A Game-Theoretic Approach to Fine Surface Registration without Initial Motion Estimation

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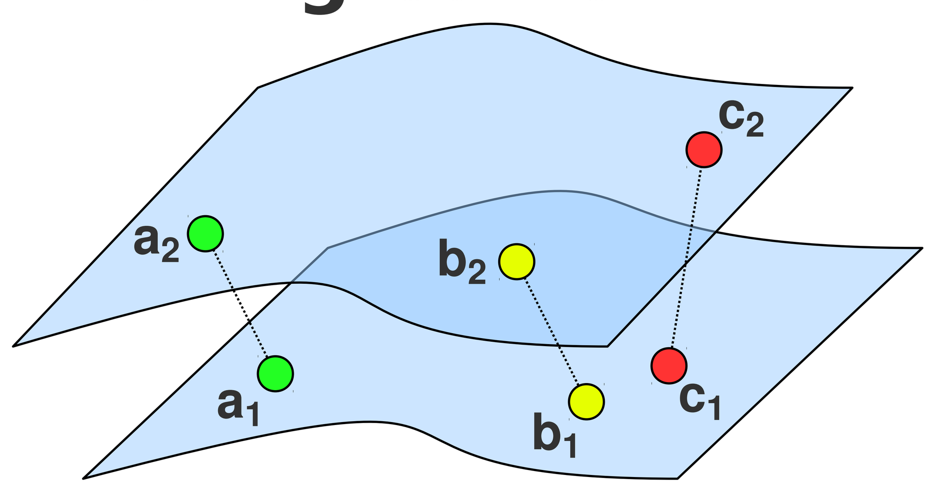
Research Goal

Surface registration is typically a two-step process where an initial coarse motion estimation is followed by a refinement. Coarse techniques exploit local descriptors intrinsic to the shape, while fine registration is attained by minimizing a distance function between plausible mates and is strongly dependent on the initial alignment.

We cast the selection of correspondences between points on the surfaces in a game-theoretic framework, relying only on their global geometric compatibility.

Mating Game

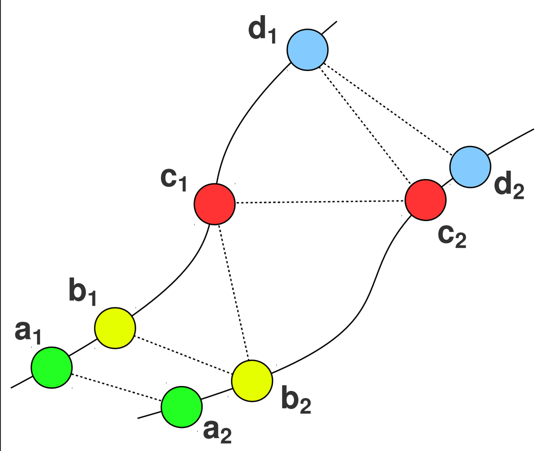


Given a set of model points M and a set of data points D we call a *mating strategy* any pair (a_1, a_2) with $a_1 \in M$ and $a_2 \in D$.

We assign to each pair of mating strategies a payoff that is inversely proportional to a measure of violation of the rigidity constraint.

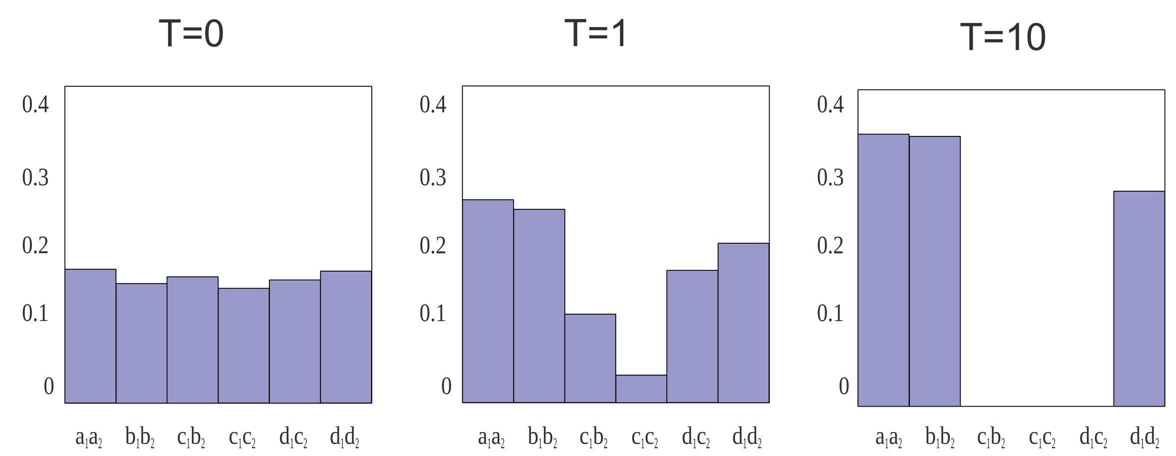
Surface Registration

Two *players* extracted from a large population select a pair of corresponding points from two surfaces to be registered with one another. The player then receives a payoff from the other players proportional to how "compatible" his pairings are with respect to the other player's choice, where the compatibility is expressed by a *rigidity-enforcing payoff function*.



π

	a_1a_2	b_1b_2	c_1b_2	c_1c_2	d_1c_2	d_1d_2
a_1a_2	0	1	0.1	0.1	0.7	0.9
b_1b_2	1	0	0	0.1	0.7	0.9
c_1b_2	0.1	0	0	0	0.6	0.4
c_1c_2	0.1	0.1	0	0	0	0.1
d_1c_2	0.7	0.7	0.6	0	0	0
d_1d_2	0.9	0.9	0.4	0.1	0	0



As the game is repeated, players will adapt their behavior to prefer matings that yield larger payoffs, driving all inconsistent hypotheses to extinction.

The solutions of the matching problem correspond to evolutionary stable states (ESS's). The search for a stable state is performed by simulating the evolution of a natural selection process; we chose to use the *replicator dynamics*.

Experimental Results

- We evaluated the technique both on real-world data and synthetically generated surfaces.
- Spin Images were associated to each interest point.
- The rigidity-enforcing payoff function chosen was:

$$\pi((a_1, a_2), (b_1, b_2)) = \frac{min(|a_1 - b_1|, |a_2 - b_2|)}{max(|a_1 - b_1|, |a_2 - b_2|)}$$

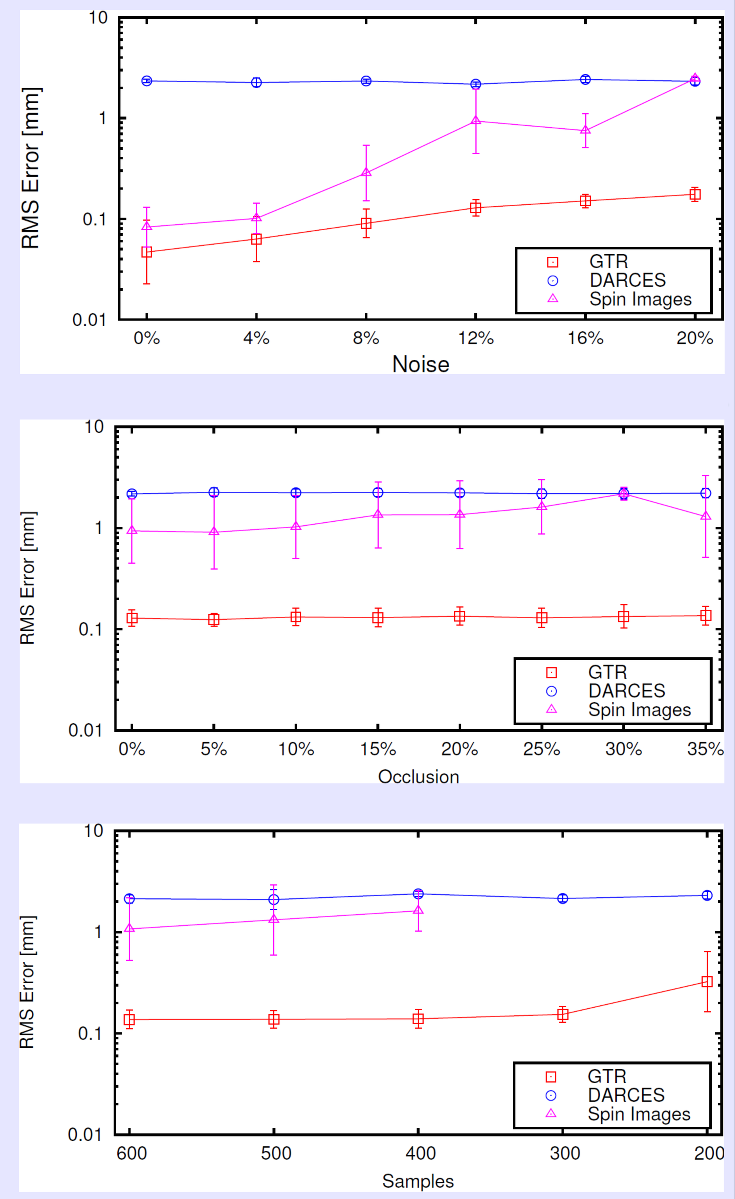
We always plot a "ground" RMS based on the *true* pairings

Coarse Registration

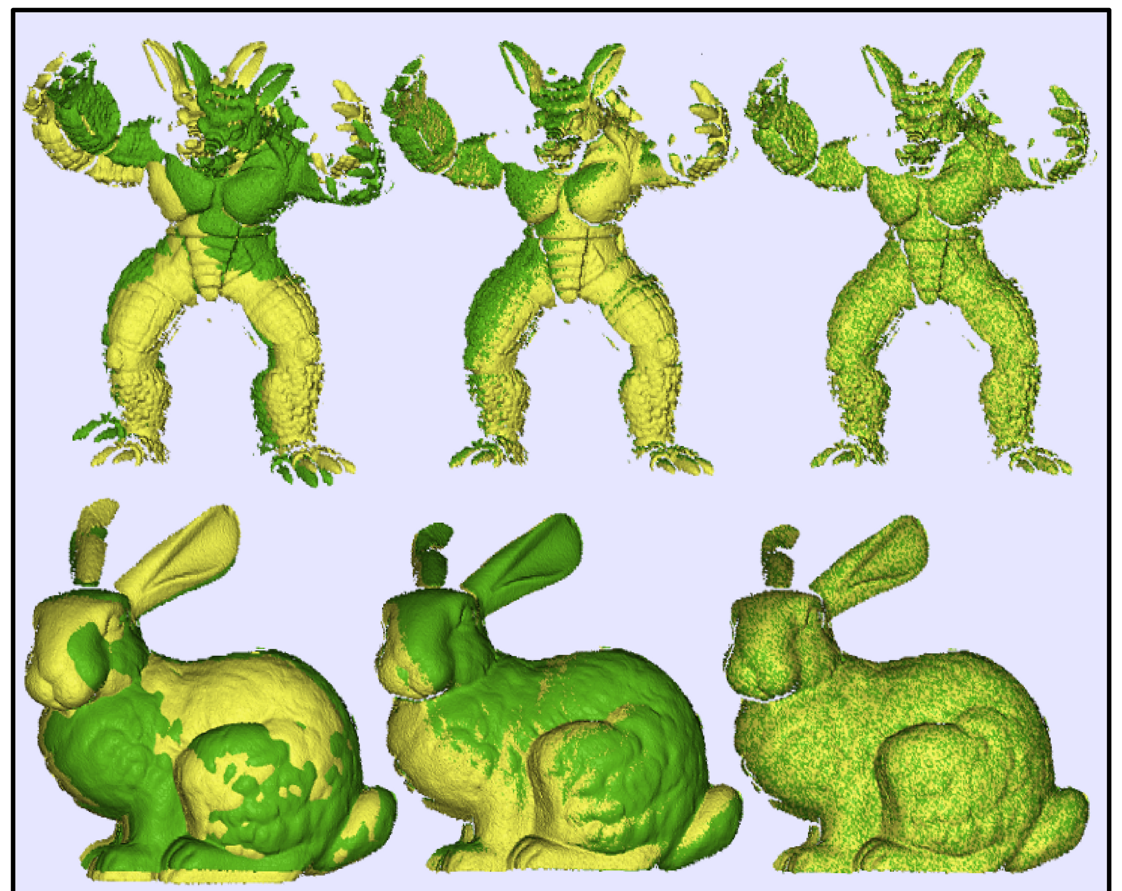
- We compared our method with RANSAC-based DARCES and the Spin Images pipeline
- Each test consists of 12 runs per level of noise, occlusion and sub-sampling
- Our method is named GTR

Fine Registration

- We compare against a trimmed ICP variant based on normal space sampling, normal shooting and weighted matings
- 100 tests were performed by applying a random rotation and translation to real-world range images perturbed with Gaussian noise

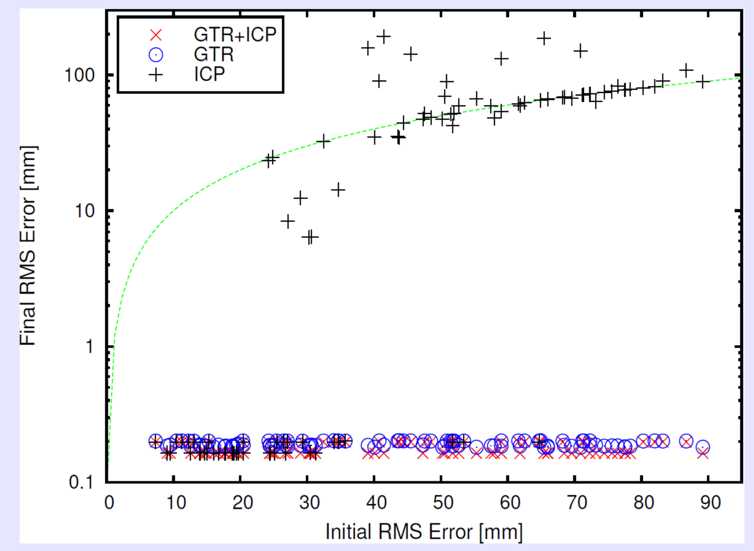


Our unoptimized C++ implementation of the framework required less than 2 seconds (on a typical desktop PC) to evolve a population of 4000 strategies to a stable state.



We want to evaluate our quality as a complete alignment tool.

GTR is able to obtain excellent alignment regardless of the initial motion perturbation.



Conclusions

- We introduce a novel game-theoretic technique that tackles both the coarse and fine surface registration problems at once.
- It is not affected by a large number of outliers since it operates an explicit search for good inliers.
- A sound correspondence between optimal alignments and evolutionary equilibria is established.
- A wide range of experiments validates both the robustness of the approach with respect to noise and its performance in comparison with other well-known techniques.