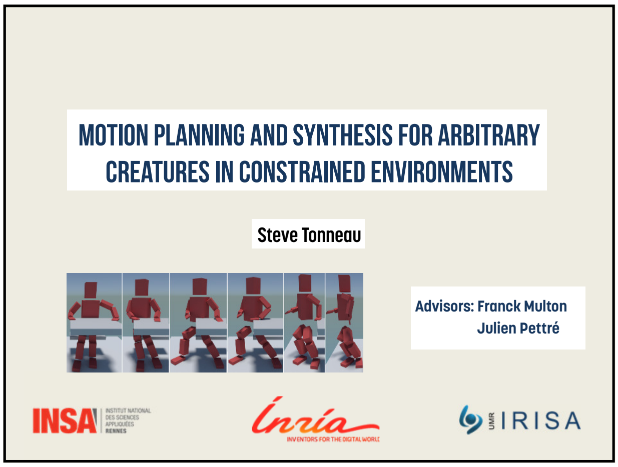
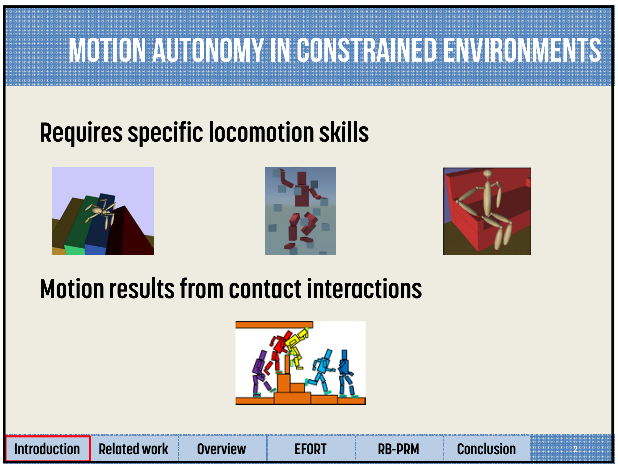


MOTION PLANNING AND SYNTHESIS FOR ARBITRARY CREATURES IN CONSTRAINED ENVIRONMENTS

Steve Tonneau

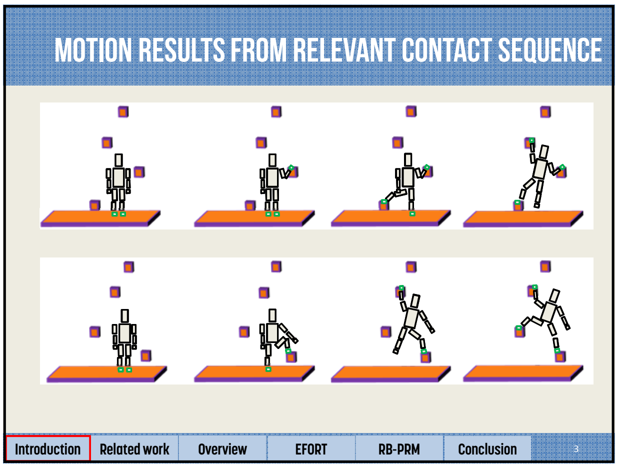
Advisors: Franck Multon
Julien Pettré



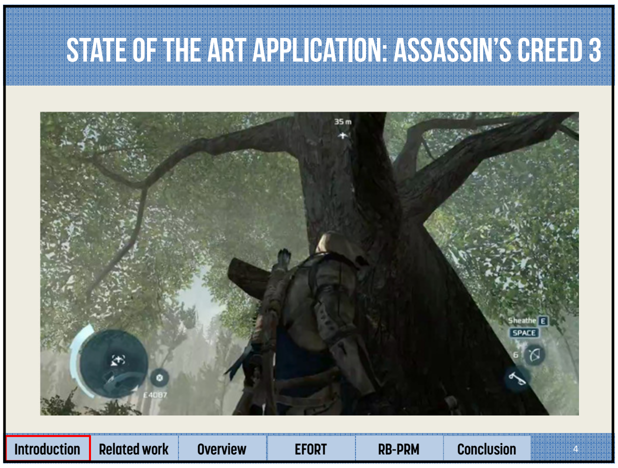
MOTION AUTONOMY IN CONSTRAINED ENVIRONMENTS

Requires specific locomotion skills

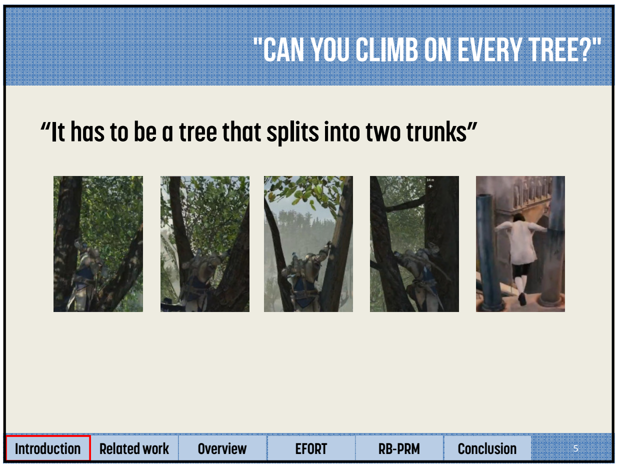
Motion results from contact interactions



MOTION RESULTS FROM RELEVANT CONTACT SEQUENCE

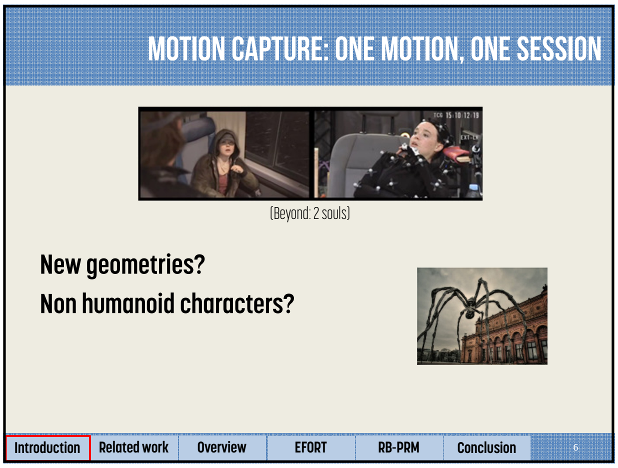


STATE OF THE ART APPLICATION: ASSASSIN'S CREED 3



"CAN YOU CLIMB ON EVERY TREE?"

"It has to be a tree that splits into two trunks"

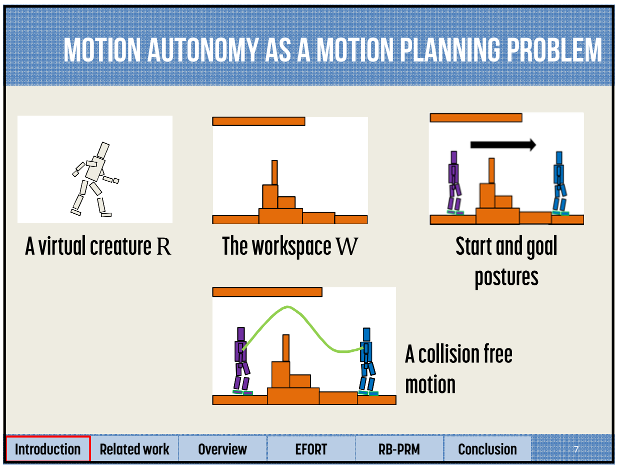


MOTION CAPTURE: ONE MOTION, ONE SESSION

(Beyond: 2 souls)

New geometries?

Non humanoid characters?



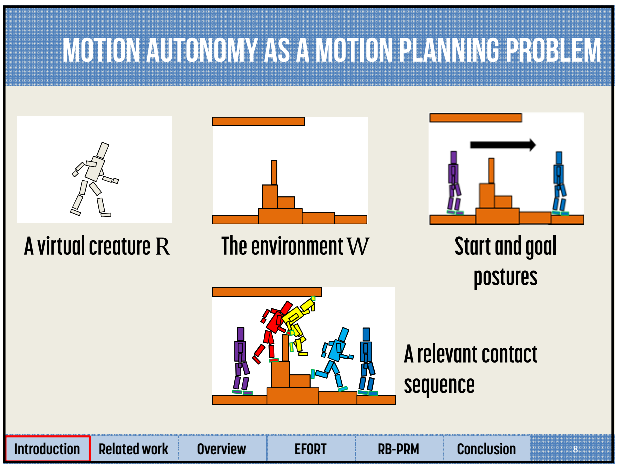
MOTION AUTONOMY AS A MOTION PLANNING PROBLEM

A virtual creature R

The workspace W

Start and goal postures

A collision free motion



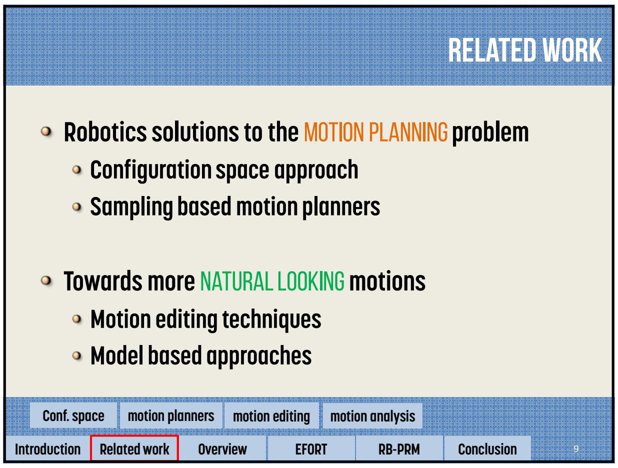
MOTION AUTONOMY AS A MOTION PLANNING PROBLEM

A virtual creature R

The environment W

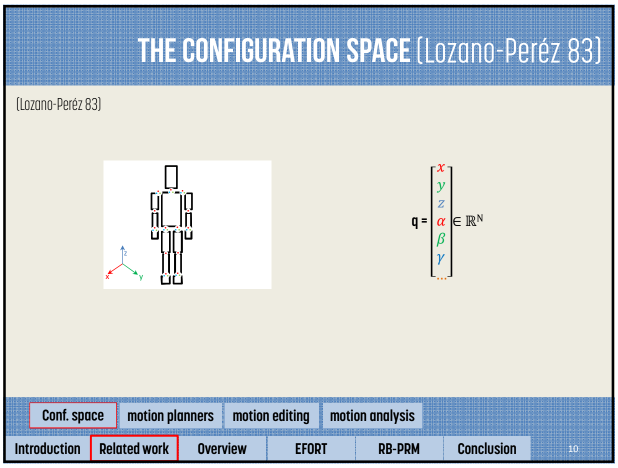
Start and goal postures

A relevant contact sequence



RELATED WORK

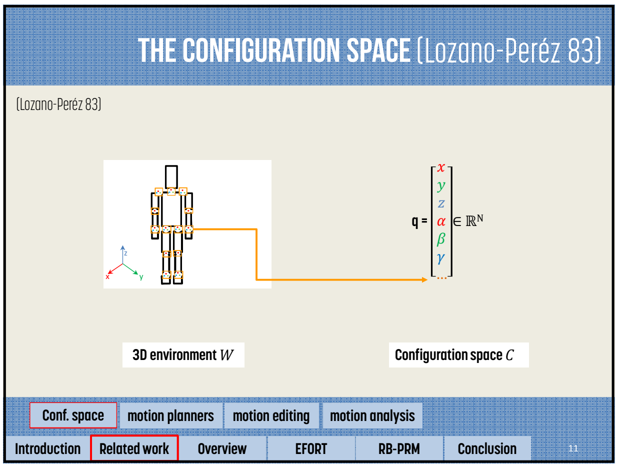
- Robotics solutions to the MOTION PLANNING problem
  - Configuration space approach
  - Sampling based motion planners
- Towards more NATURAL LOOKING motions
  - Motion editing techniques
  - Model based approaches



THE CONFIGURATION SPACE (Lozano-Peréz 83)

(Lozano-Peréz 83)

$q = \begin{bmatrix} x \\ y \\ z \\ \alpha \\ \beta \\ \gamma \\ \dots \end{bmatrix} \in \mathbb{R}^N$



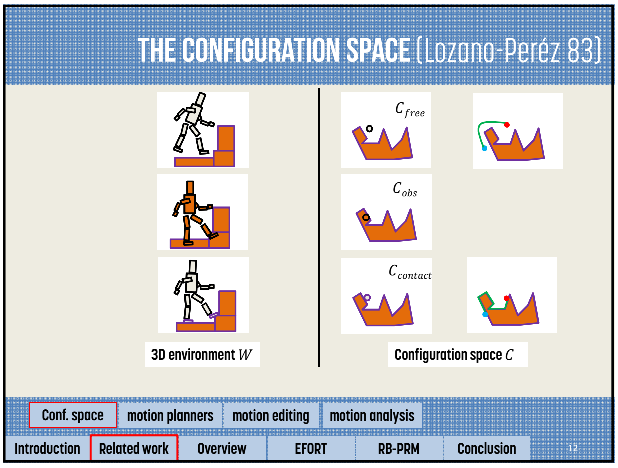
THE CONFIGURATION SPACE (Lozano-Peréz 83)

(Lozano-Peréz 83)

$q = \begin{bmatrix} x \\ y \\ z \\ \alpha \\ \beta \\ \gamma \\ \dots \end{bmatrix} \in \mathbb{R}^N$

3D environment W

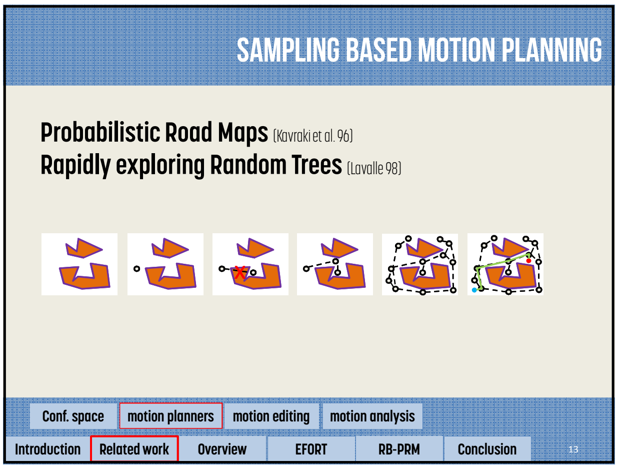
Configuration space C



THE CONFIGURATION SPACE (Lozano-Peréz 83)

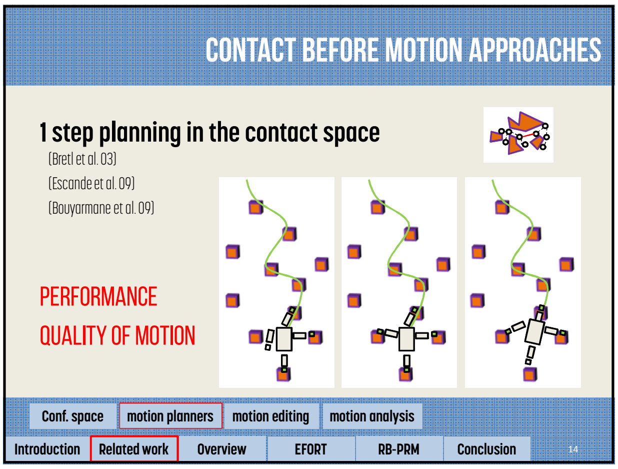
3D environment W

Configuration space C



SAMPLING BASED MOTION PLANNING

Probabilistic Road Maps (Kavraki et al. 96)
Rapidly exploring Random Trees (Lavalle 98)

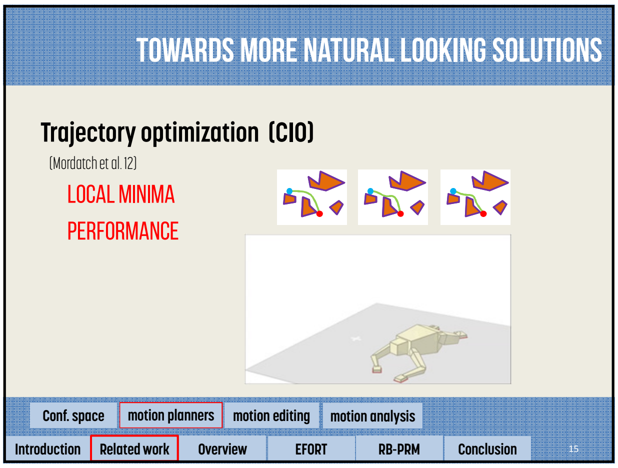


CONTACT BEFORE MOTION APPROACHES

1 step planning in the contact space
(Bretl et al. 03)
(Escande et al. 09)
(Bouyarmane et al. 09)

PERFORMANCE

QUALITY OF MOTION

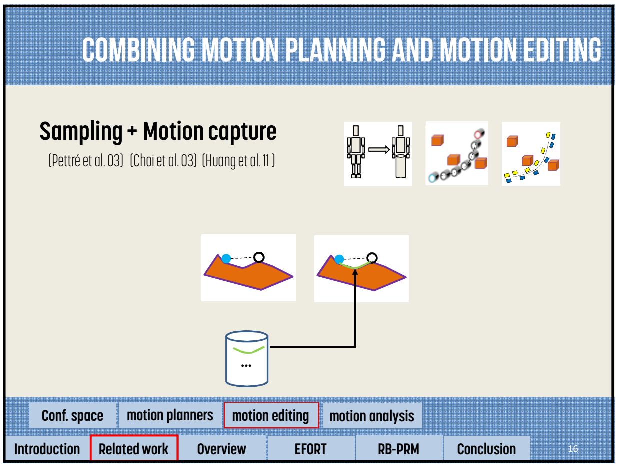


TOWARDS MORE NATURAL LOOKING SOLUTIONS

Trajectory optimization (CIO)
(Mordatch et al. 12)

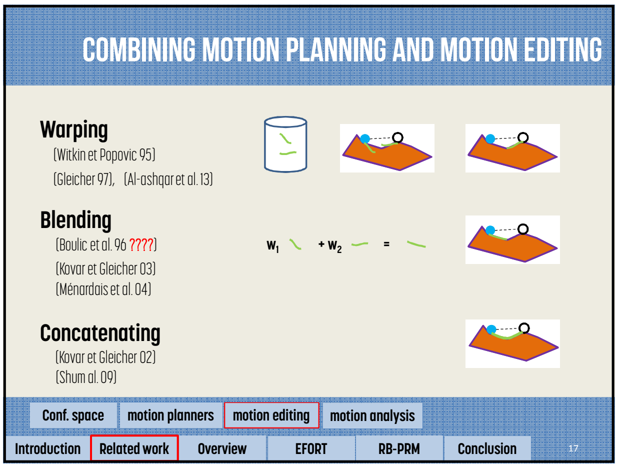
LOCAL MINIMA

PERFORMANCE



COMBINING MOTION PLANNING AND MOTION EDITING

Sampling + Motion capture
(Pettré et al. 03) (Choi et al. 03) (Huang et al. 11)



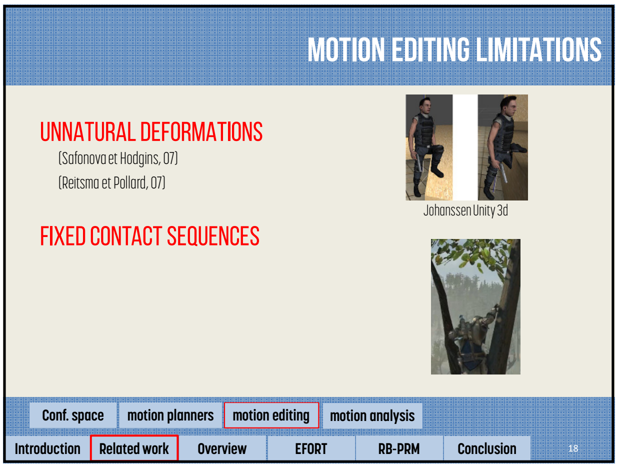
COMBINING MOTION PLANNING AND MOTION EDITING

Warping
(Witkin et Popovic 95)
(Gleicher 97), (Al-ashqar et al. 13)

Blending
(Boulic et al. 96 ????)
(Kovar et Gleicher 03)
(Ménardais et al. 04)

w_1 + w_2 =

Concatenating
(Kovar et Gleicher 02)
(Shum al. 09)

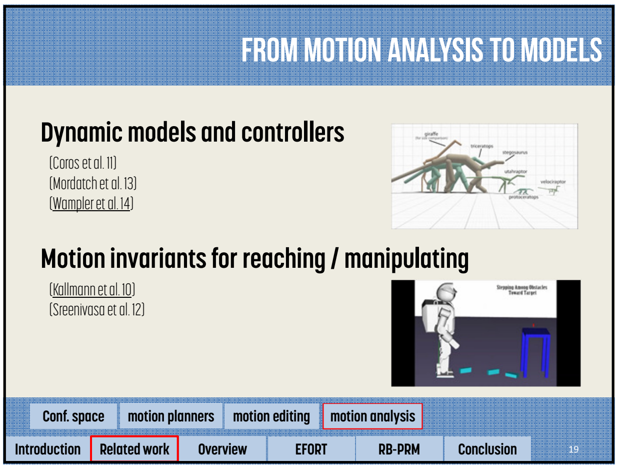


MOTION EDITING LIMITATIONS

UNNATURAL DEFORMATIONS
(Safonova et Hodgins, 07)
(Reitsma et Pollard, 07)

Johanssen Unity 3d

FIXED CONTACT SEQUENCES



FROM MOTION ANALYSIS TO MODELS

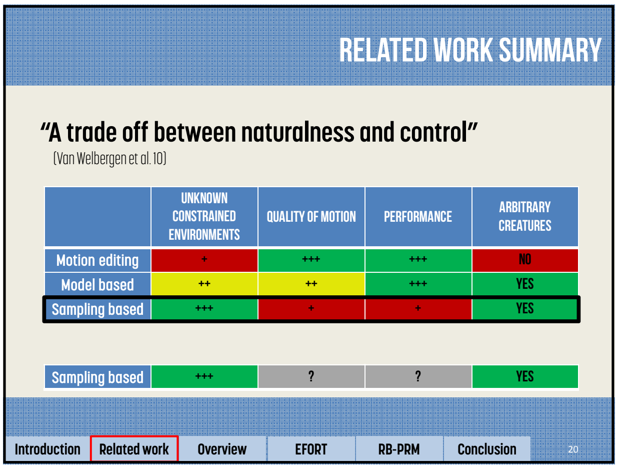
Dynamic models and controllers

(Coros et al. 11)
(Mordatch et al. 13)
(Wampler et al. 14)

Motion invariants for reaching / manipulating

(Kallmann et al. 10)
(Sreenivasa et al. 12)

giraffe
triceratops
stegosaurus
utahraptor
velociraptor
protoceratops
Stepping Among Obstacles Toward Target

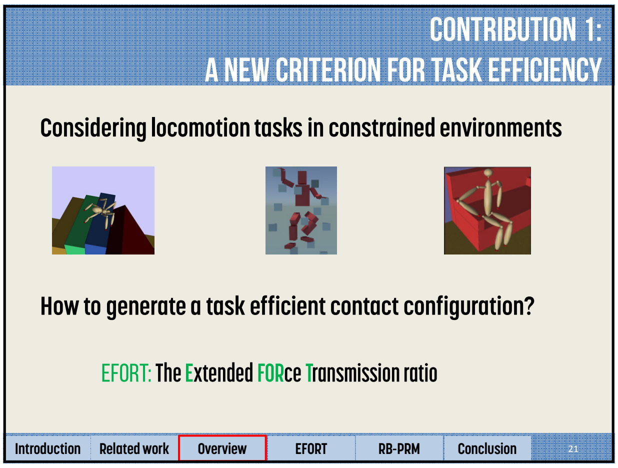


RELATED WORK SUMMARY

"A trade off between naturalness and control"
(Van Welbergen et al. 10)

	UNKNOWN CONSTRAINED ENVIRONMENTS	QUALITY OF MOTION	PERFORMANCE	ARBITRARY CREATURES
Motion editing	+	+++	+++	NO
Model based	++	++	+++	YES
Sampling based	+++	+	+	YES

Sampling based	+++	?	?	YES

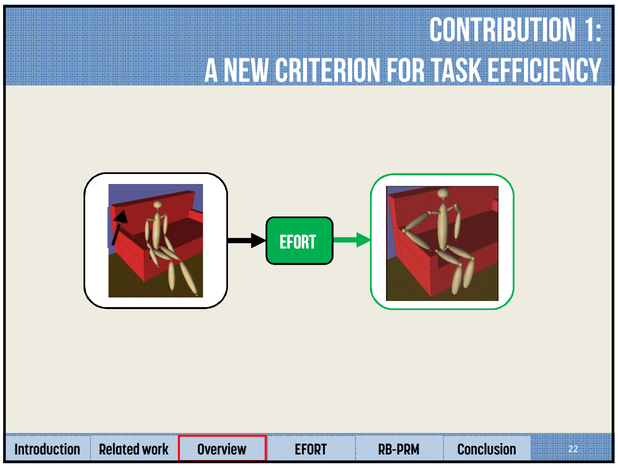


CONTRIBUTION 1: A NEW CRITERION FOR TASK EFFICIENCY

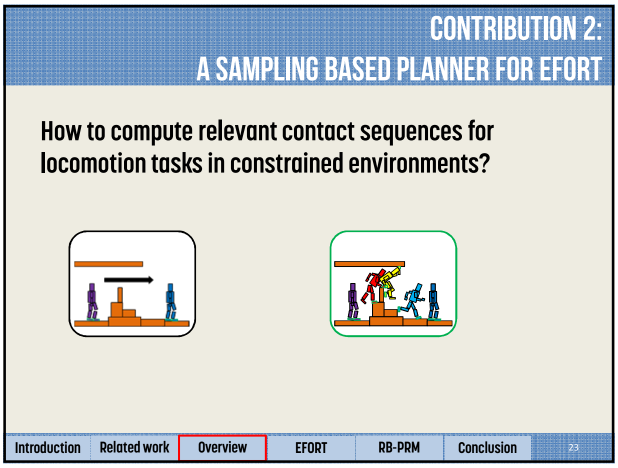
Considering locomotion tasks in constrained environments

How to generate a task efficient contact configuration?

EFORT: The Extended FORce Transmission ratio

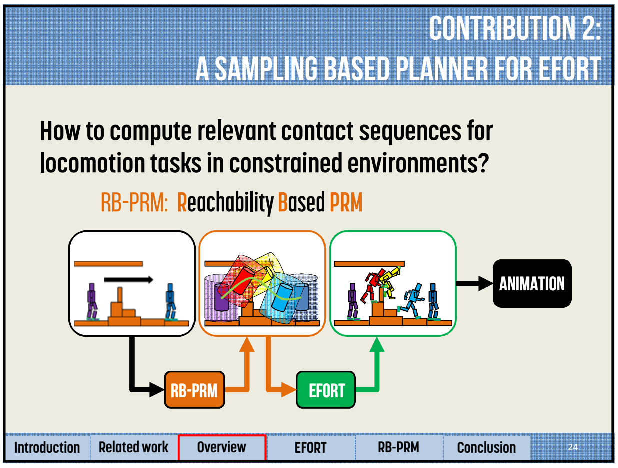


CONTRIBUTION 1: A NEW CRITERION FOR TASK EFFICIENCY



CONTRIBUTION 2: A SAMPLING BASED PLANNER FOR EFORT

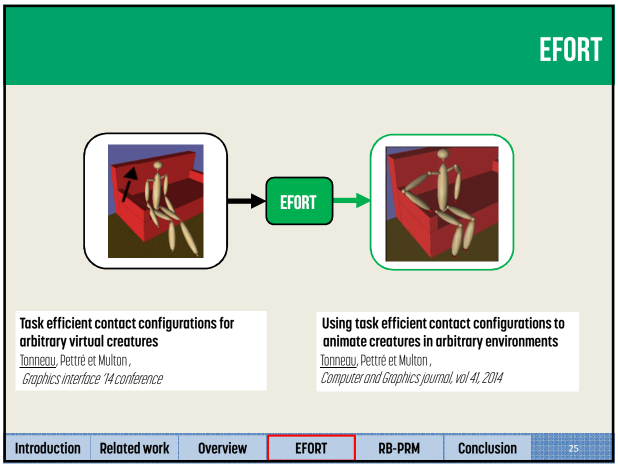
How to compute relevant contact sequences for locomotion tasks in constrained environments?



CONTRIBUTION 2: A SAMPLING BASED PLANNER FOR EFORT

How to compute relevant contact sequences for locomotion tasks in constrained environments?

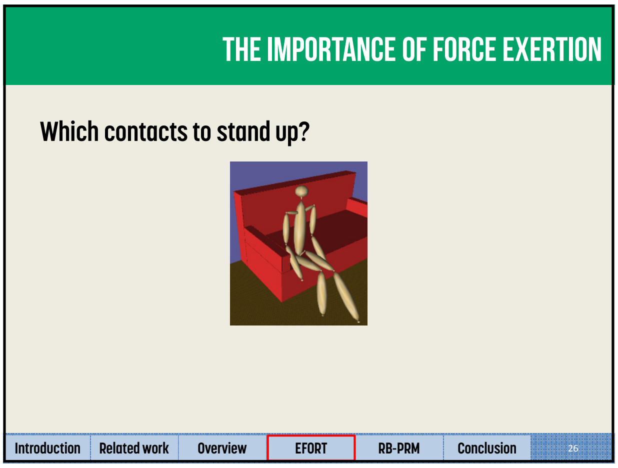
RB-PRM: Reachability Based PRM



EFORT

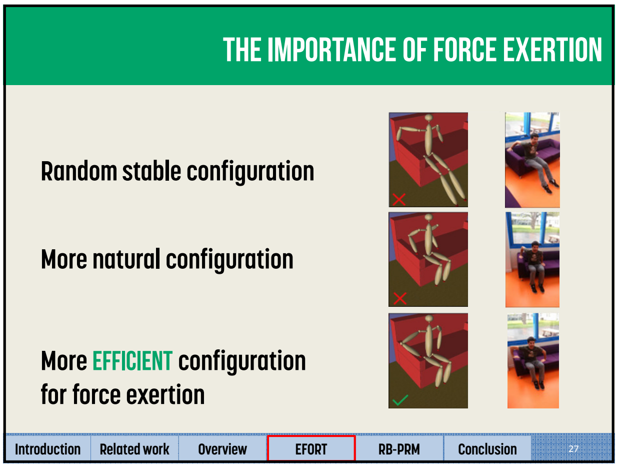
Task efficient contact configurations for arbitrary virtual creatures
Tonneau, Pettré et Multon ,
Graphics interface '14 conference

Using task efficient contact configurations to animate creatures in arbitrary environments
Tonneau, Pettré et Multon ,
Computer and Graphics journal, vol 41, 2014



THE IMPORTANCE OF FORCE EXERTION

Which contacts to stand up?

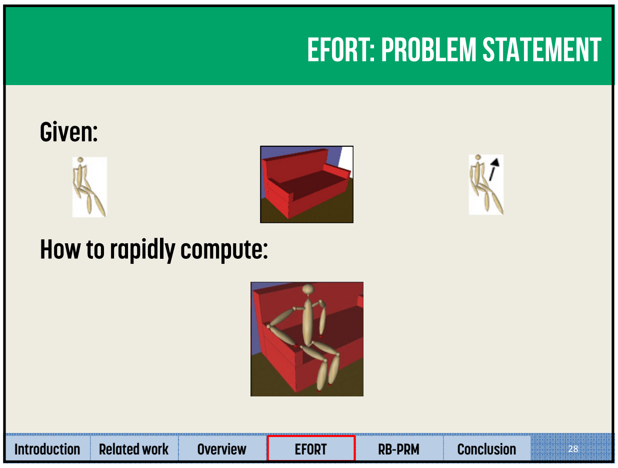


THE IMPORTANCE OF FORCE EXERTION

Random stable configuration

More natural configuration

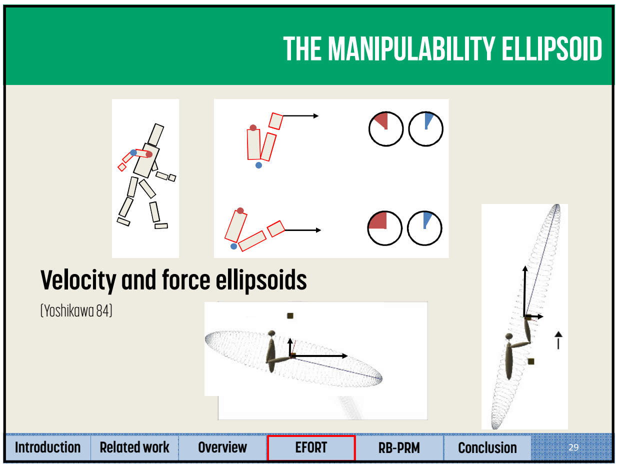
More EFFICIENT configuration for force exertion



EFORT: PROBLEM STATEMENT

Given:

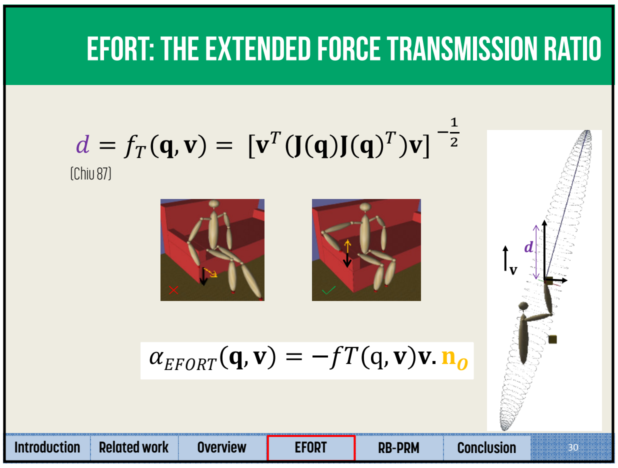
How to rapidly compute:



THE MANIPULABILITY ELLIPSOID

Velocity and force ellipsoids

(Yoshikawa 84)

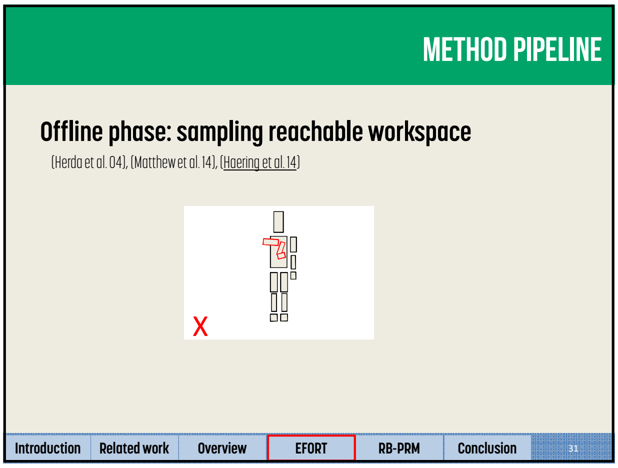


EFORT: THE EXTENDED FORCE TRANSMISSION RATIO

$$d = f_T(\mathbf{q}, \mathbf{v}) = [\mathbf{v}^T(\mathbf{J}(\mathbf{q})\mathbf{J}(\mathbf{q})^T)\mathbf{v}]^{-\frac{1}{2}}$$

(Chiu 87)

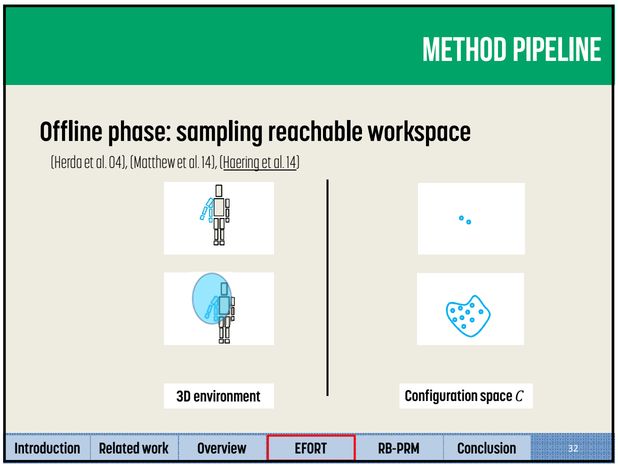
$$\alpha_{EFORT}(\mathbf{q}, \mathbf{v}) = -fT(\mathrm{q}, \mathbf{v})\mathbf{v}.\mathbf{n}_O$$



METHOD PIPELINE

Offline phase: sampling reachable workspace

(Herda et al. 04), (Matthew et al. 14), (Haering et al. 14)



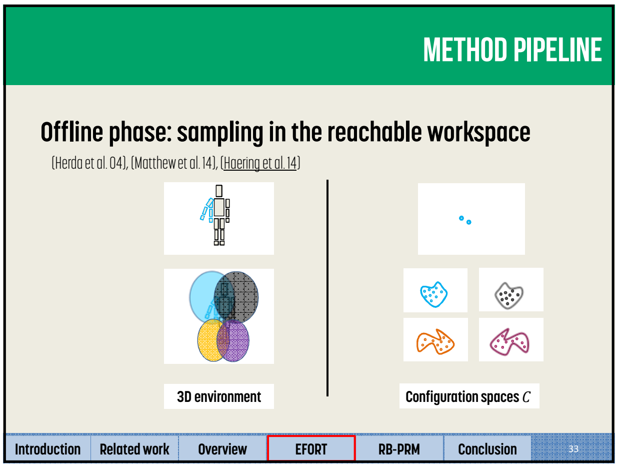
METHOD PIPELINE

Offline phase: sampling reachable workspace

(Herda et al. 04), (Matthew et al. 14), (Haering et al. 14)

3D environment

Configuration space C



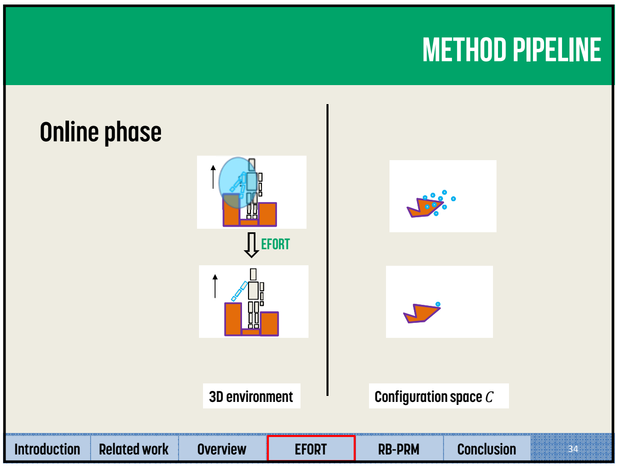
METHOD PIPELINE

Offline phase: sampling in the reachable workspace

(Herda et al. 04), (Matthew et al. 14), (Haering et al. 14)

3D environment

Configuration spaces C

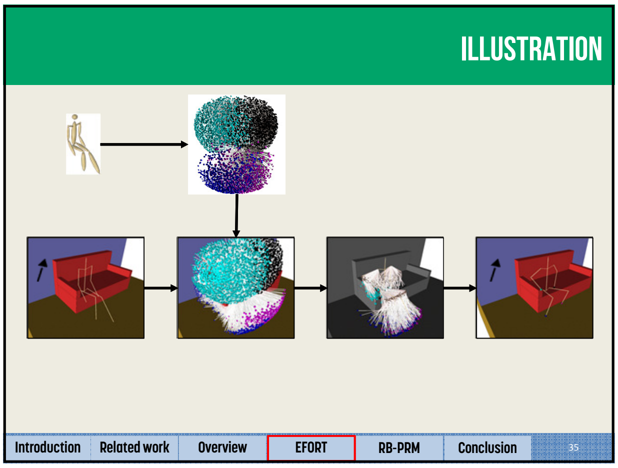


METHOD PIPELINE

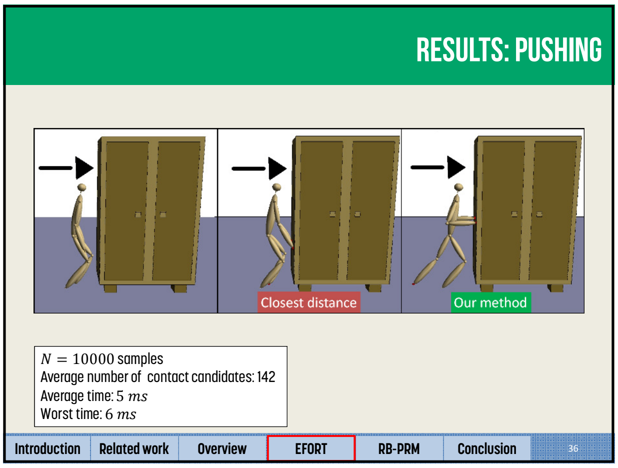
Online phase

3D environment

Configuration space C

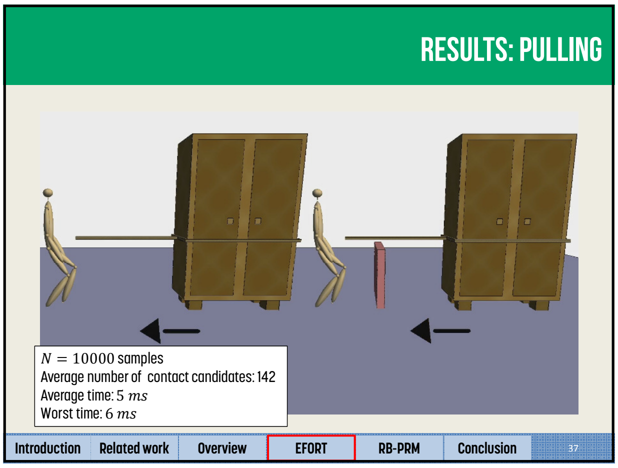


ILLUSTRATION



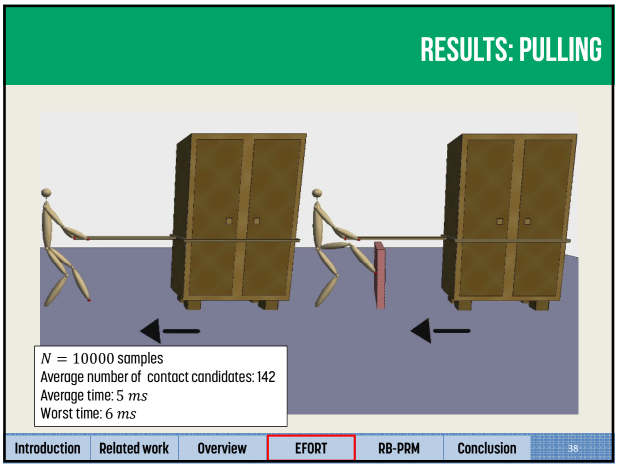
RESULTS: PUSHING

$N = 10000$ samples
Average number of contact candidates: 142
Average time: 5 ms
Worst time: 6 ms



RESULTS: PULLING

$N = 10000$ samples
Average number of contact candidates: 142
Average time: $5\ ms$
Worst time: $6\ ms$



RESULTS: PULLING

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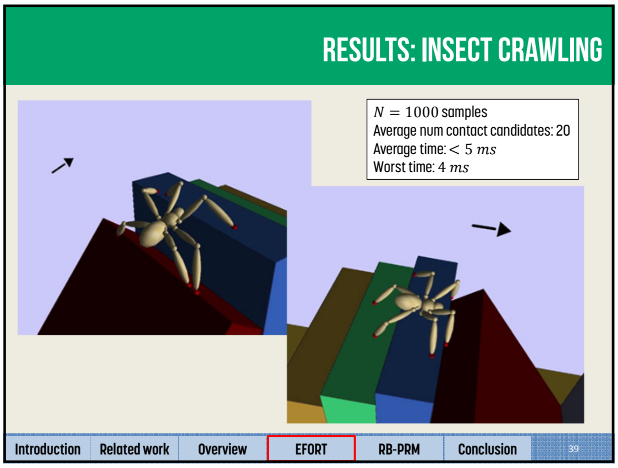
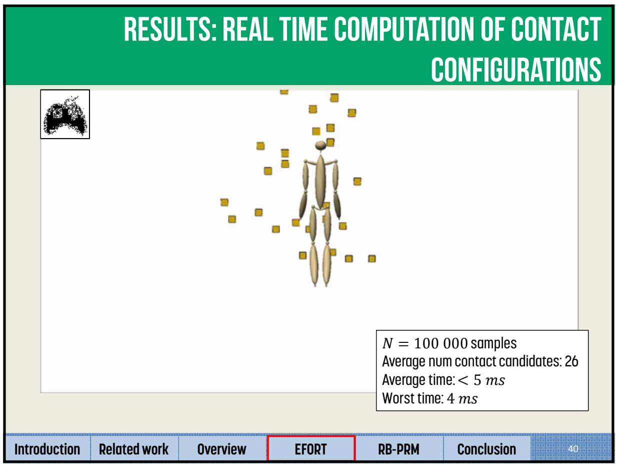


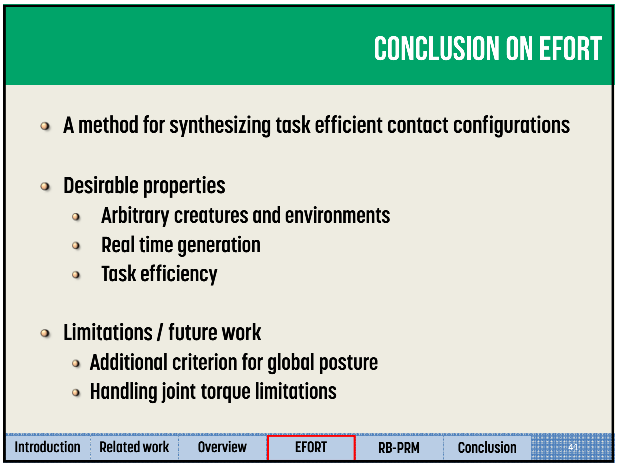
RESULTS: INSECT CRAWLING

$N = 1000$ samples
Average num contact candidates: 20
Average time: $< 5\ ms$
Worst time: $4\ ms$



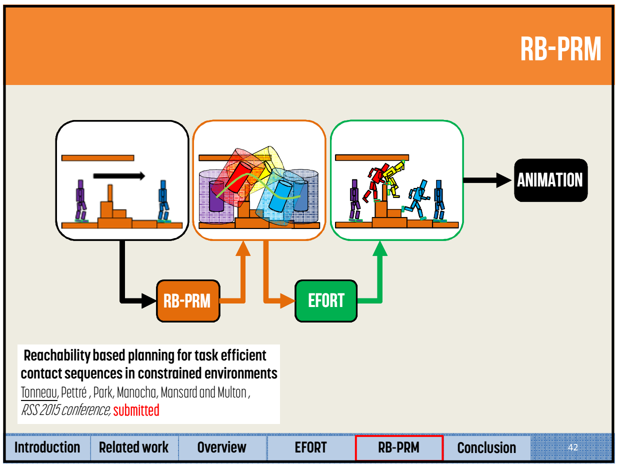
RESULTS: REAL TIME COMPUTATION OF CONTACT CONFIGURATIONS

$N = 100\ 000$ samples
Average num contact candidates: 26
Average time: $< 5\ ms$
Worst time: $4\ ms$



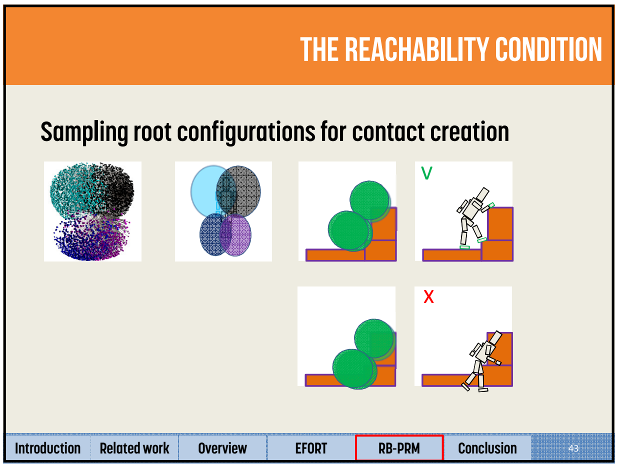
CONCLUSION ON EFORT

- A method for synthesizing task efficient contact configurations
- Desirable properties
  - Arbitrary creatures and environments
  - Real time generation
  - Task efficiency
- Limitations / future work
  - Additional criterion for global posture
  - Handling joint torque limitations



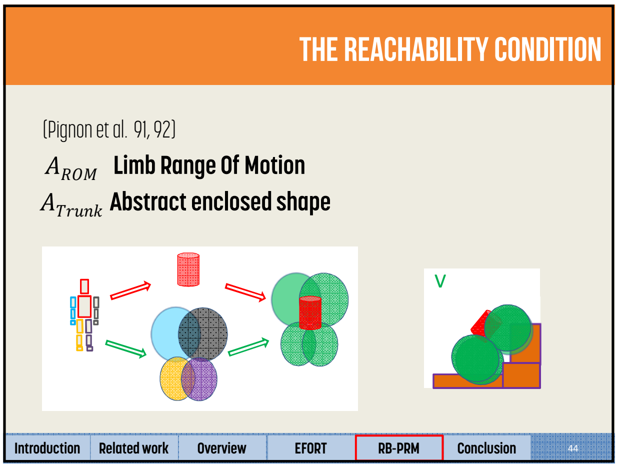
RB-PRM

Reachability based planning for task efficient contact sequences in constrained environments
Tonneau, Pettré , Park, Manocha, Mansard and Multon ,
RSS 2015 conference, submitted



THE REACHABILITY CONDITION

Sampling root configurations for contact creation

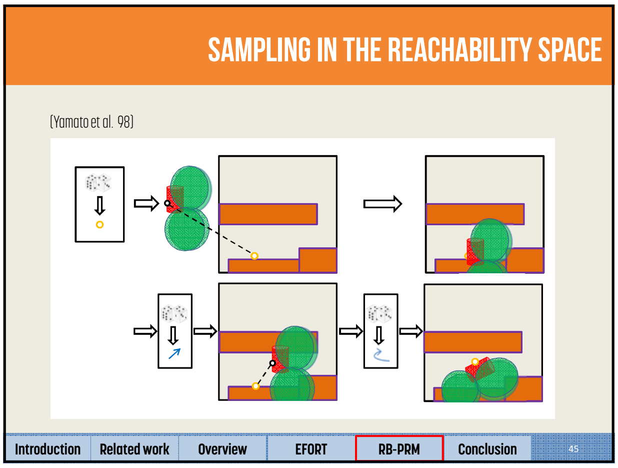


THE REACHABILITY CONDITION

(Pignon et al. 91, 92)

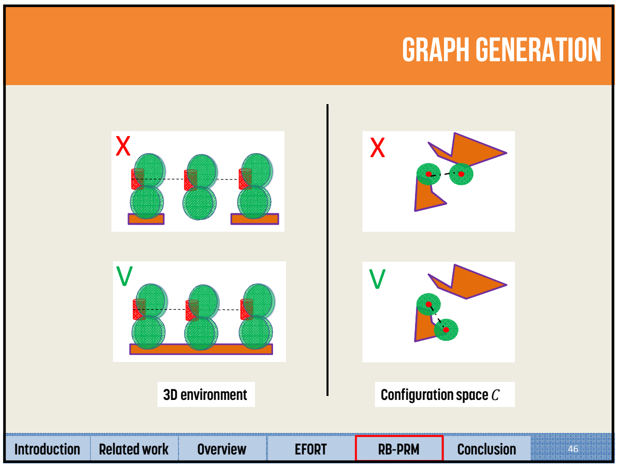
A_{ROM} Limb Range Of Motion

A_{Trunk} Abstract enclosed shape



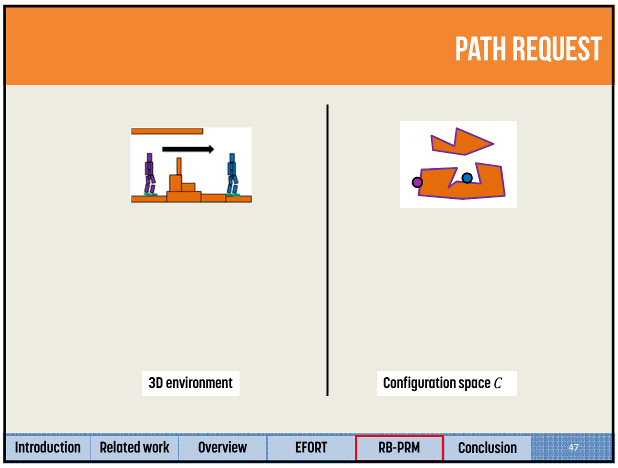
SAMPLING IN THE REACHABILITY SPACE

(Yamato et al. 98)



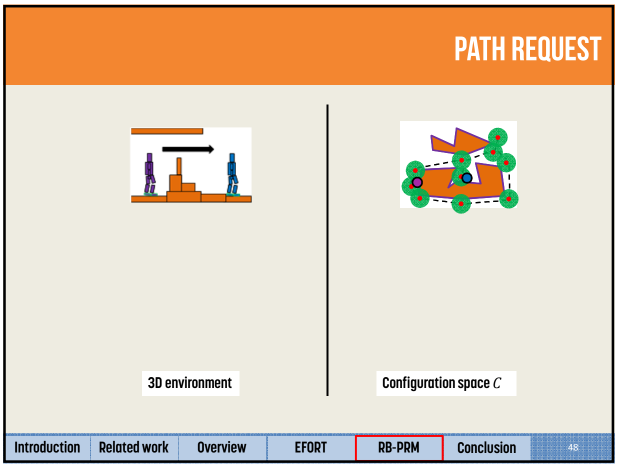
GRAPH GENERATION

X
X
V
V
3D environment
Configuration space C



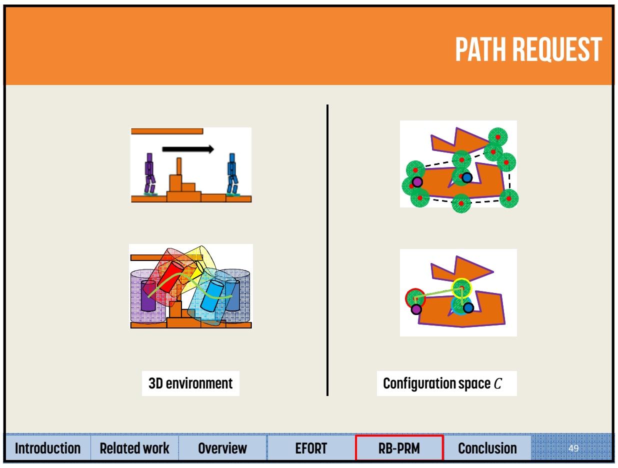
PATH REQUEST

3D environment
Configuration space C



PATH REQUEST

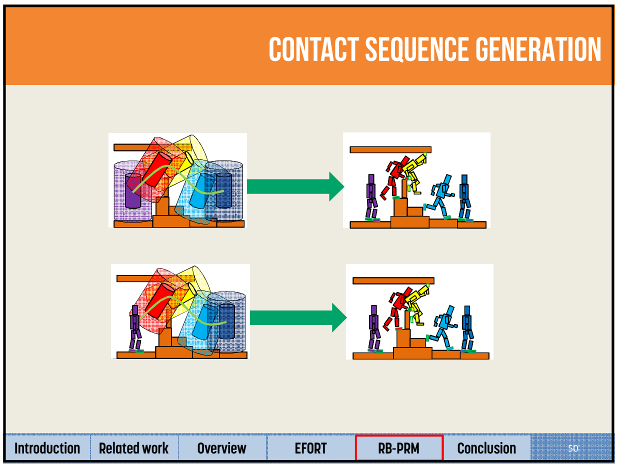
3D environment
Configuration space C



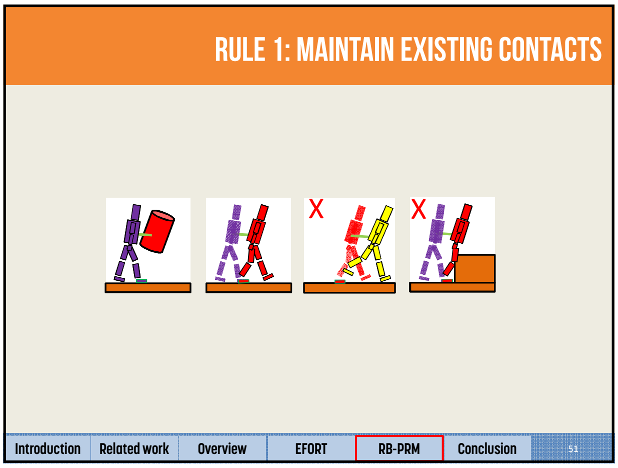
PATH REQUEST

3D environment

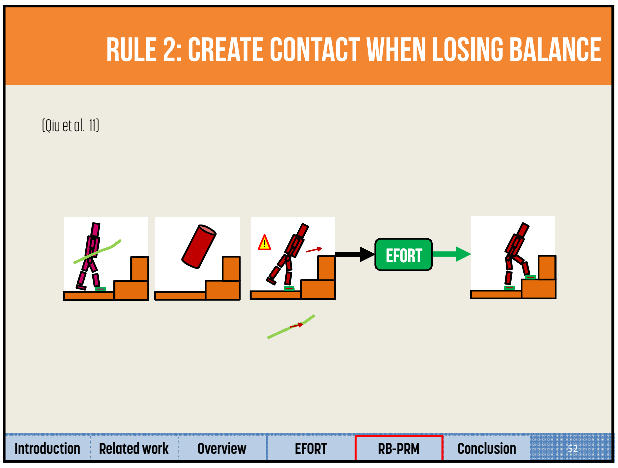
Configuration space C



CONTACT SEQUENCE GENERATION

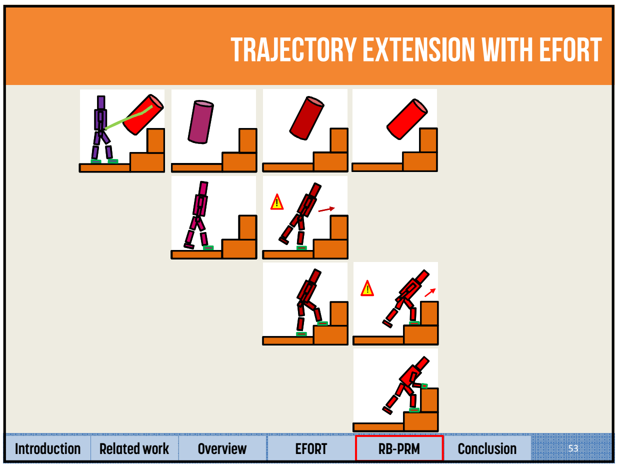


RULE 1: MAINTAIN EXISTING CONTACTS

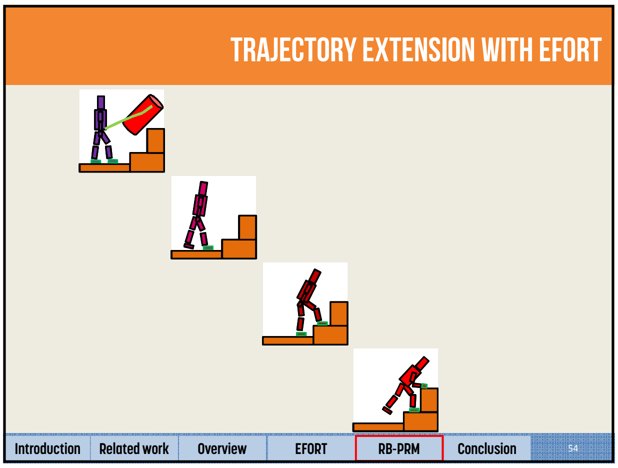


RULE 2: CREATE CONTACT WHEN LOSING BALANCE

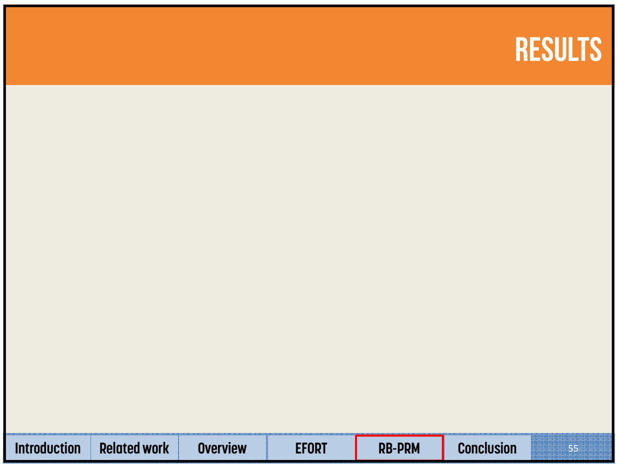
(Qiu et al. 11)



TRAJECTORY EXTENSION WITH EFORT

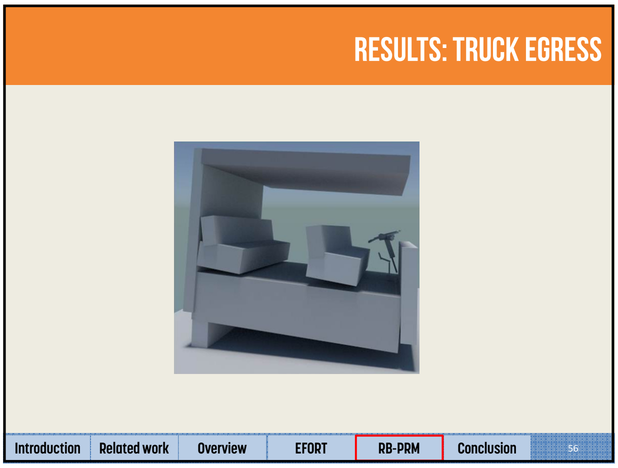


TRAJECTORY EXTENSION WITH EFORT



RESULTS

Introduction | Related work | Overview | EFORT | RB-PRM | Conclusion



RESULTS: TRUCK EGRESS

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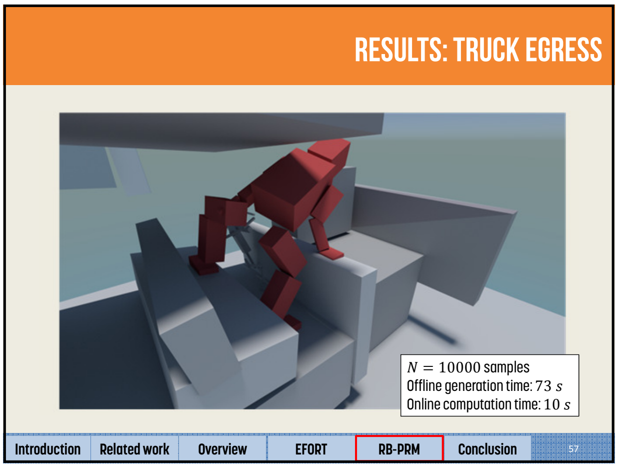

RESULTS: TRUCK EGRESS

$N = 10000$ samples
Offline generation time: 73 s
Online computation time: 10 s

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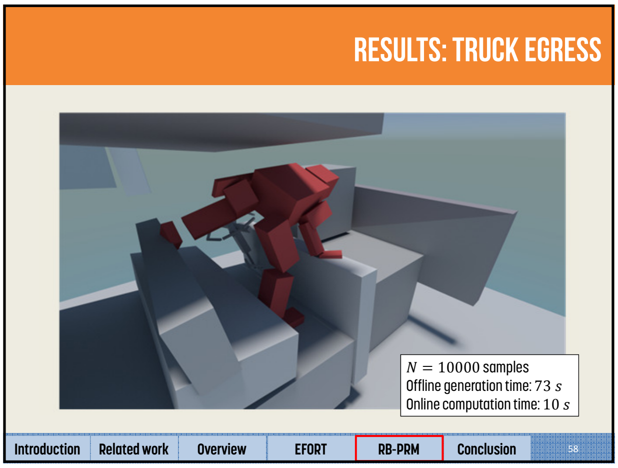

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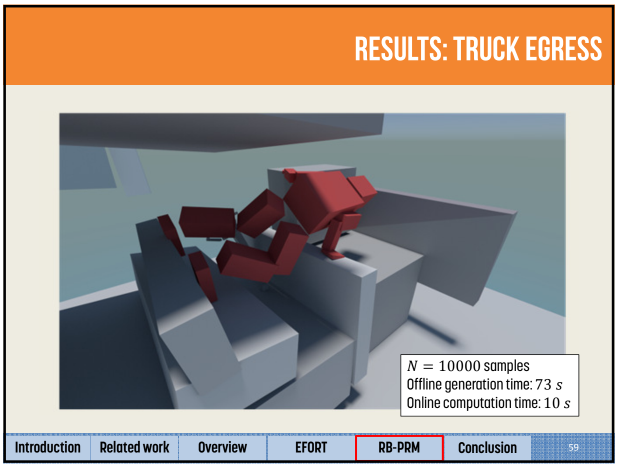

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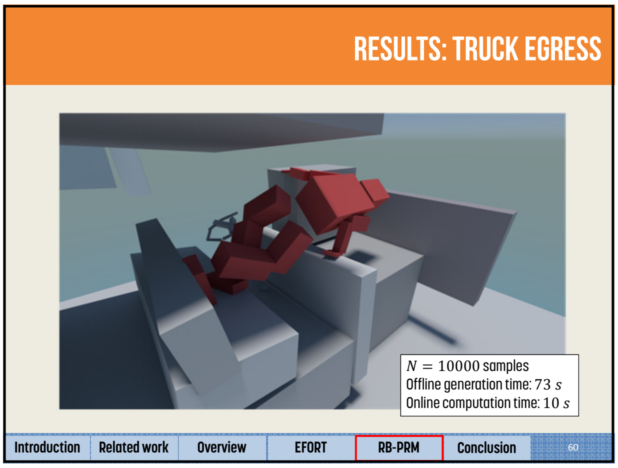

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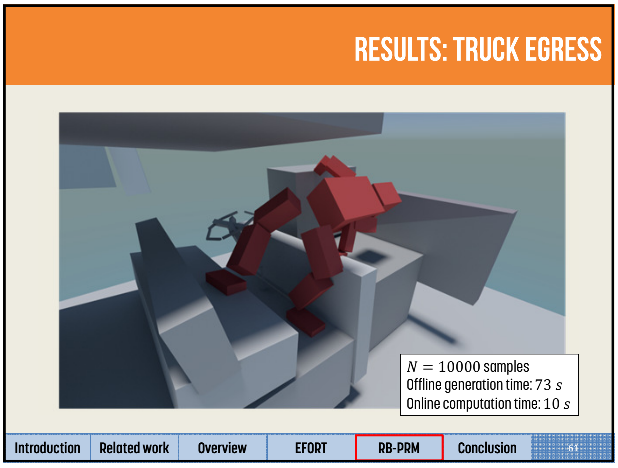

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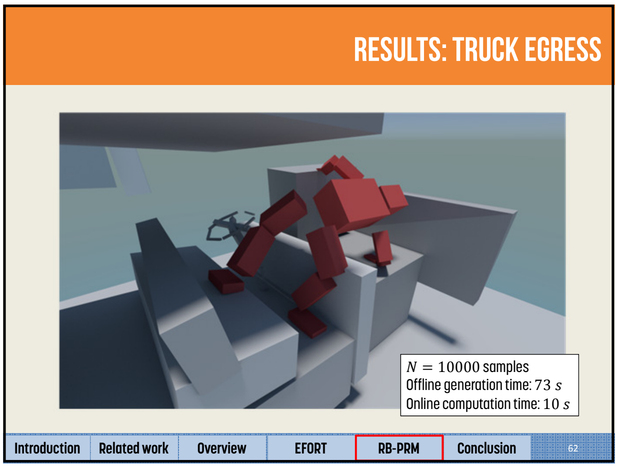
Online computation time: $10\ s$



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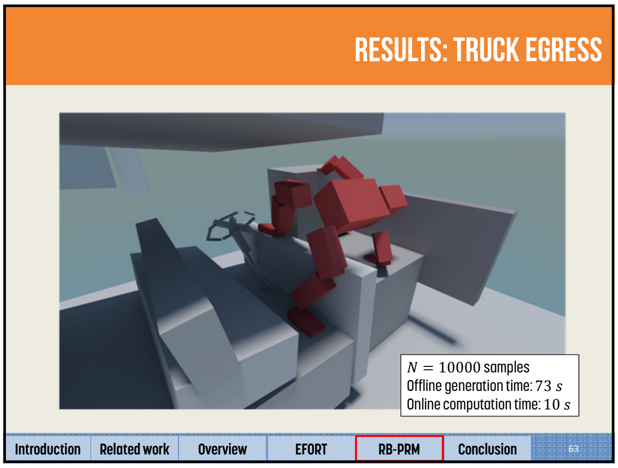

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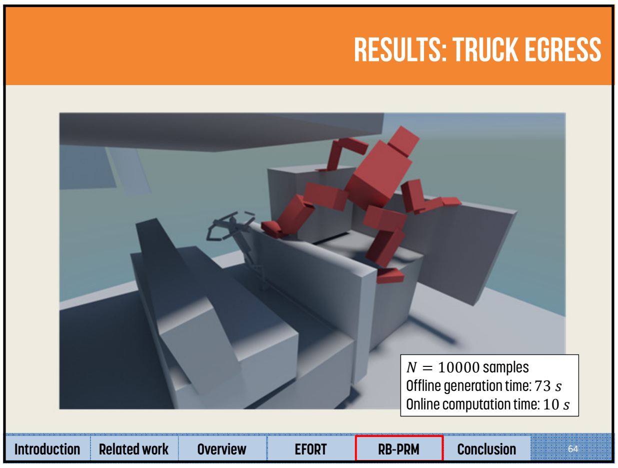

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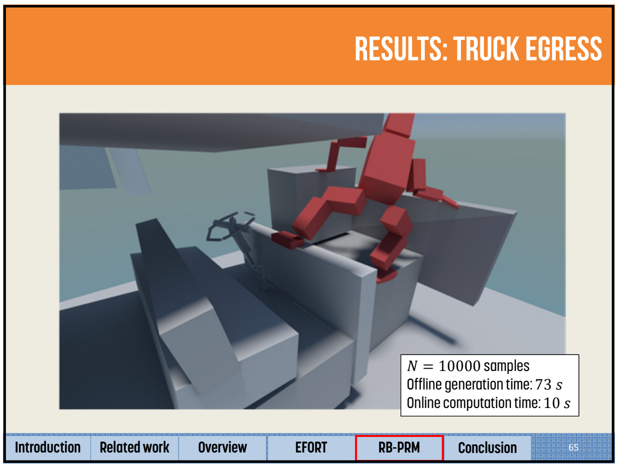

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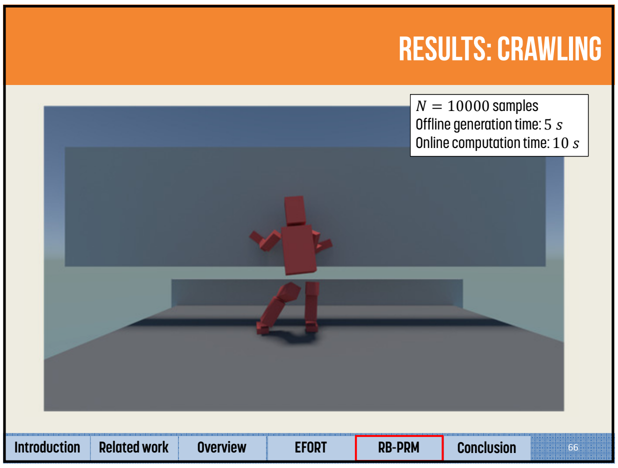
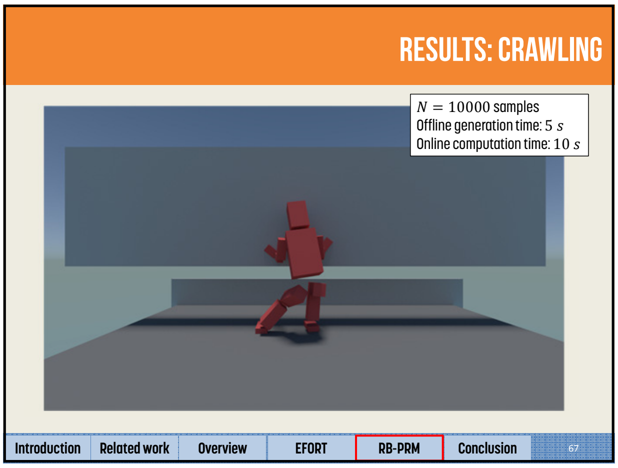


RESULTS: CRAWLING

$N = 10000$ samples
Offline generation time: $5\ s$
Online computation time: $10\ s$



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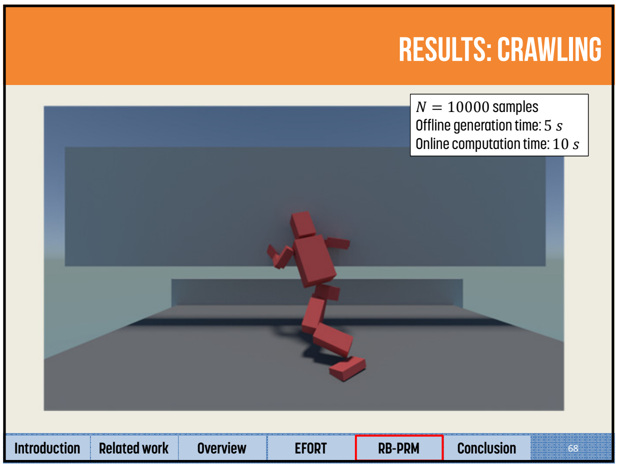

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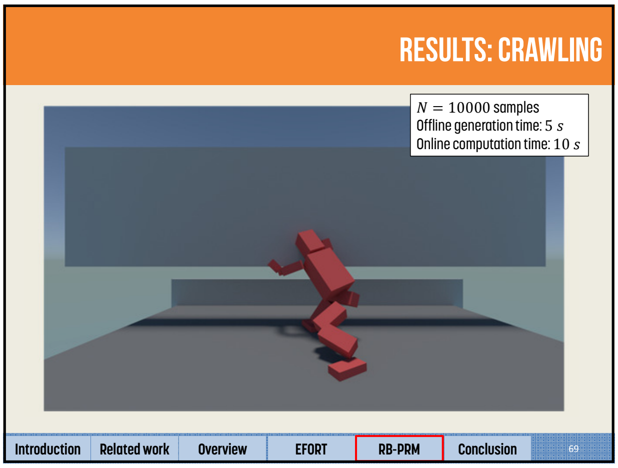

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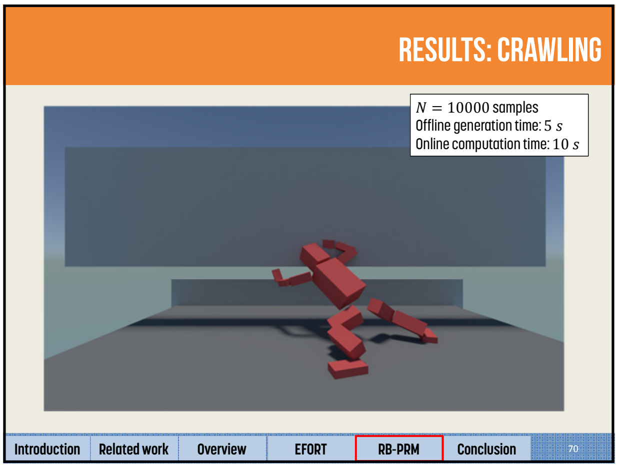

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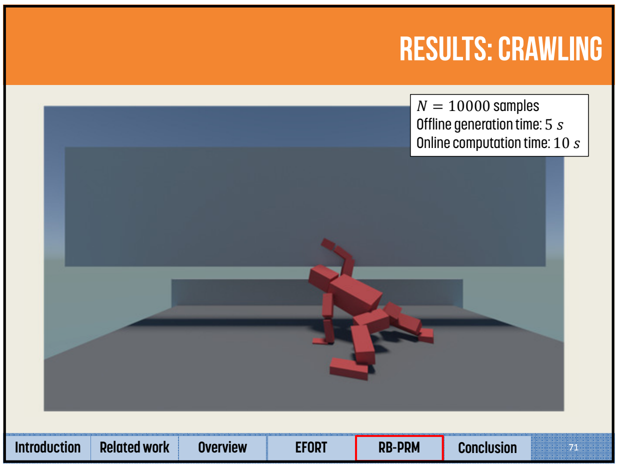

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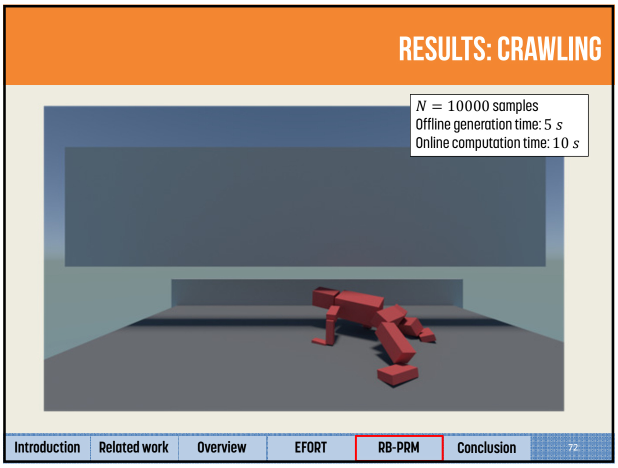

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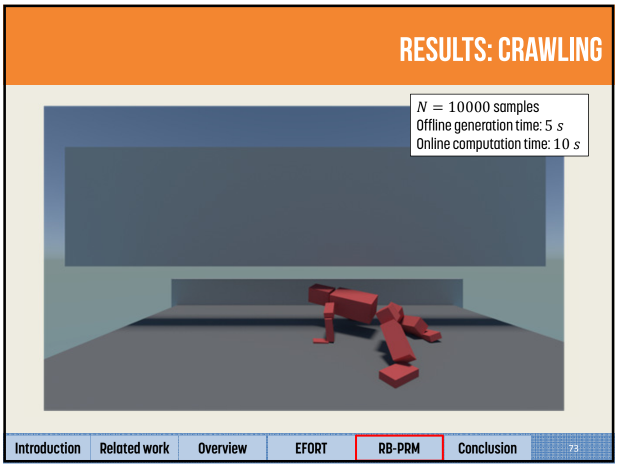

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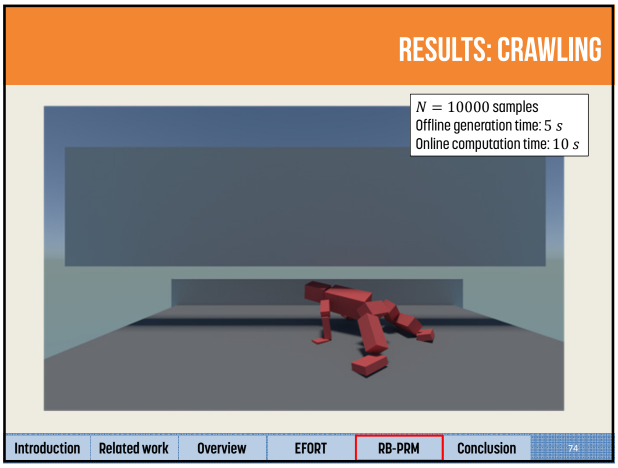

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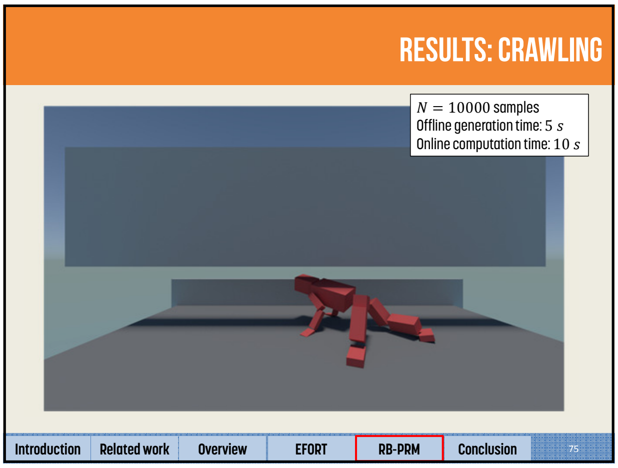

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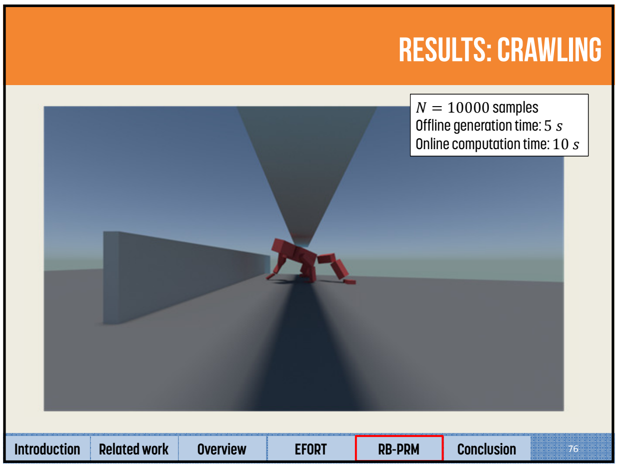

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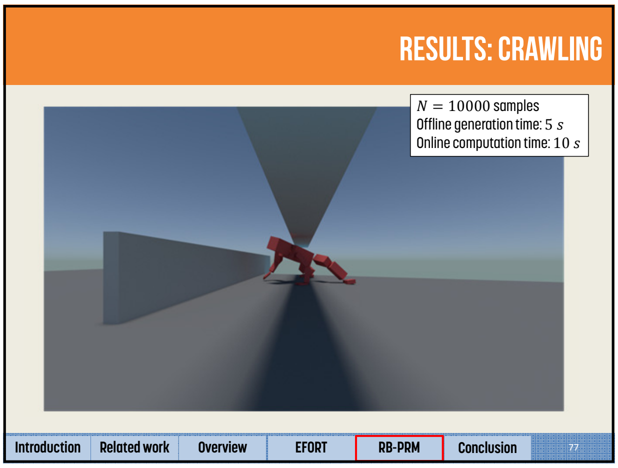

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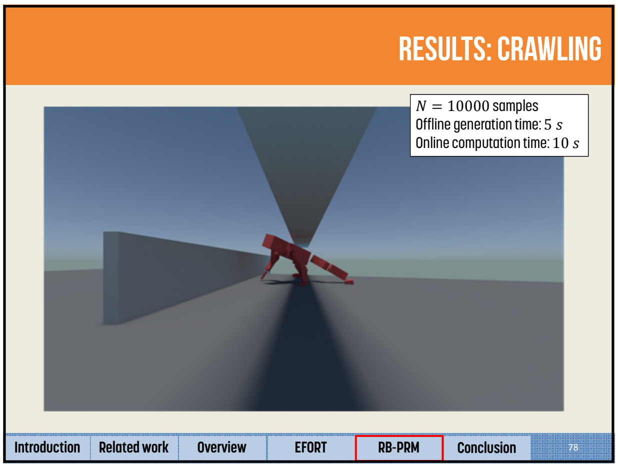

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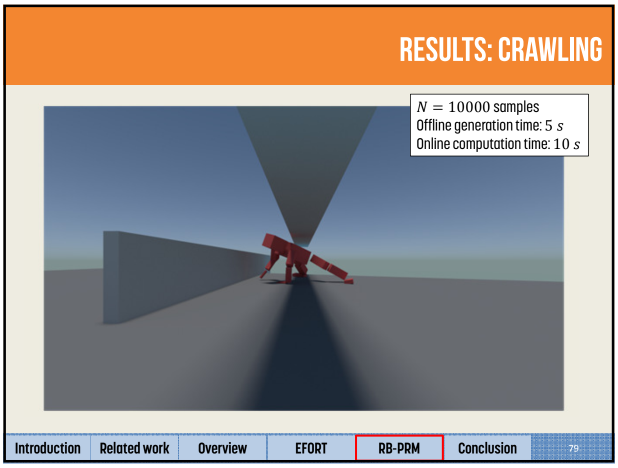

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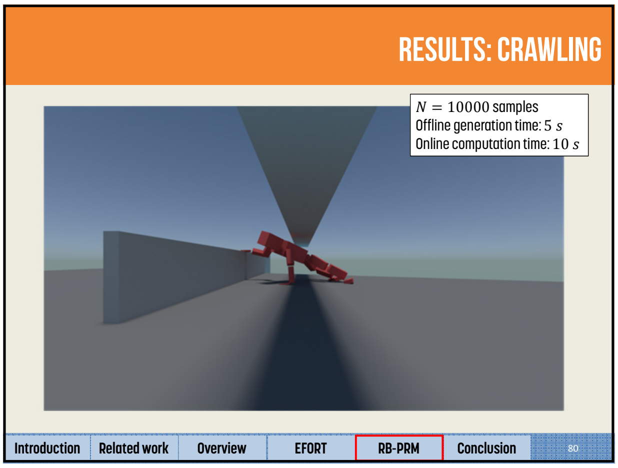

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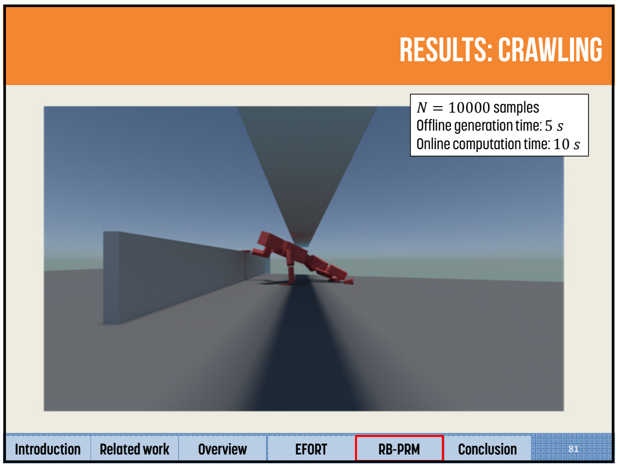

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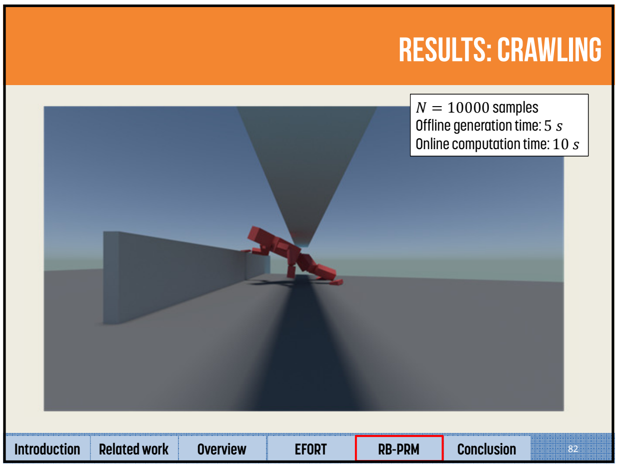

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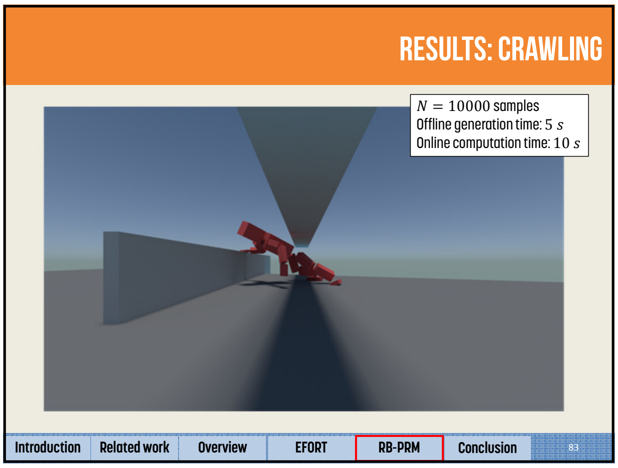

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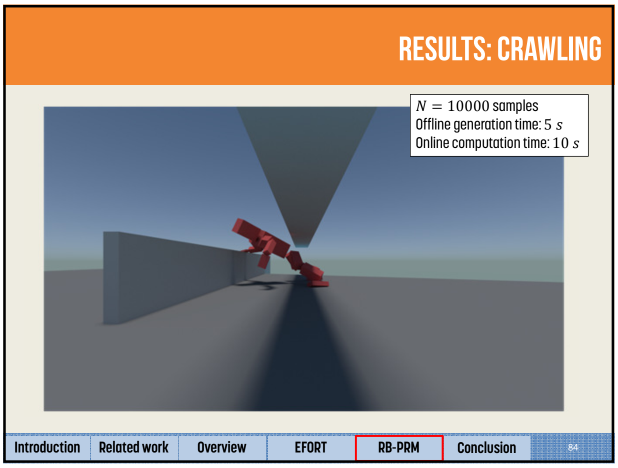
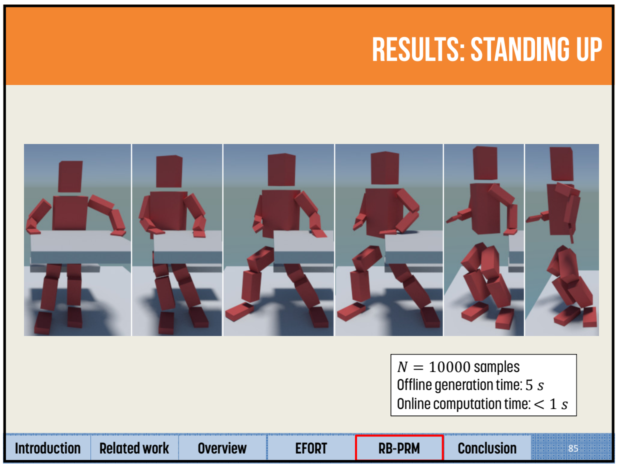


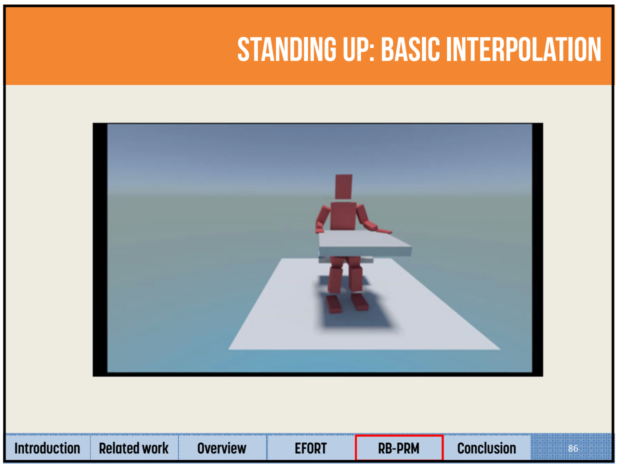
RESULTS: CRAWLING

$N = 10000$ samples
Offline generation time: 5 s
Online computation time: 10 s

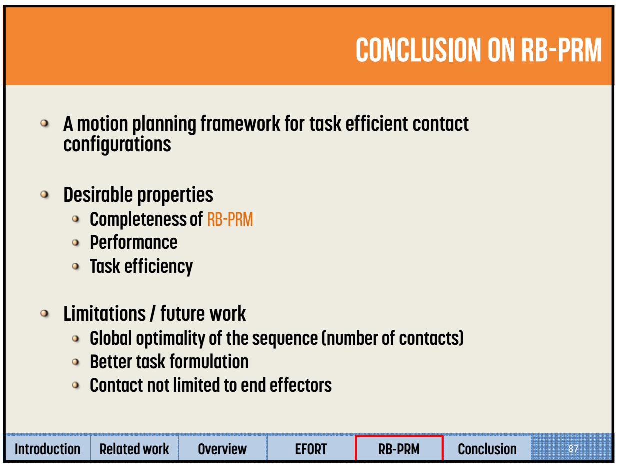


RESULTS: STANDING UP

$N = 10000$ samples
Offline generation time: $5\ s$
Online computation time: $< 1\ s$

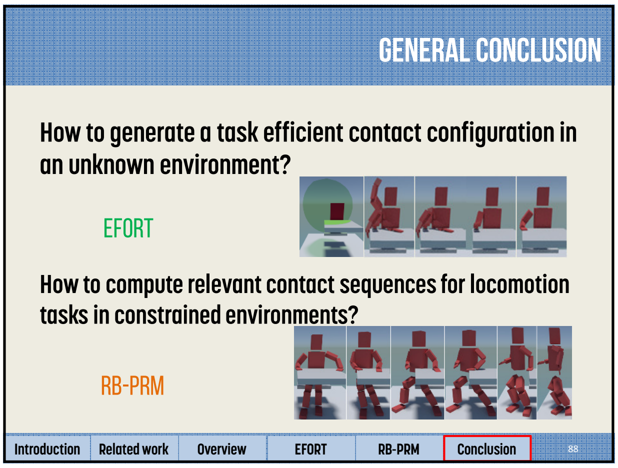


STANDING UP: BASIC INTERPOLATION



CONCLUSION ON RB-PRM

- A motion planning framework for task efficient contact configurations
- Desirable properties
  - Completeness of RB-PRM
  - Performance
  - Task efficiency
- Limitations / future work
  - Global optimality of the sequence (number of contacts)
  - Better task formulation
  - Contact not limited to end effectors



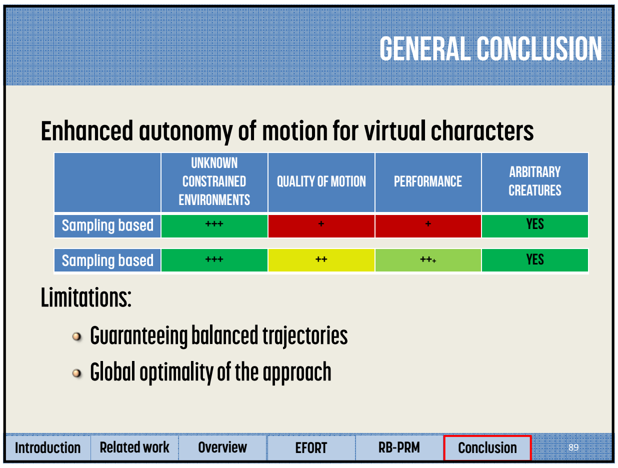
GENERAL CONCLUSION

How to generate a task efficient contact configuration in an unknown environment?

EFORT

How to compute relevant contact sequences for locomotion tasks in constrained environments?

RB-PRM



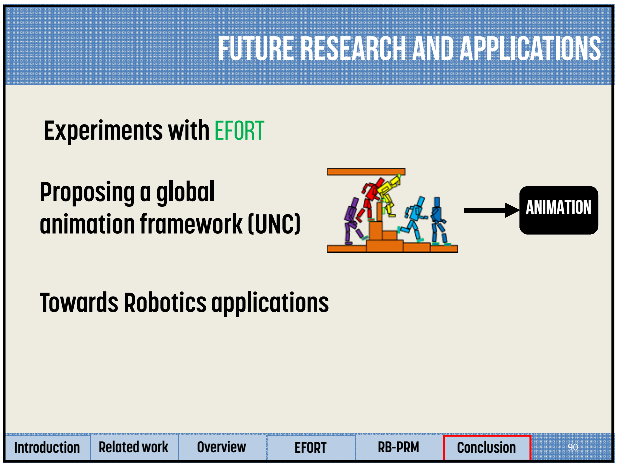
GENERAL CONCLUSION

Enhanced autonomy of motion for virtual characters

	UNKNOWN CONSTRAINED ENVIRONMENTS	QUALITY OF MOTION	PERFORMANCE	ARBITRARY CREATURES
Sampling based	+++	+	+	YES
Sampling based	+++	++	++₊	YES

Limitations:

- Guaranteeing balanced trajectories
- Global optimality of the approach

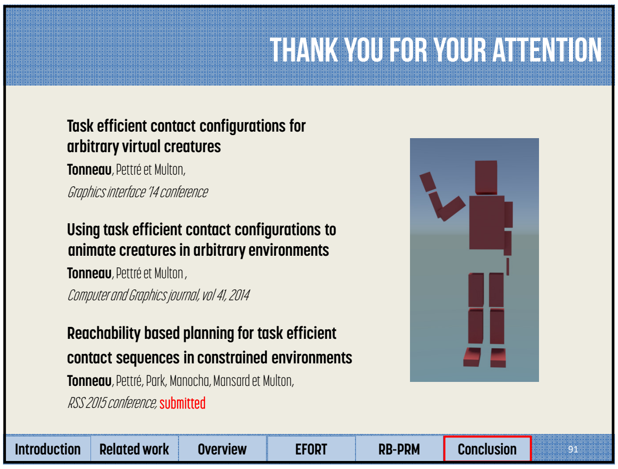


FUTURE RESEARCH AND APPLICATIONS

Experiments with EFORT

Proposing a global animation framework (UNC)

Towards Robotics applications



THANK YOU FOR YOUR ATTENTION

Task efficient contact configurations for arbitrary virtual creatures
Tonneau, Pettré et Multon,
Graphics interface '14 conference

Using task efficient contact configurations to animate creatures in arbitrary environments
Tonneau, Pettré et Multon ,
Computer and Graphics journal, vol 41, 2014

Reachability based planning for task efficient contact sequences in constrained environments
Tonneau, Pettré, Park, Manocha, Mansard et Multon,
RSS 2015 conference, submitted