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Pre-computed Data-driven Free Fall Animation

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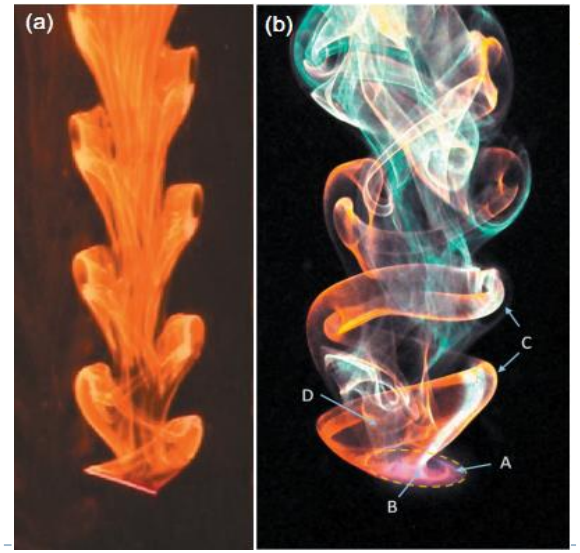
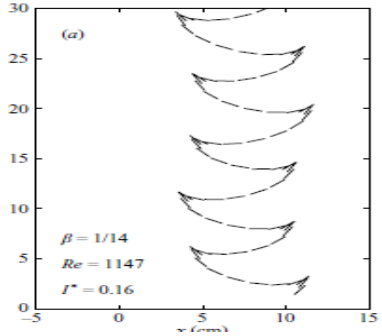
Introduction

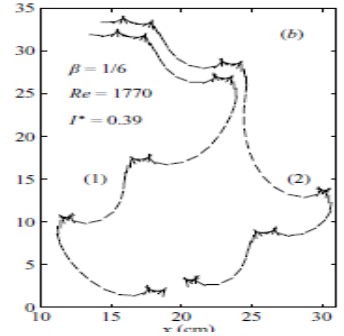
- Free fall motions of lightweight objects
- Trajectory search tree and pre-computed trajectory database
- Free fall motion graphs
- Data-driven probability model

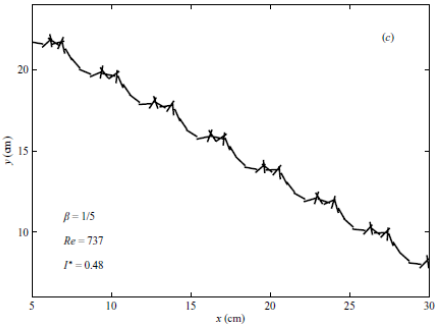
Related Work

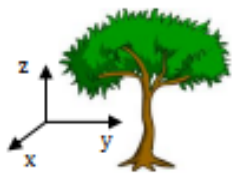
- Physical Research
  - from Maxwell,1853
  - [FIELD 1997]
  - [ANDERSEN 2005]
  - [RAZAVI 2010]
  - [ZHONG 2011]





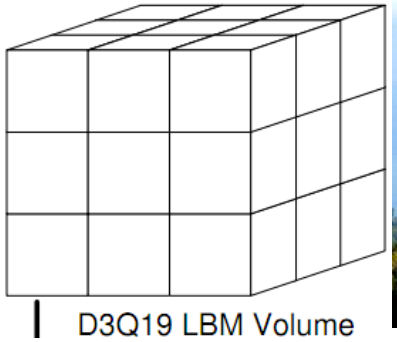


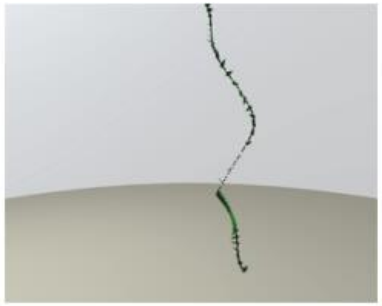


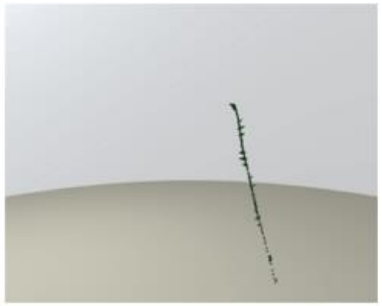


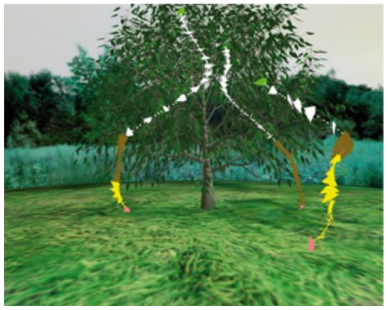
Graphical Research

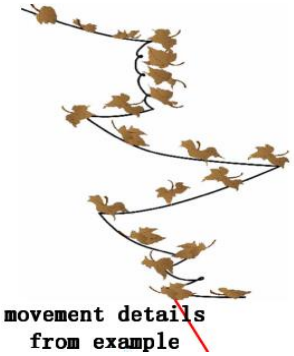
- [WEI 2003]
- [VAZUQUEZ 2008]
- [LI 2010]
- LightWave10

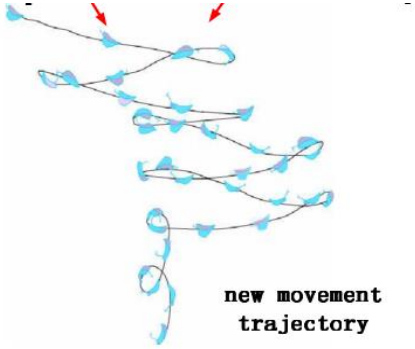




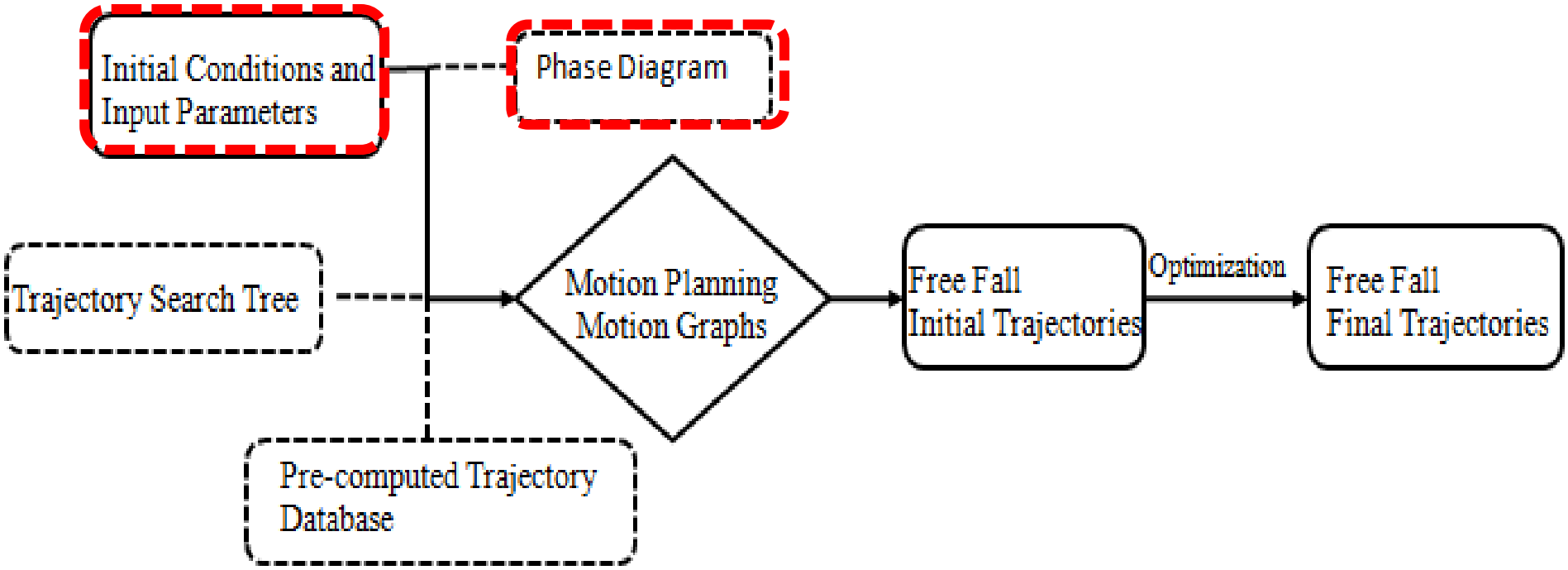






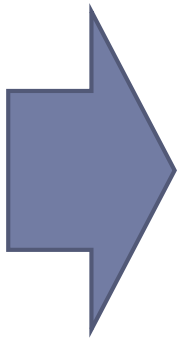


System Overview



Parameter Redefinition

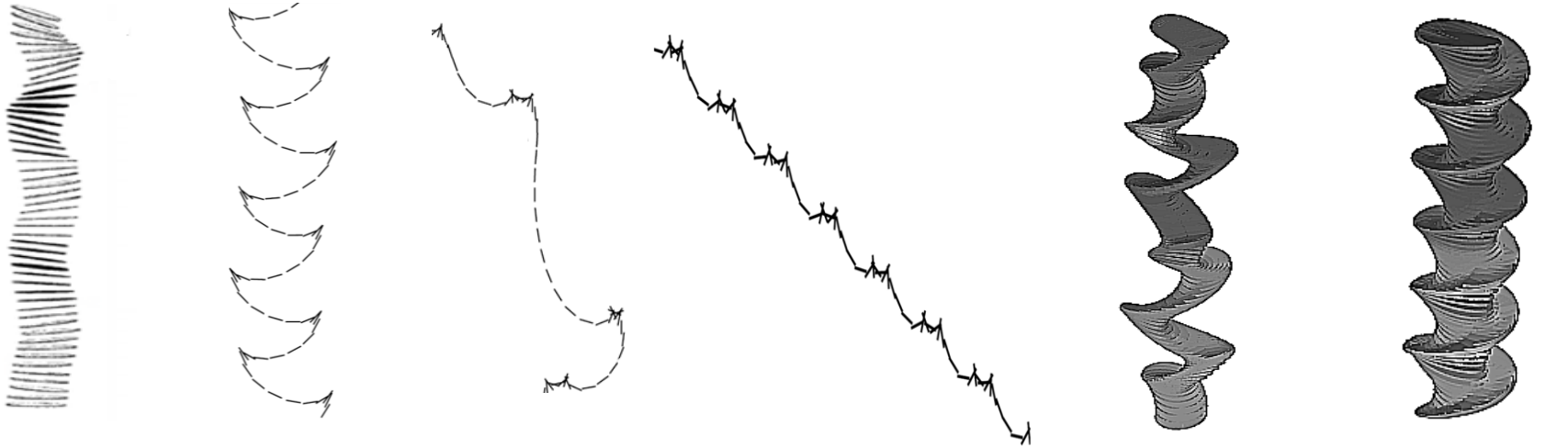
- Rigid-body
  - the length of object l
  - the length and width of the cross section: a, b
  - the density of the object
  - Released height h
  - Released initial angle
- Fluid
  - the density of the fluid
  - the kinematic viscosity of the fluid v
- Others
  - the gravity acceleration g



- Three dimensionless quantities
  - Reynolds number Re
  - Aspect ratio of object ε
  - The dimensionless moment of inertia I^*
- Average descent velocity

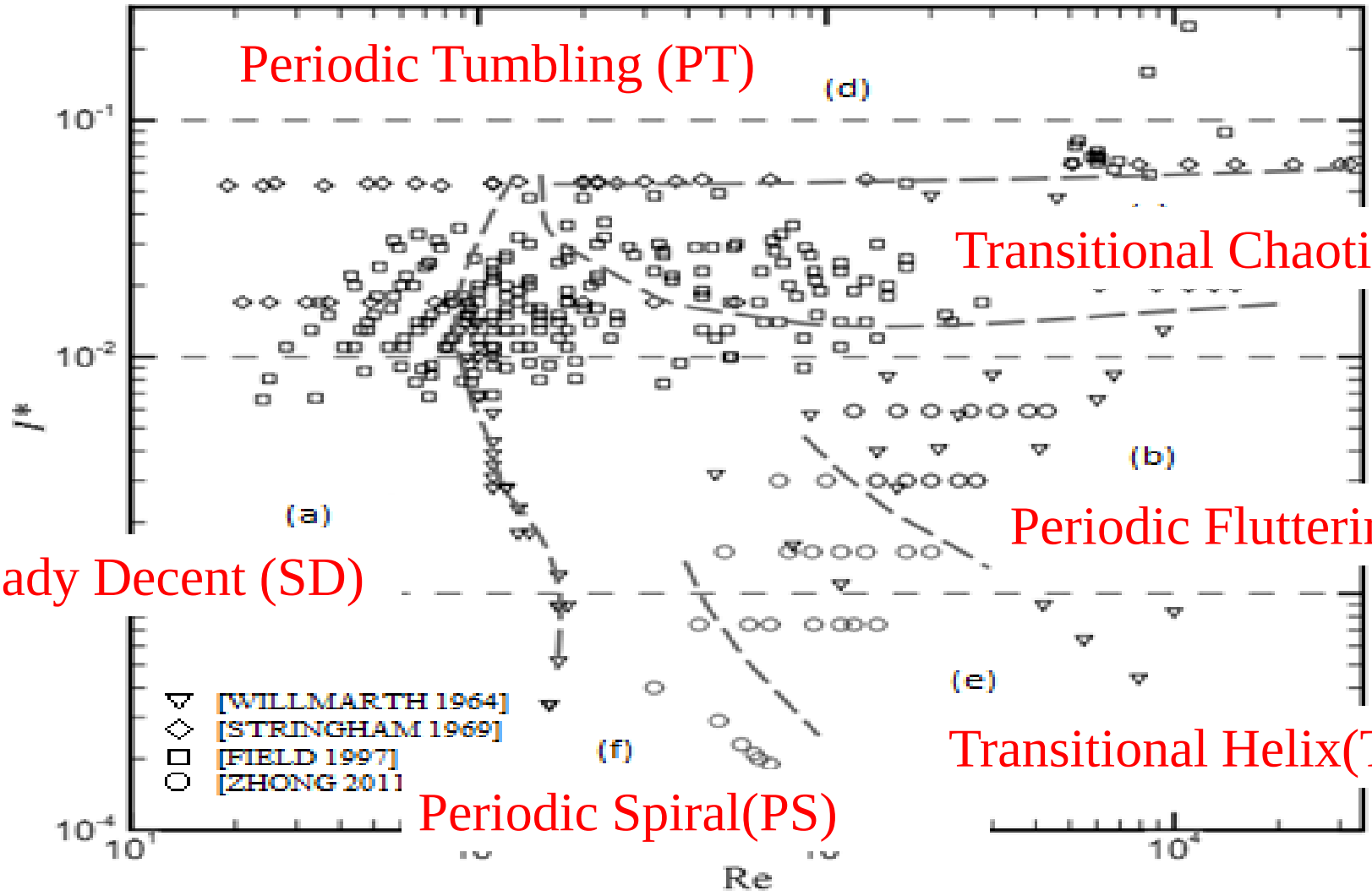
Measured Trajectories

Measured trajectories of six Motion Prototypes



(a)	(b)	(c)	(d)	(e)	(f)
Steady Decent	Periodic Fluttering	Transitional Chaotic	Periodic Tumbling	Transitional Helix	Periodic Spiral

Phase Diagram--**Six Motion Prototypes**



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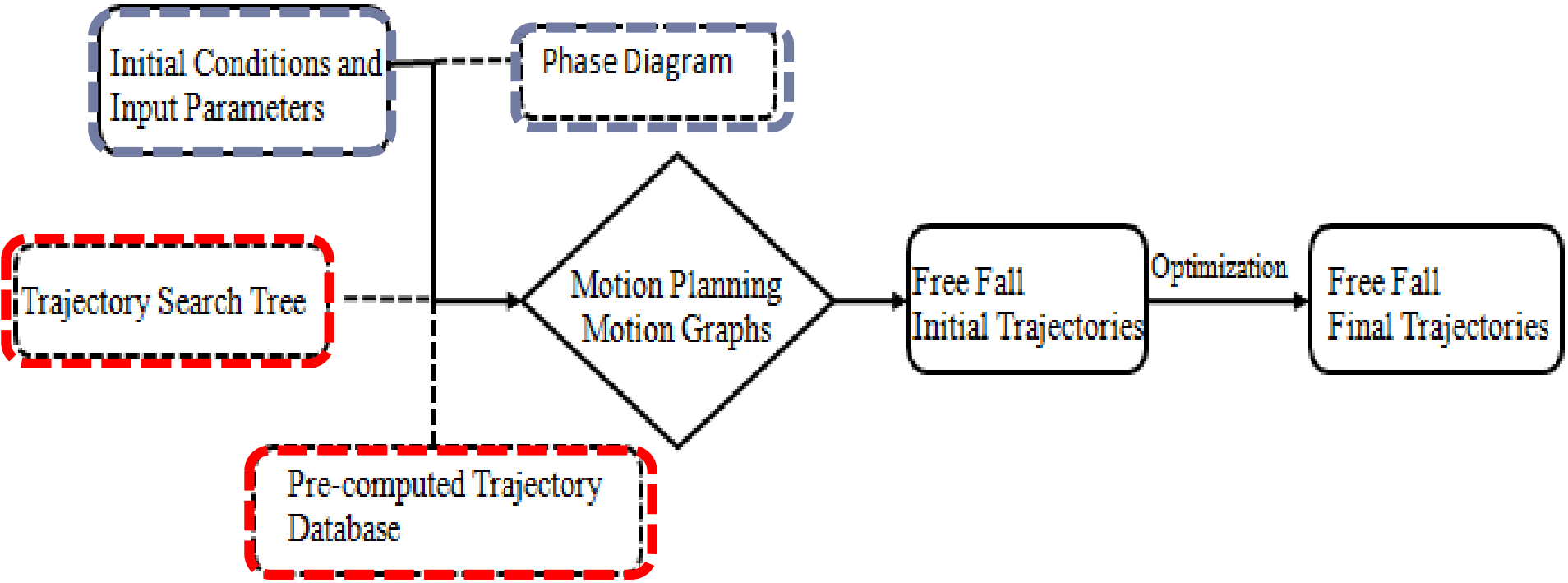
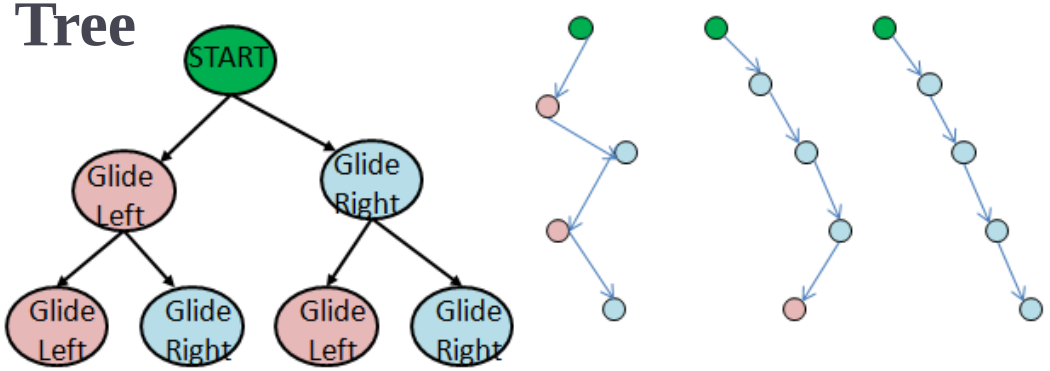
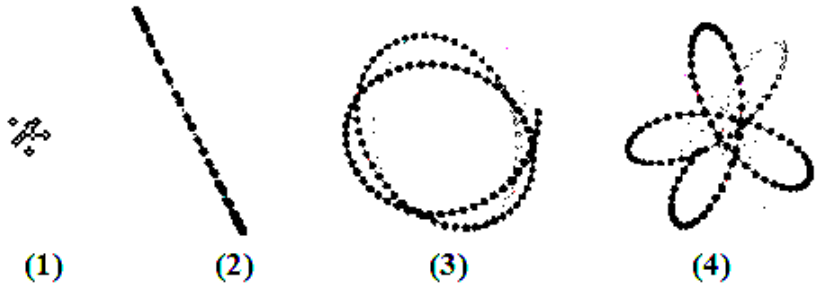


Trajectories of Motion Prototypes

- Fluttering, Tumbling and Chaotic
  - **Trajectory Search Tree**



- Helix and Spiral Motion
  - Top view of motion prototypes
  - Unified harmonic function



Descent

Tumbling
Fluttering
Chaotic

Spiral

Helix

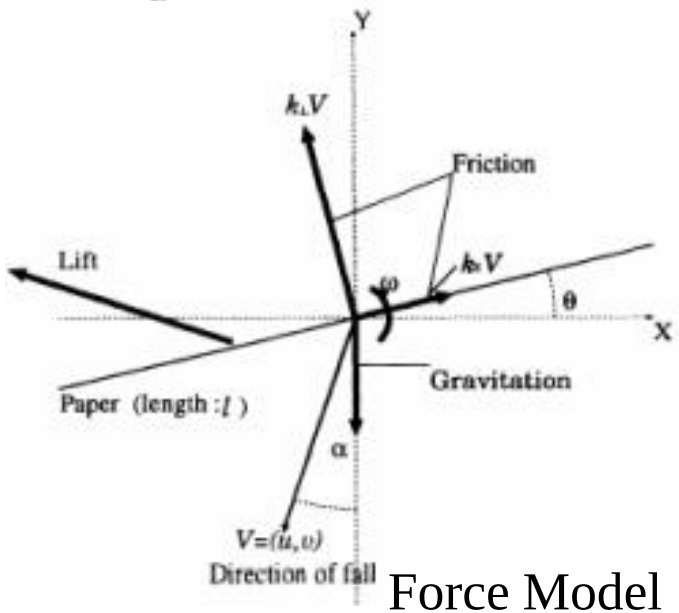
Force Model of Free Fall in 2D (ODEs)

[TANABE 1994]

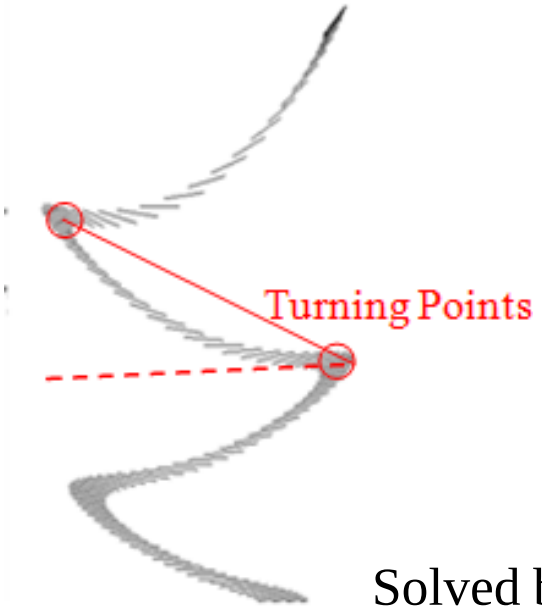
$$\frac{du}{dt} = -(A_\perp \sin^2\theta + A_\parallel \cos^2\theta)u + (A_\perp - A_\parallel)\sin\theta\cos\theta v - k\pi\rho V^2\cos\beta\cos\alpha$$

$$\frac{dv}{dt} = -(A_\perp \cos^2\theta + A_\parallel \sin^2\theta)v + (A_\perp - A_\parallel)\sin\theta\cos\theta u + k\pi\rho V^2\cos\beta\sin\alpha - g$$

$$\frac{d\omega}{dt} = -A_\perp\omega - \frac{3\pi\rho V^2}{a}\cos\beta\sin\beta$$



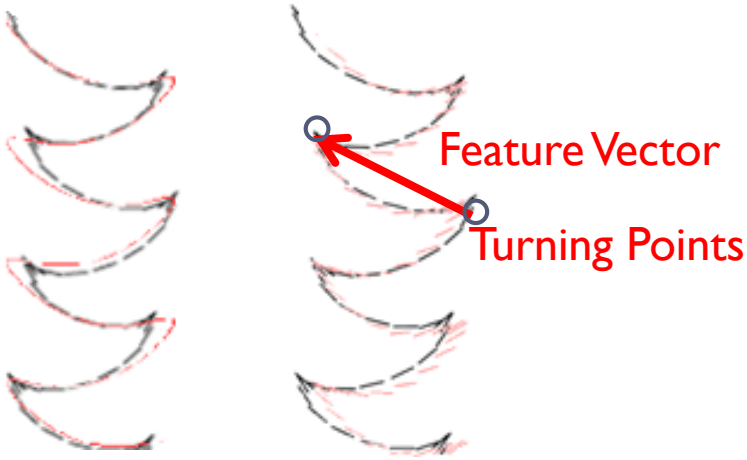
Force Model



Solved by Runge-Kutta

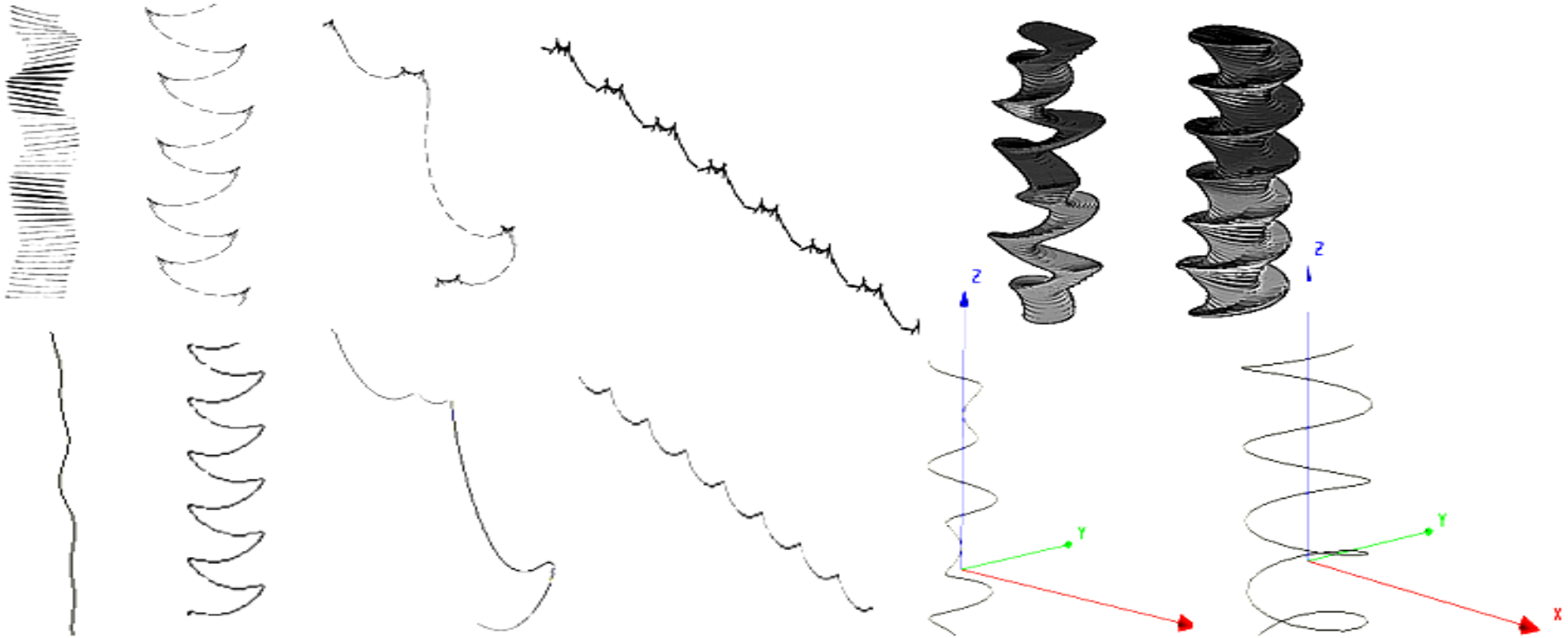
Pre-computed Trajectory Database

- Segmentation
  - Positions: Harmonic functions
  - Orientations
    - Linear interpolation by looking up the segments of ODEs
- Clustering
  - K-means algorithm[REISSELL 2001]



V1	10						40						70					
V2	10		30		50		10		30		50		10		30		50	
V3	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20
Trajectory segment (right)																		
Trajectory segment (left)																		

Synthesized Trajectories of Motion Prototypes



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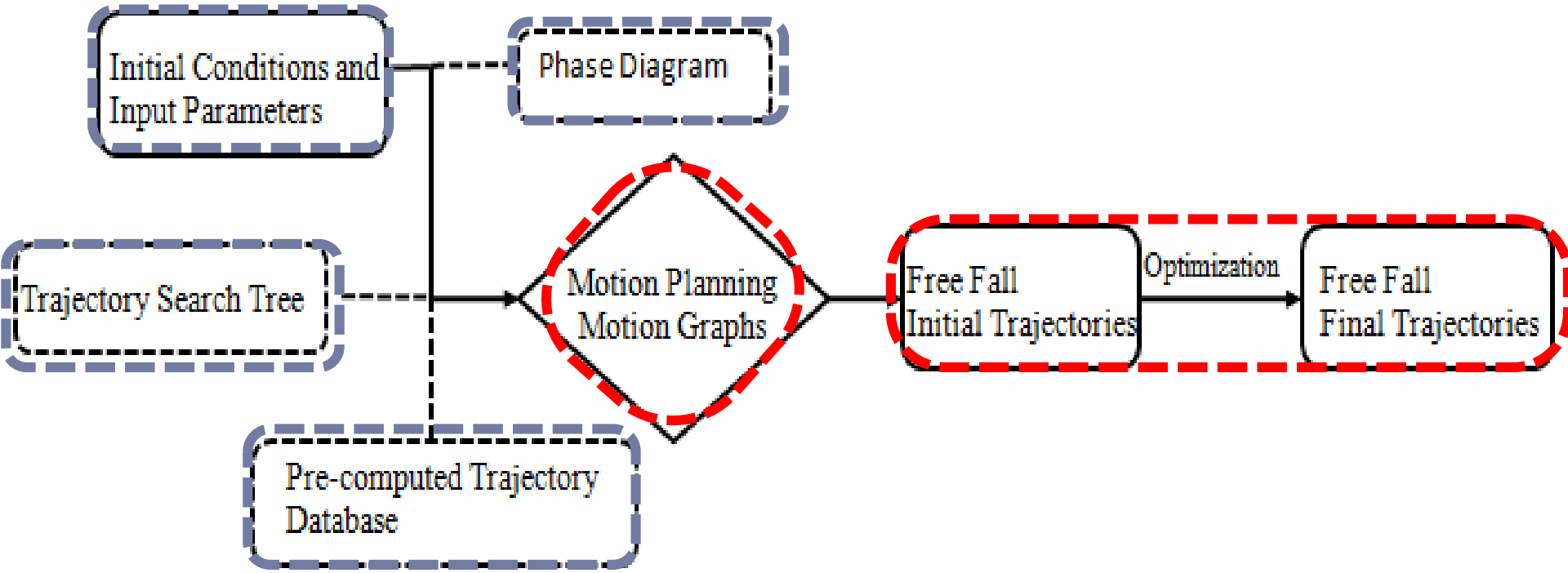
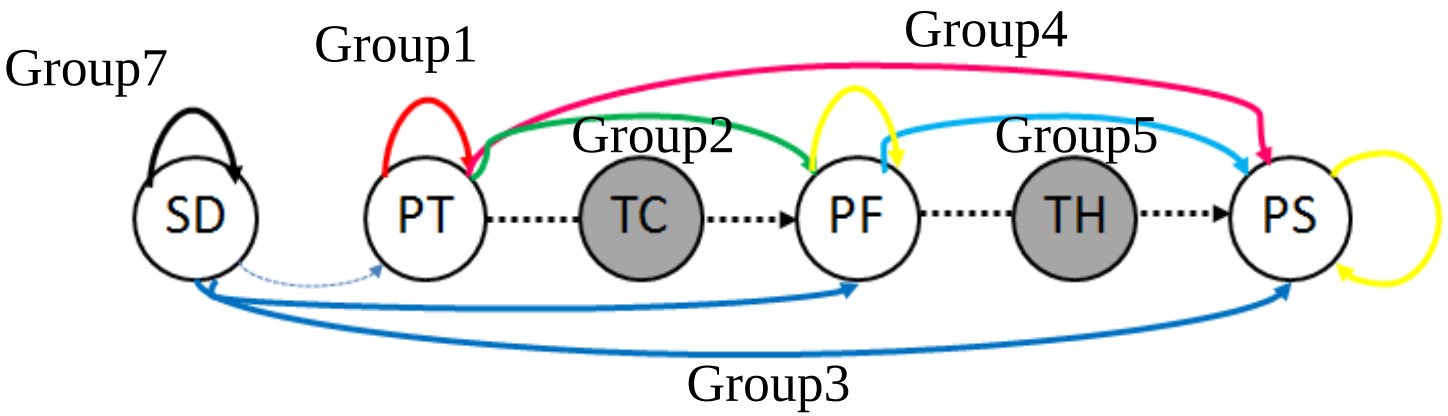
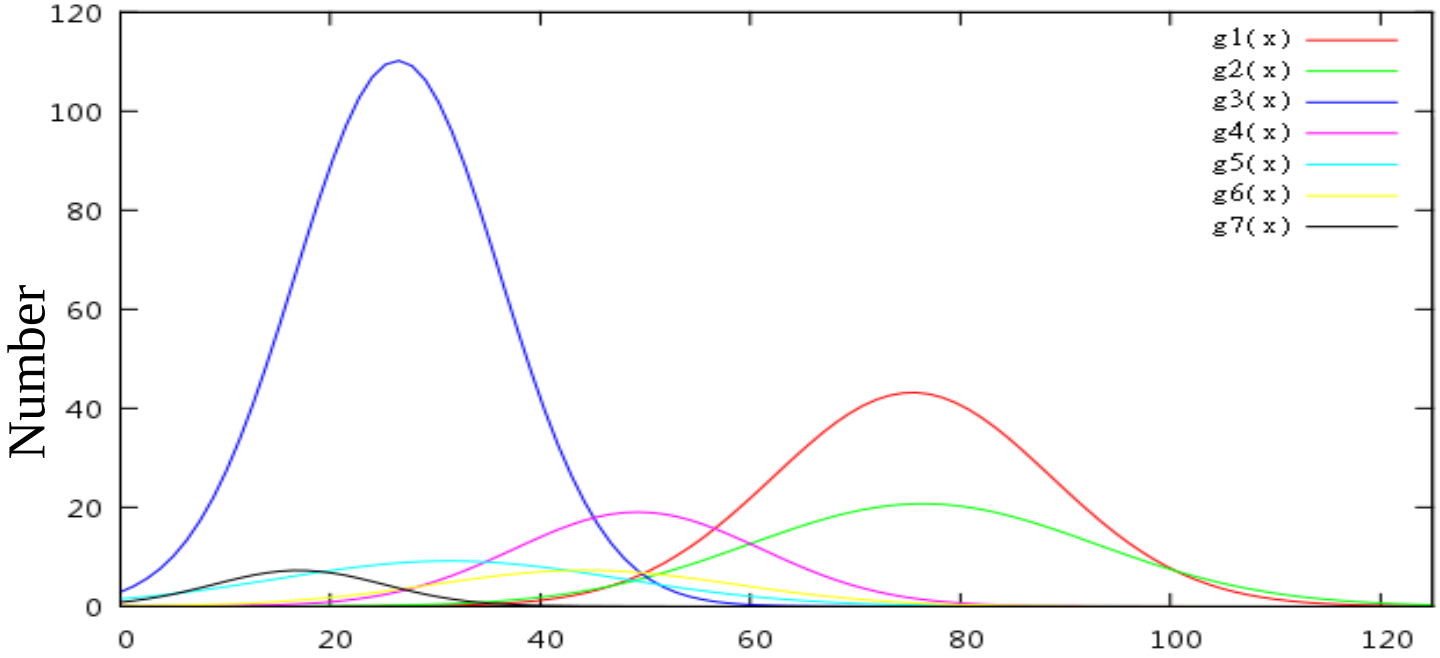


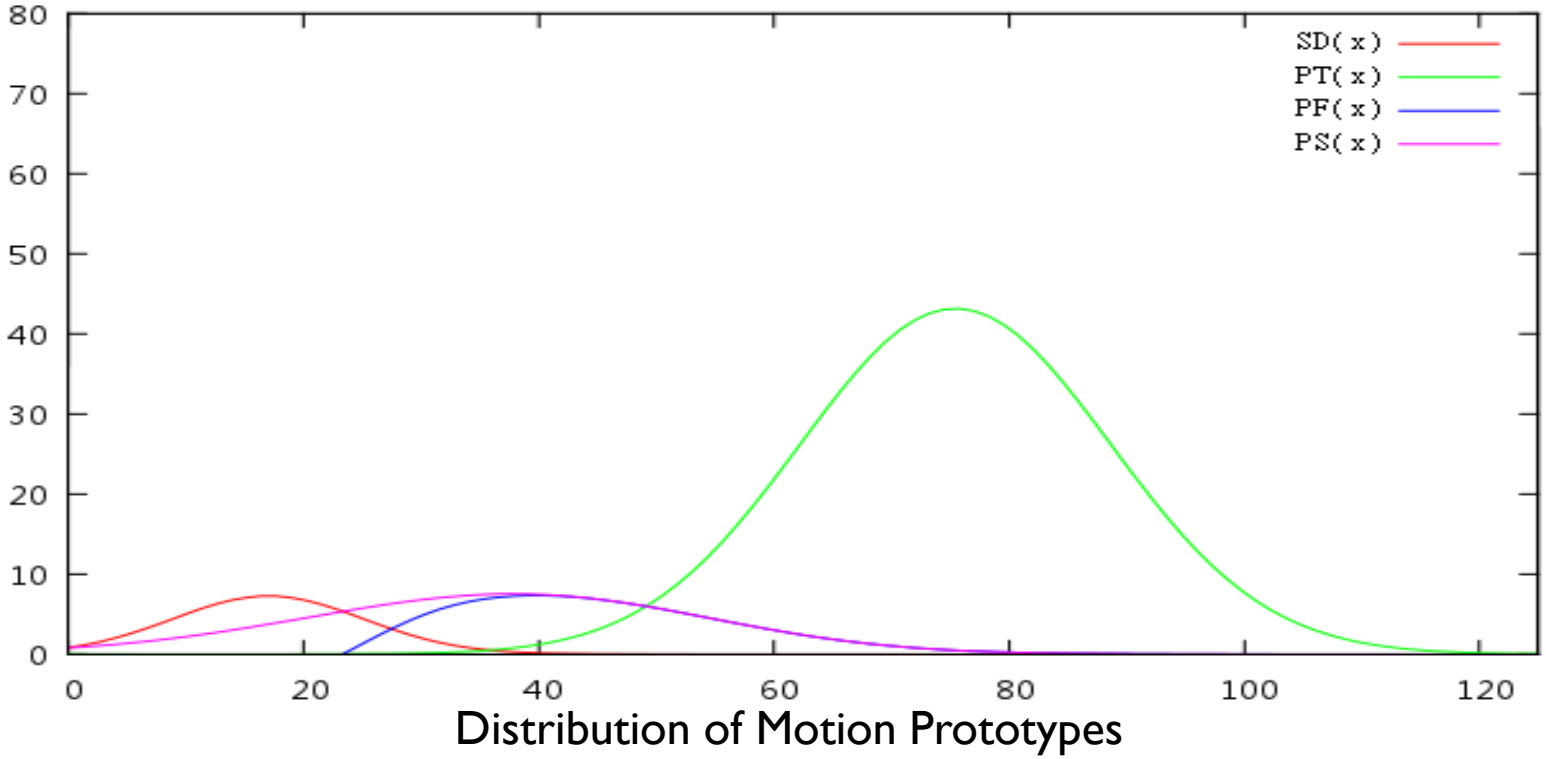
Motion Groups [RAZAVI 2010]





Distribution of Motion Groups

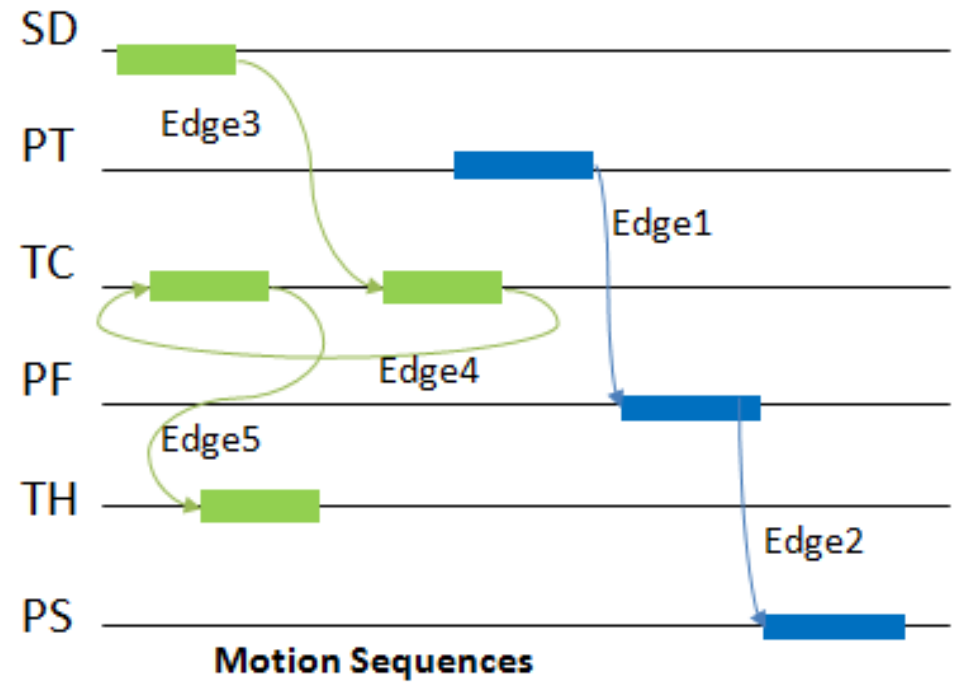
Probability Model

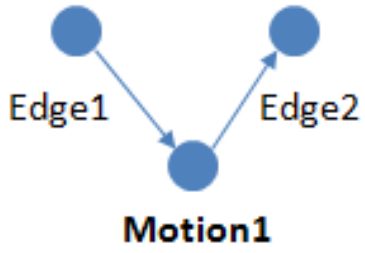


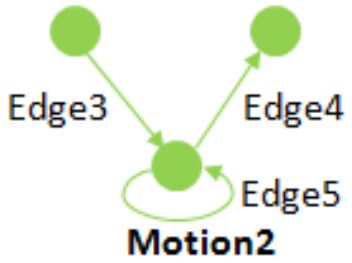
Probability of different motion prototypes

$$P\left(\bigcup_{j=1}^{1} E_j\right) = \sum_{j=1}^{1} P(E_j) = 1$$

Motion Graph with Probability

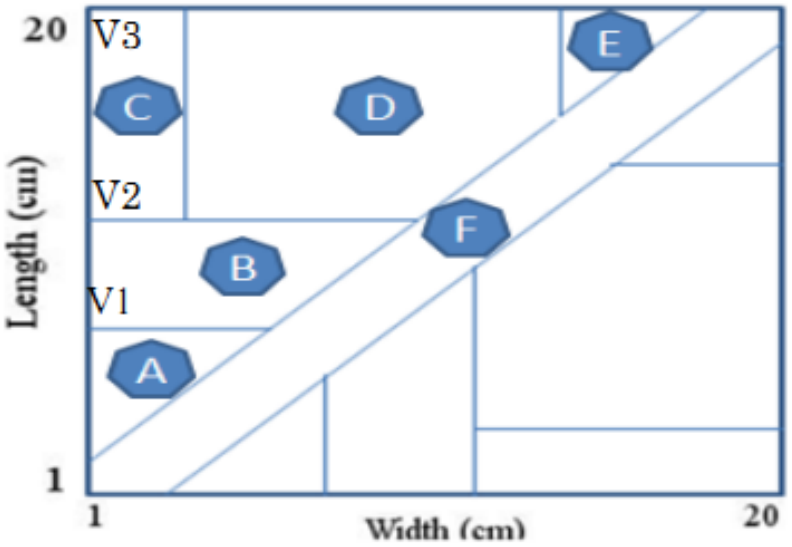






Optimizations

- Smoothen Curves(C1 continuity)
  - Positions by linear interpolation
  - rotations by spherical linear interpolation
- Rotations



- **A** Fall perpendicular
- **B** Flutter in width axis→Rotation in width axis→rotation in length axis
- **C** Flutter in width axis
- **D** Flutter in width axis→rotation in length axis
- **E** Irregular
- **F** Flutter in diagonal→rotation in diagonal

Simulate Results

One yen coin

Ground truth

Simulation result

Leaf

Ground truth

Simulation result

Red elliptical paper

Ground truth

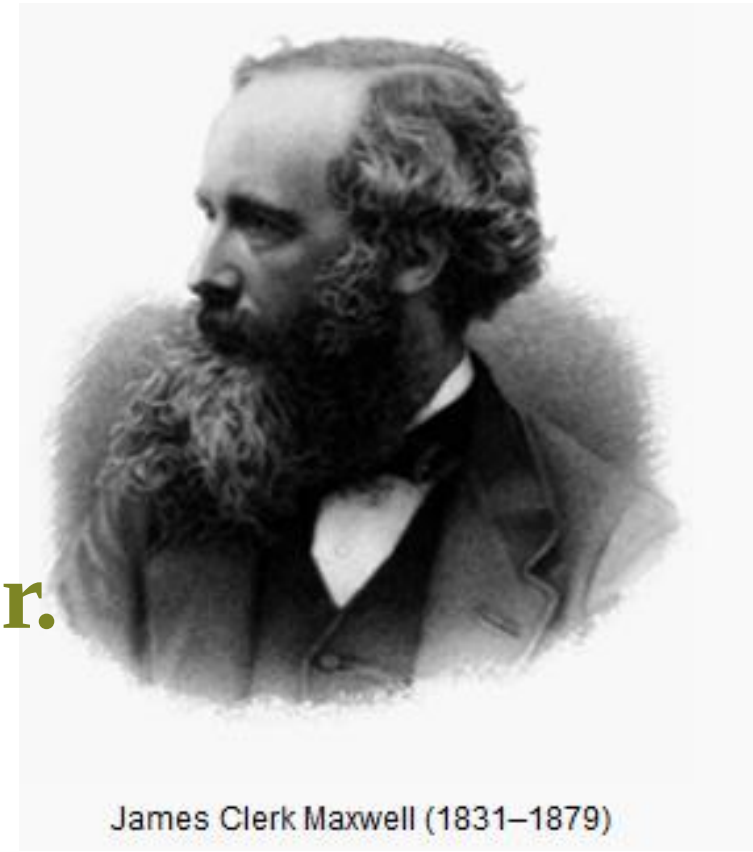
Simulation result

Conclusion

- A framework for generating free fall animation by data-driven motion synthesis and pre-computed trajectory database
- First research about the **details** of free fall motion, looking through physical characteristics
- First research about the **motion synthesis** of free fall
- Realistic and Controllable animation

Thank you very much!

A slip of paper falls through the air, its motion though undecided and wavering at first, sometimes becomes regular.



James Clerk Maxwell (1831–1879)