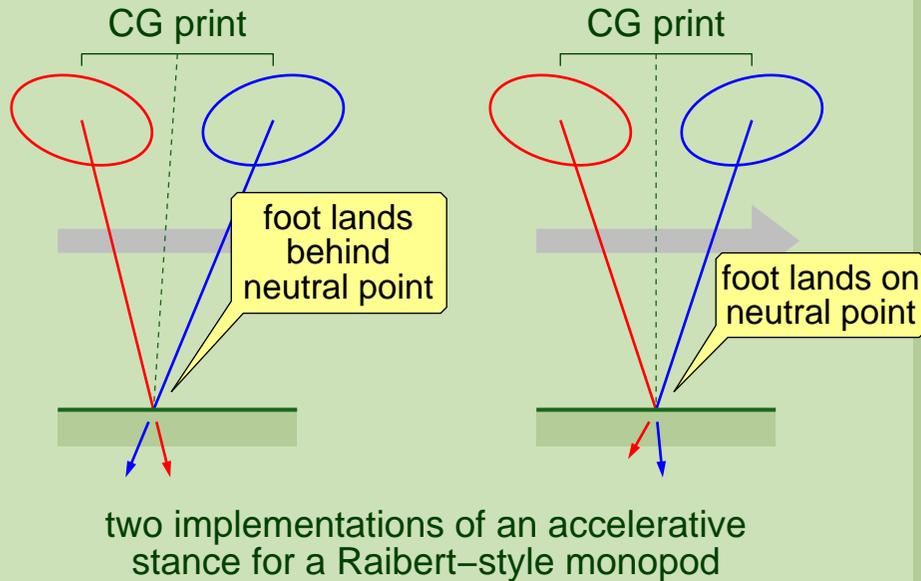- walking stance phase, strong acceleration

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)
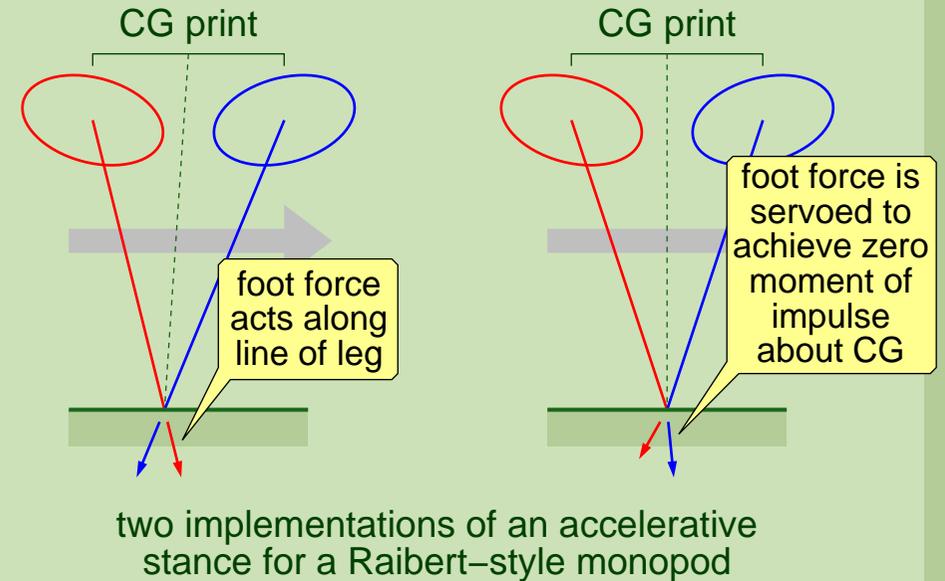
A redundancy example

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

Slide 9

A redundancy example

CG print   CG print

foot lands behind neutral point

foot lands on neutral point

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

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Slide 10

A redundancy example

CG print   CG print

foot force acts along line of leg

foot force is servoed to achieve zero moment of impulse about CG

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

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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

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Slide 12

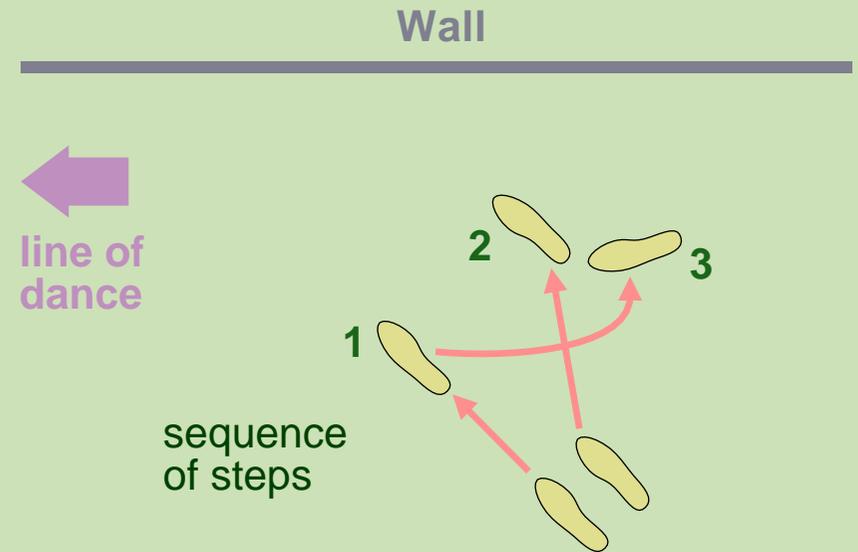What does (ballroom) dancing have to offer?

- 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
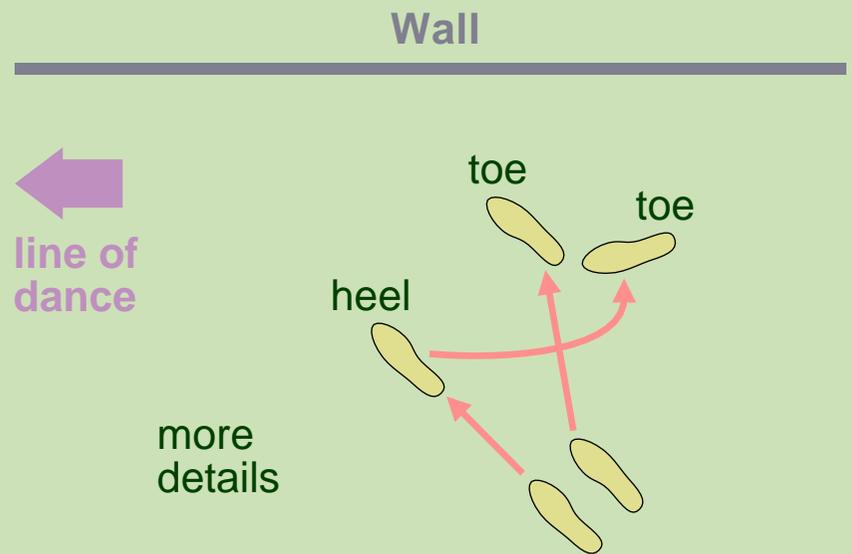- dancing can be codified

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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
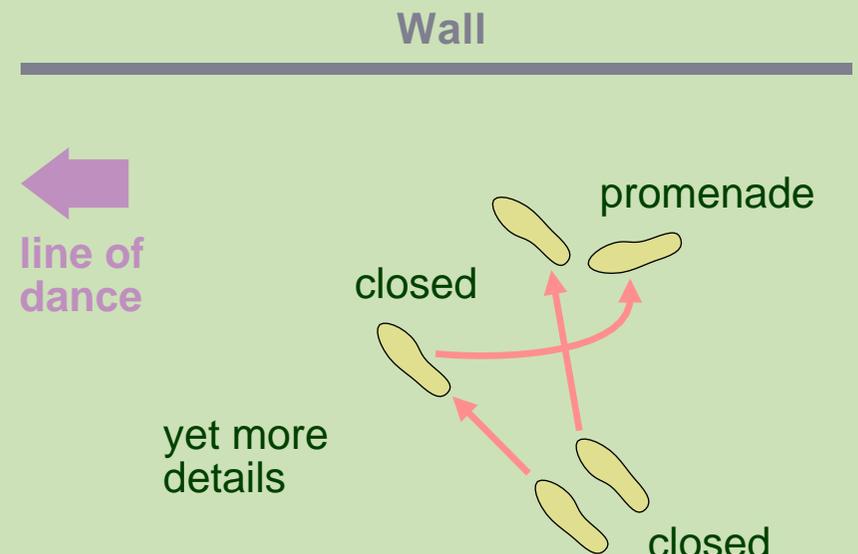
Here's an example . . .

Whisk (Waltz)

Wall

line of dance

2 **3** **1**

sequence of steps

Whisk (Waltz)

Wall

line of dance

toe
toe
heel

more details

Whisk (Waltz)

Wall

line of dance

promenade
closed
closed

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.
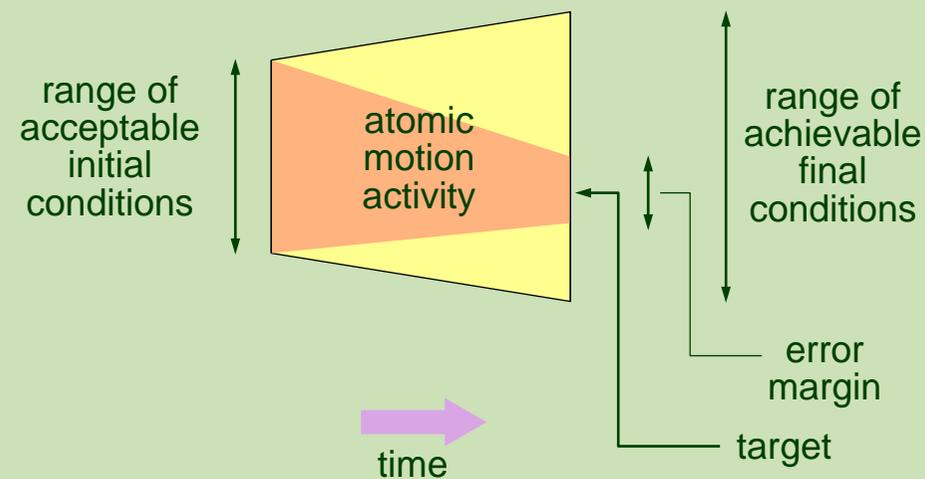
dance step ⟷ atomic motion activity
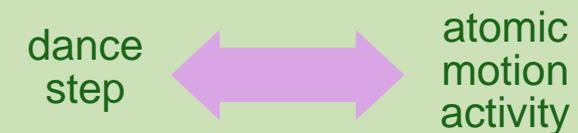
Is this a useful analogy?

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

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Sequencing atomic motion activities

range of acceptable initial conditions

atomic motion activity

range of achievable final conditions

error margin

target

time

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Sequencing atomic motion activities
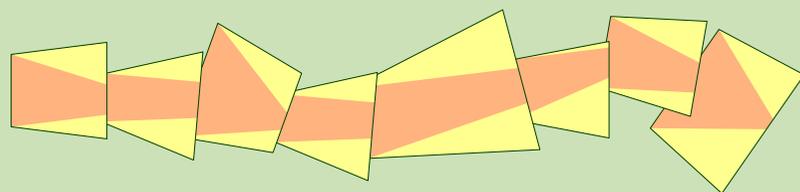
a sequence like this meets all entry/exit conditions, and therefore should execute correctly

planning a sequence like this looks like an AI constraint satisfaction problem

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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

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