Atomic Motions

Towards bottom-up motion synthesis for digital humans

Self Introduction

2021

James Cook University

Bachelor

Information Technology & Game Design

2022

MMLab, Nanyang Technological University

Research Intern

Evolutionary GAN Compression

2023

National University of Singapore

Master

Computer Science

2024

Human Motion Synthesis

New adventure!

What creates motion?

Motivation

Shaolin Temple, 18 km from my city

I always wanted to learn kung fu…

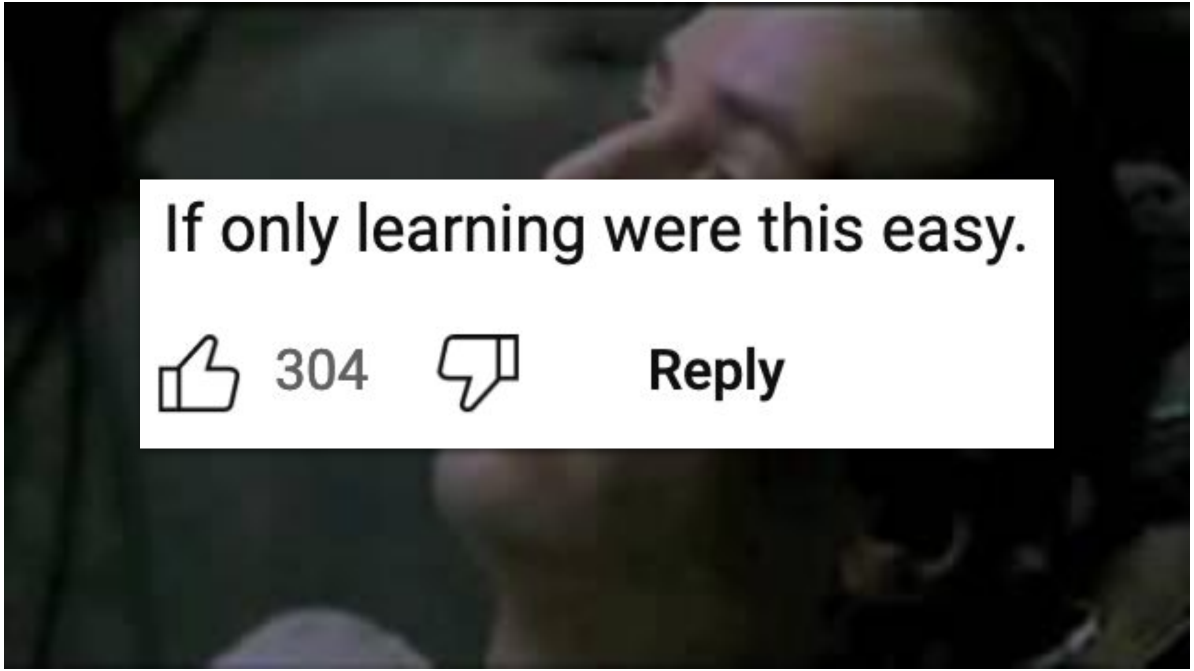
until I discovered computers.

How to do both?

Motivation

“I know kung fu.” (His digital human does.)

Motivation



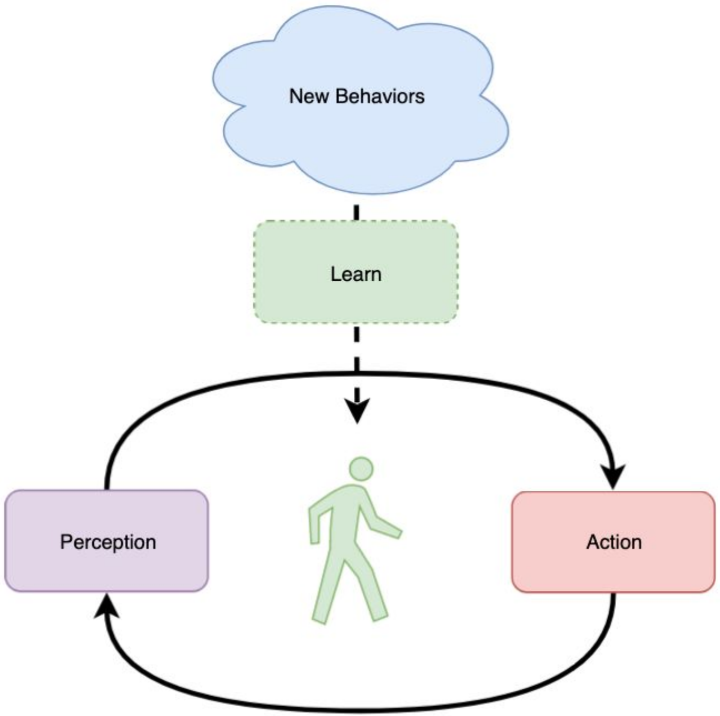
Top comment of “I know kung fu.”

Motivation

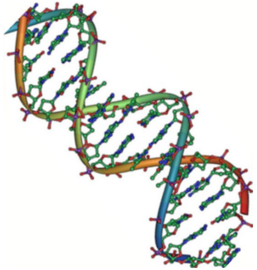
Digital humans should perform human-like behaviors like kung fu.

If not, can only call them “puppets”.

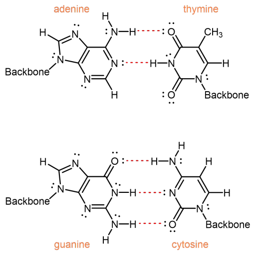
The basic behavior is motion.



What creates motion?



DNA



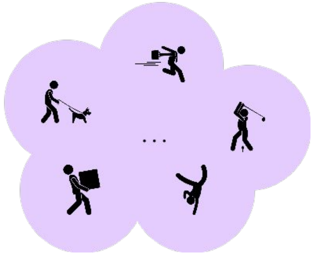
Nucleobases

The quick brown fox
jumps over
the lazy dog.

Sentence

quick brown
fox jump
lazy
dog

Words



Motion

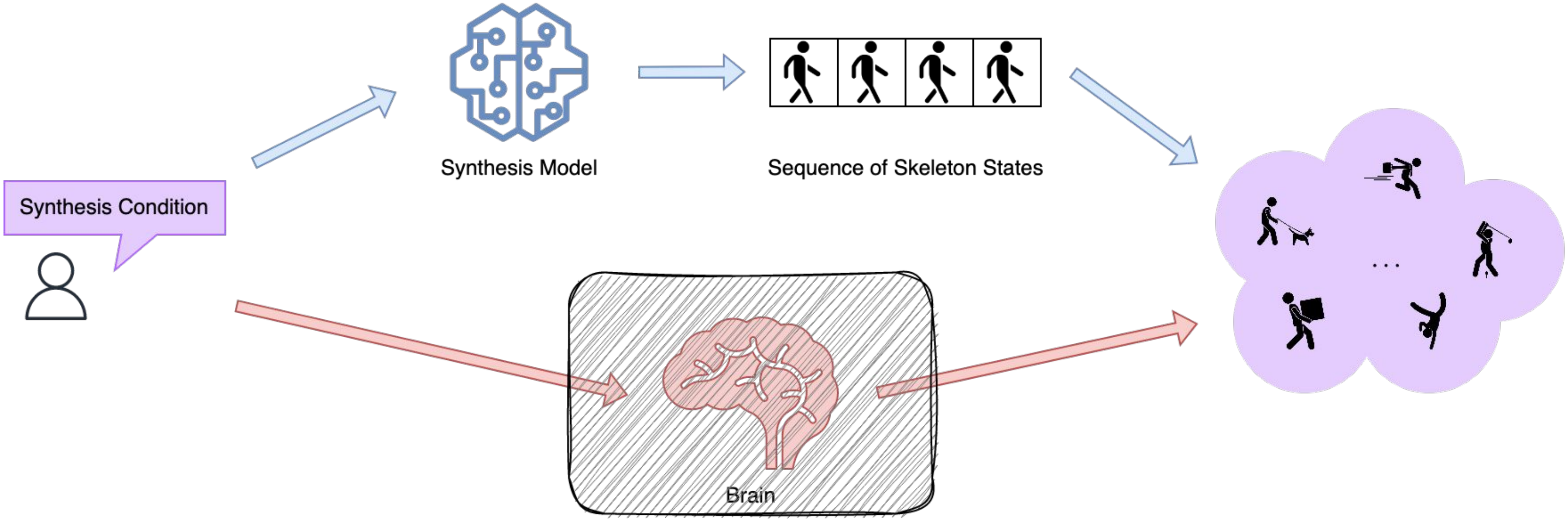
?

What creates motion?

We know how to capture and represent motion.

What creates motion?

Produce skeleton states instead.

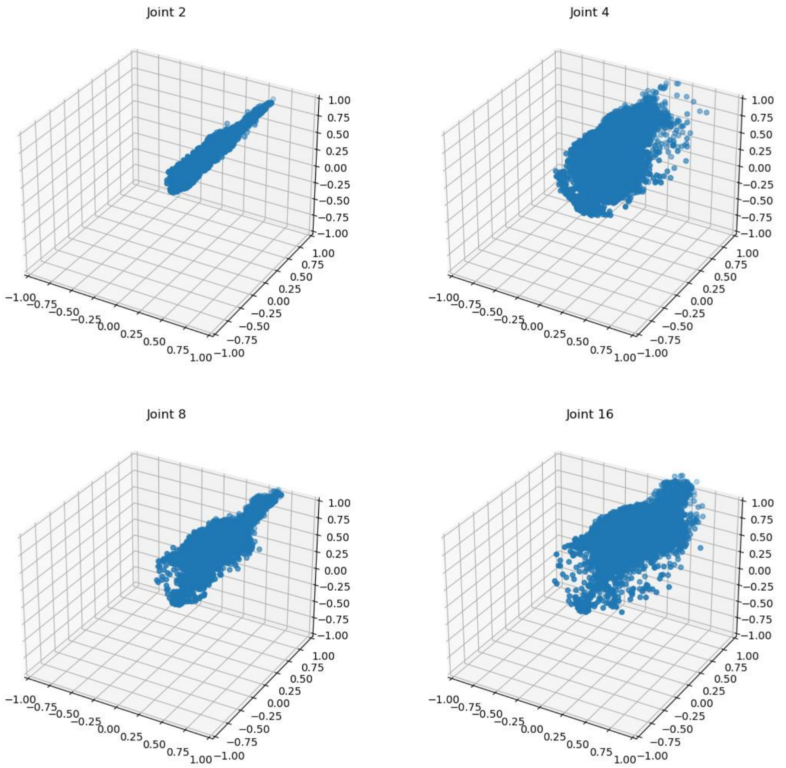


What creates motion?

Human motion occupies a very small portion of skeleton state space.

Weeding out this space is challenging.

What about humans?



What creates motion?

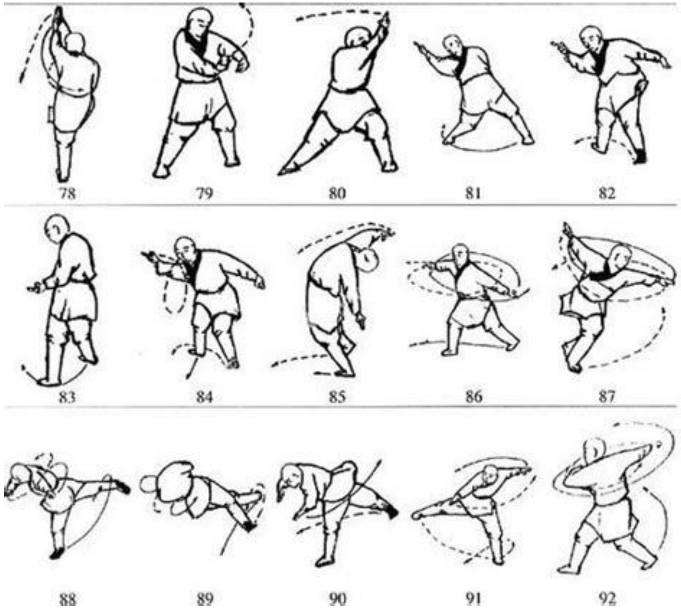
Humans learn how to move from

very small data

108 illustrations

=> 3 hours of performance

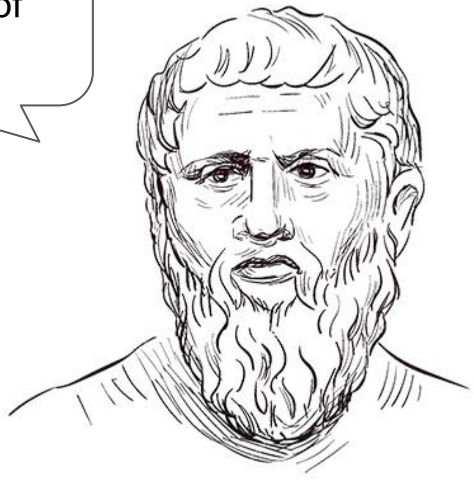
=> 129600 frames of 12Hz animation



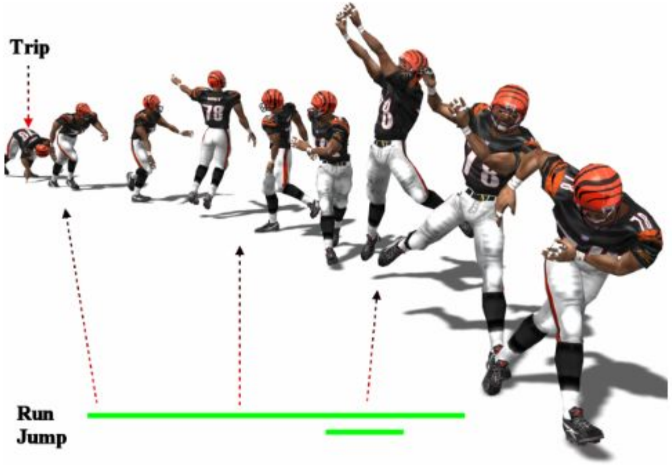
What creates motion efficiently?

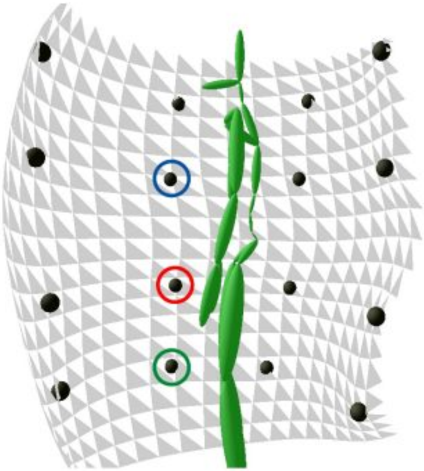
Plato

Self-motion is the very idea and essence of the soul.



2000s: Motions as Editing Templates

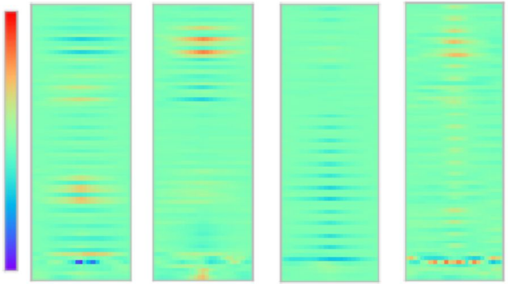




Dynamic programming to select from template motion snippets with a cost function.

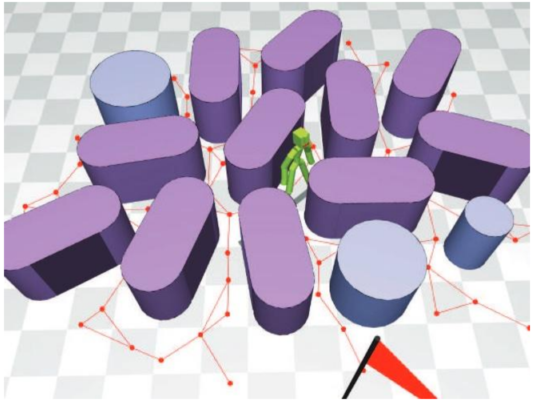
Interpolate template motion snippets (black dots) with kriging to reach new states (other vertices).

2010s: Motion Manifolds and other Goodies



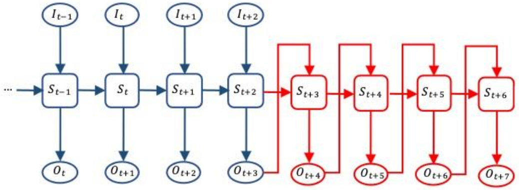
A motion manifold constraining a motion's degrees of freedom along time.

"Motions as low-dim features."*



Generating squeeze-through motions via path exploration.

"Motions as path optimization."

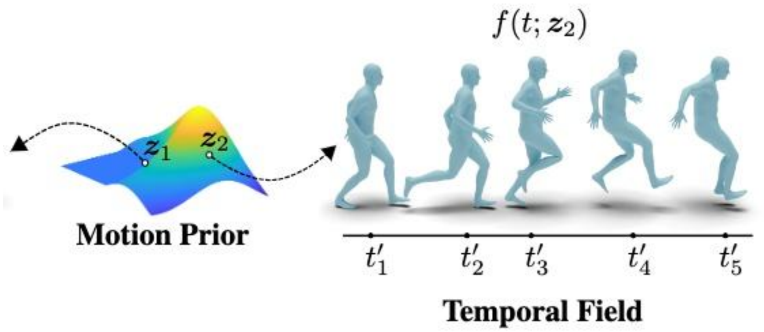


Predicting motion transitions in a Markov chain.

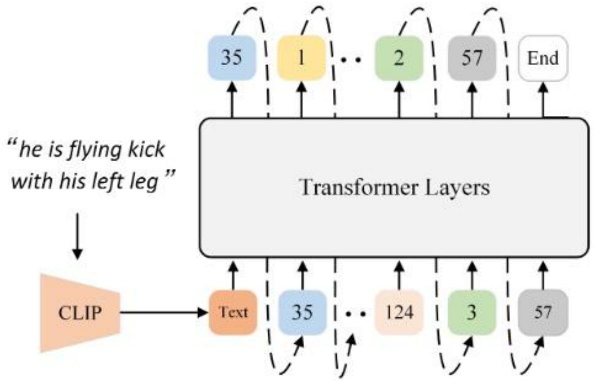
"Motions as state transitions."

*Linearly interpolatable low-dimensional states residing on a high-dimensional manifold.

2020s: Generative Manifolds and NLP

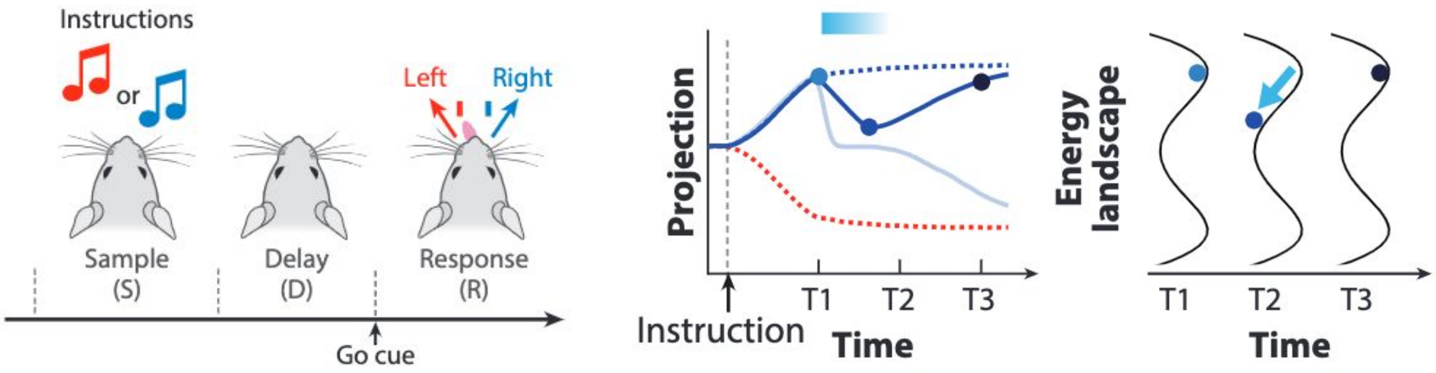


Motion manifolds become probabilistically described, or allowing noise injection.



Others treat motion as a language and translate synthesis conditions to it.

2020s: Neural Dynamics and Attractor Hypothesis



Exciting work in neuroscience: perturbation experiments change mice motions and supports attractor hypothesis:

Motion states are planned through a dynamical system.

Attractors are stable states encoding well-trained motions.

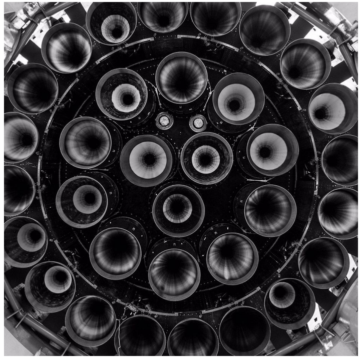
Top-down or Bottom-up?

From template editing to motion manifolds, lower-level building blocks are being explored.

RS-25 on Saturn V

Many advantages:

- Data and Computational Efficiency
- High-frequency Motion Details
- Motion Diversity



Raptors on SpaceX Starship

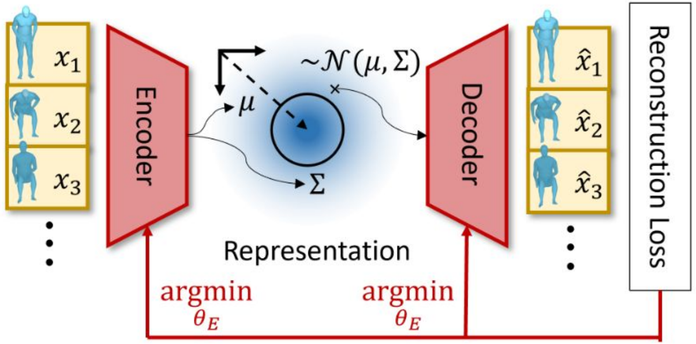
“There is plenty of room at the bottom.”
- Richard Feynman

Atomic Motions

The Existing Bottom-up Hypothesis

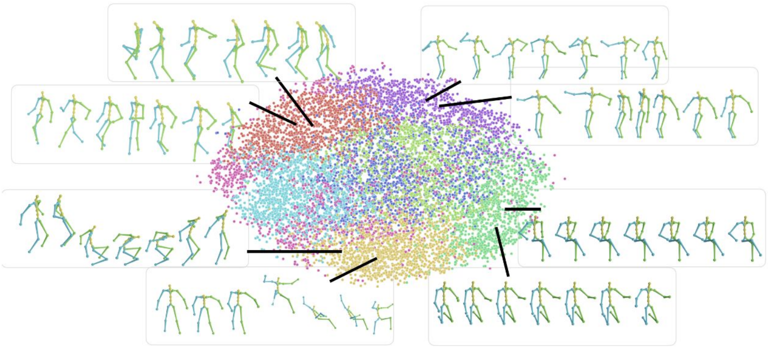
Building blocks construct a uniform, single-level structure for all motions.

- Often a hypersphere or multivariate normal.



Low distinction between building blocks.

- A uniform set of affinities.
- A uniform set of aversions.



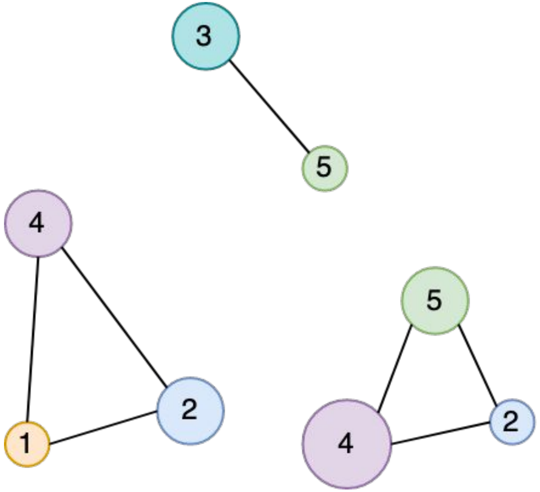
My Hypothesis

Atomic motions construct distinct, hierarchical structures to form distinct motions.

Each pair of atomic motions

- exhibits unique affinity.
- exhibits unique aversion.

A small set of atomic motions suffices to provide diverse motion structures.



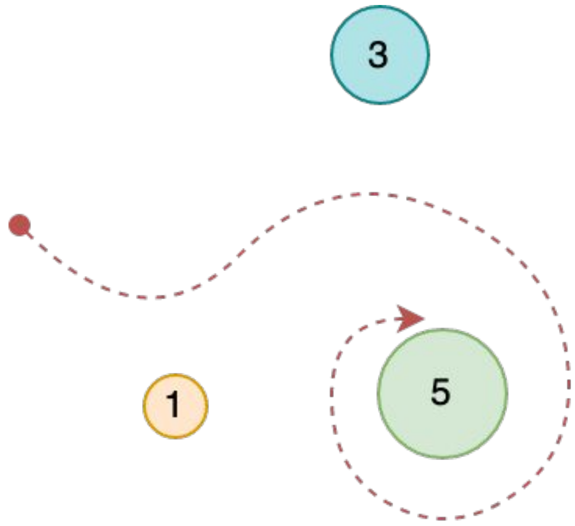
My Hypothesis

One additional assumption for motion planning:

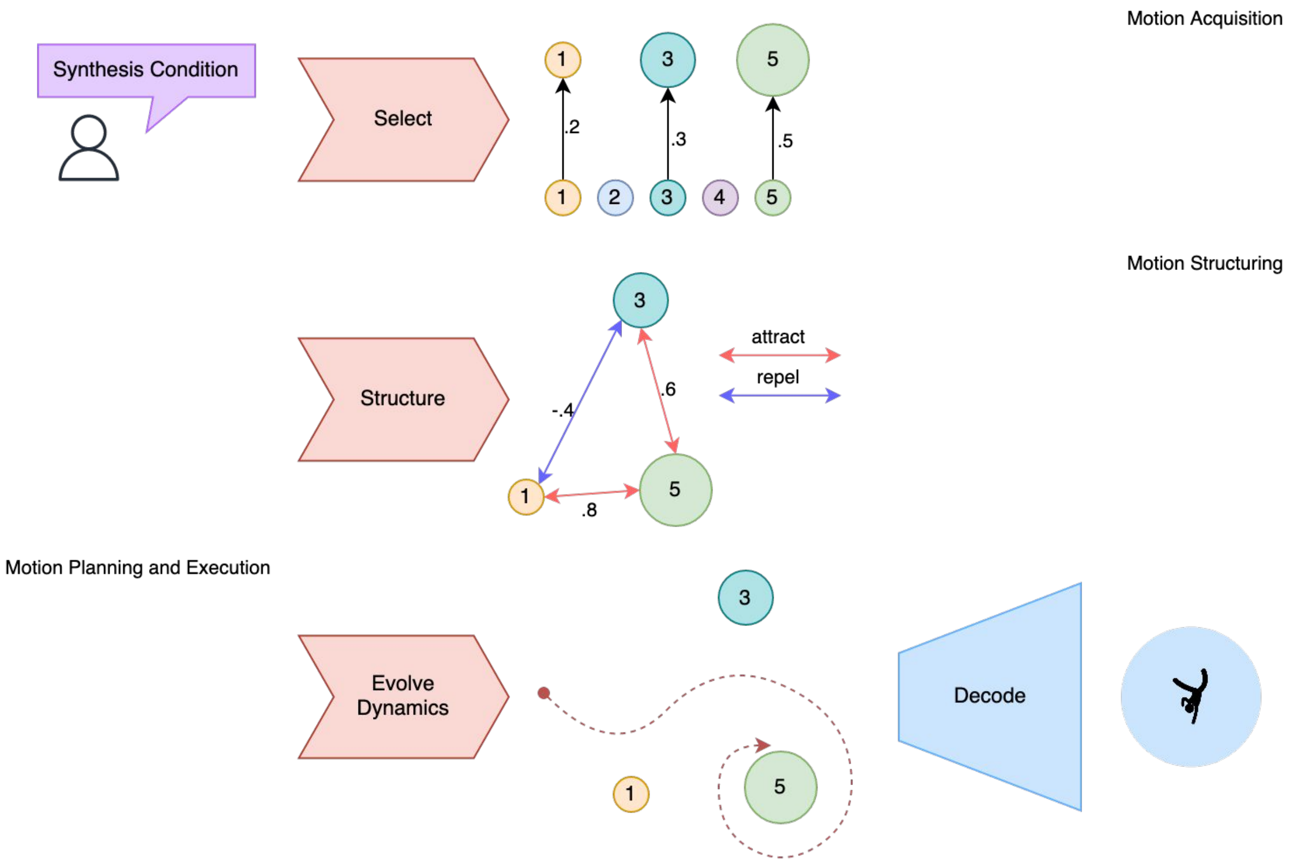
Given planning duration and motion structure,
a motion state is evolved in a
nonlinear dynamical system.

The structured atomic motions are stable states.

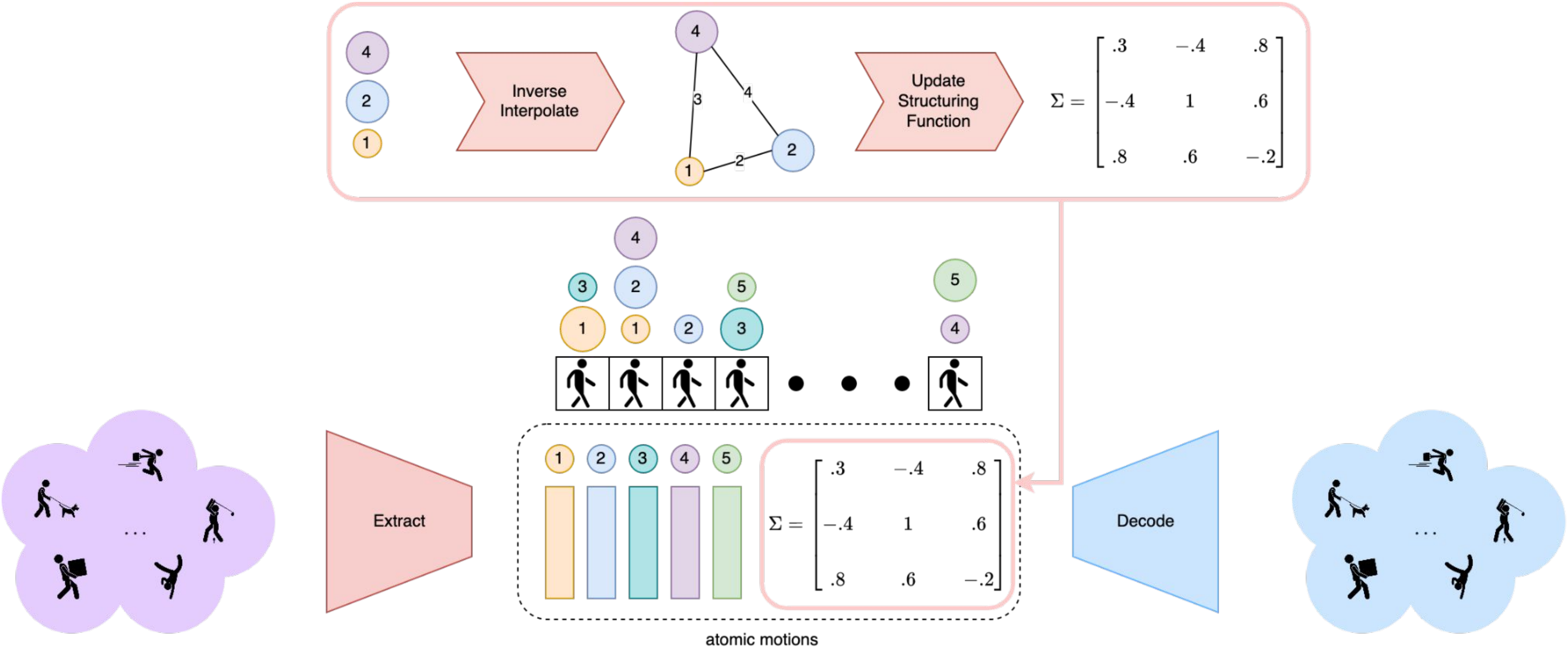
This assumption allows for optimal motion control.



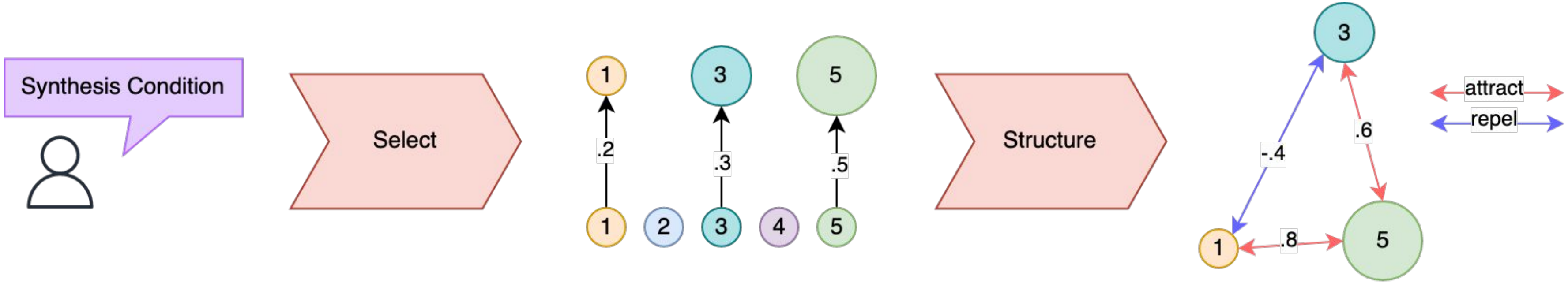
Overview of the Atomic Motions Framework



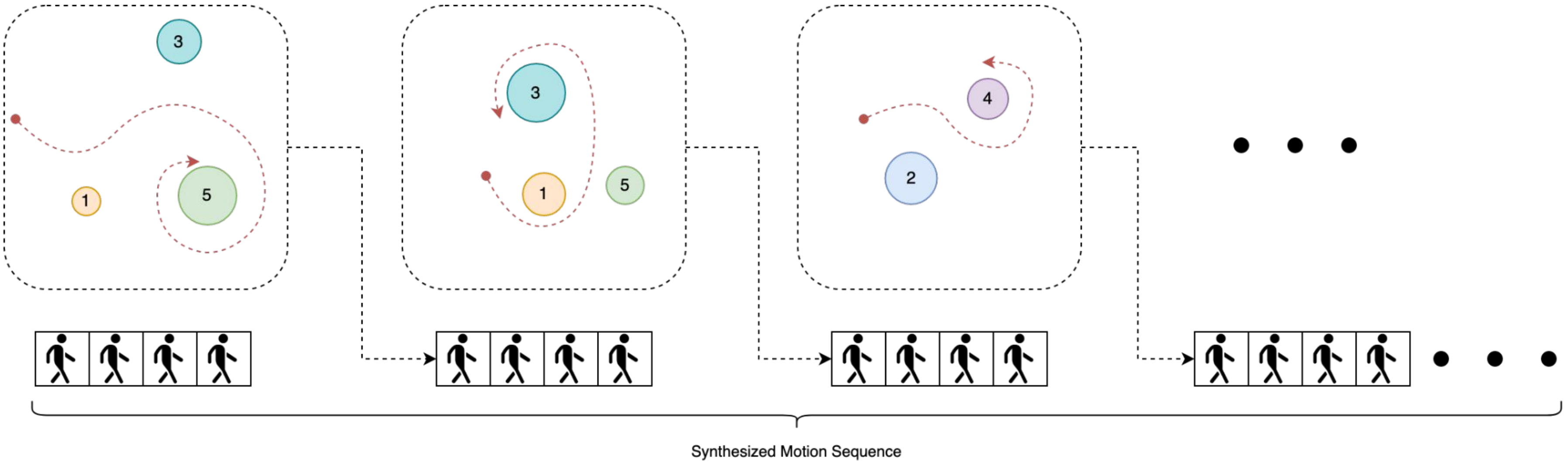
Pipeline 1: Extraction Stage



Pipeline 2: Selecting and Structuring Stages



Pipeline 3: Planning and Execution Stages



Grow structures and control dynamics with atomic motions.

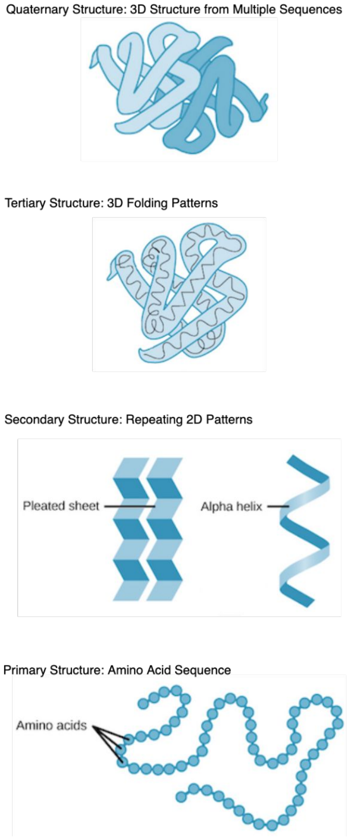
Growing Structures

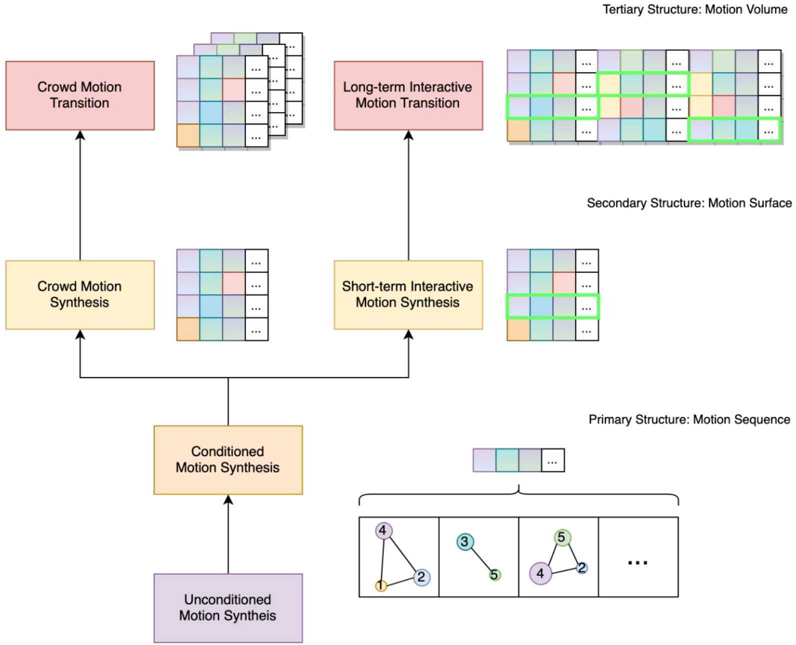
Amino acids grow into a protein structure.

Atomic motions grow to form complex motion structures.

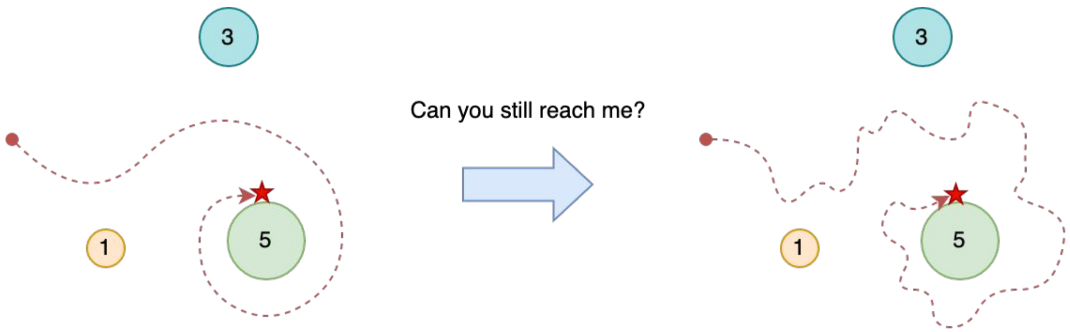
Top structures are always built with plausible low structures.

Synthesis conditions can be propagated down without looping.





Controlling Dynamics

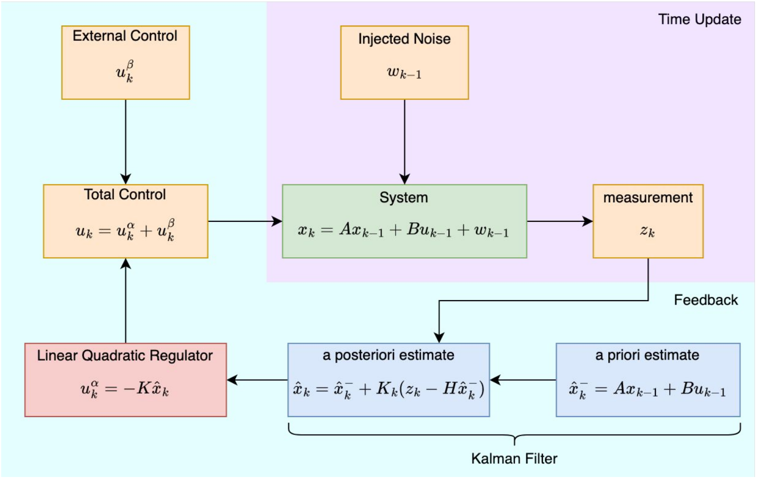


We want diverse plan dynamics between two motion states.

Disturbance noise is injected only in the middle.

Data-driven methods can't denoise the motion signal well to plan the next move.

We can get rid of it in our framework with Kalman filtering and optimal feedback control.



Controlling Dynamics: Motion Processing

Apply different filters in spectral domain of a plan trajectory to model different motion styles:

- FFT Components => Style Transfer
- Convolution => Smooth and Sharpen
- Optimal Filtering => Denoising and Compression

Nurturing data-efficient digital humans.

Data-efficent Digital Humans

Motion acquisition becomes cost-effective: atomic motions can be extracted from small data.

Computational cost also drops, meeting realtime needs in VR and crowd simulation.

Online learning is possible: atomic motions can be acquired through active sampling for novel tasks.

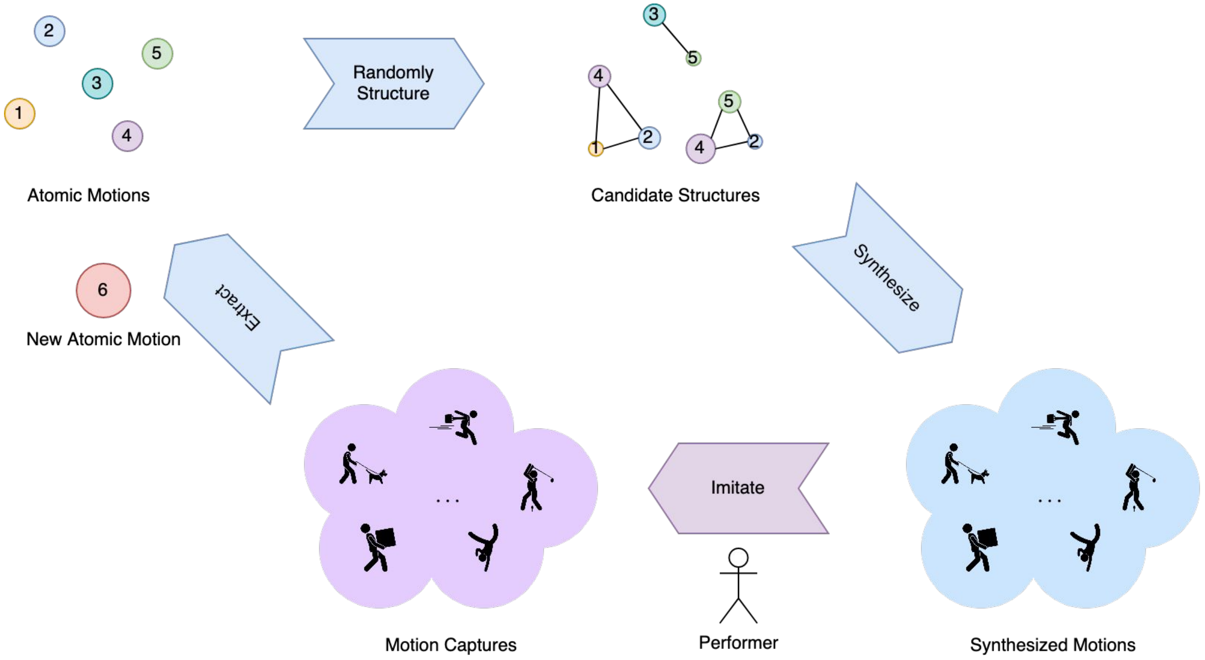
Meet challenges and limitations.

Data Collection

Essential motion features are hard to pick up if they are outliers in data.

Active sampling can help, but incurs human labor.

Its pipeline is also nontrivial to design and implement.



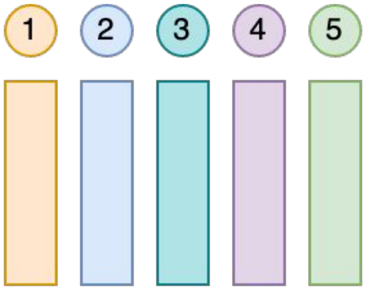
Information Quantification

How much information should we extract from a dataset?

- How many atomic motions?
- How long is each feature?
- How sparse is ∑?

Currently, can only answer with tedious ablation studies.

Better option is meta learning to optimize quantification parameters across synthesis tasks.



$$\Sigma = \begin{bmatrix} .3 & -.4 & .8 \\ -.4 & 1 & .6 \\ .8 & .6 & -.2 \end{bmatrix}$$

Motion Integration

Atomic motions only produce body motions. Eventually, we need to integrate with other partial motions:

- Face motions.
- Hand motions.

Distinct correlations between them must be respected.

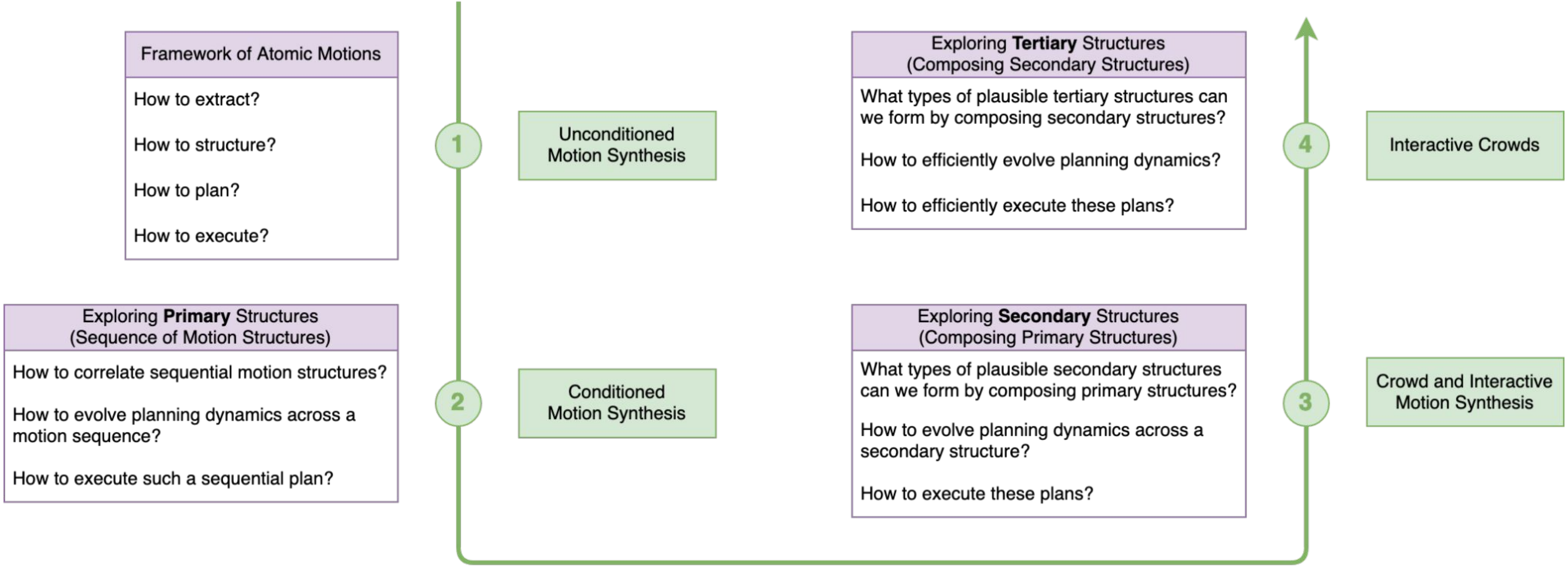
Atomic motions are too low-level to match with. Its higher-level structures are combinatorial.

It's ill-posed to observe these correlations from data.

Research Forecast

I want to nurture self-driven digital humans.

Research Forecast



Thank you. Questions?

Contact

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A much detailed version of this presentation is at https://wei-parker-guo.github.io/atomic_motions

(Alternatively, scan the QR code.)