

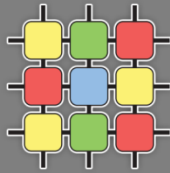
Flight Trajectory Planning

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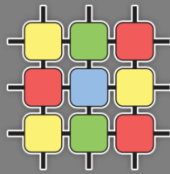
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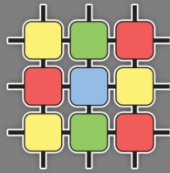
Outline



- Introduction
- Path planning task specification
- Accelerated A* algorithm
 - Key concepts
 - Algorithm details
- Empirical evaluation
 - Experiment configurations
 - Comparison results

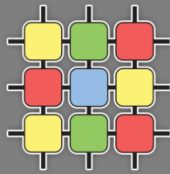


- application of the A* algorithm for flight path planning
- flight path planning domain:
 - dynamic continuous 3D space
 - obstacles and restricted areas
 - airplane is non-holonomic vehicle with complex motion dynamics
- flight path planner properties:
 - efficiency
 - allow integration of optimization criterion (like path length, fuel consumption)
- paper address only spatial part of the planning

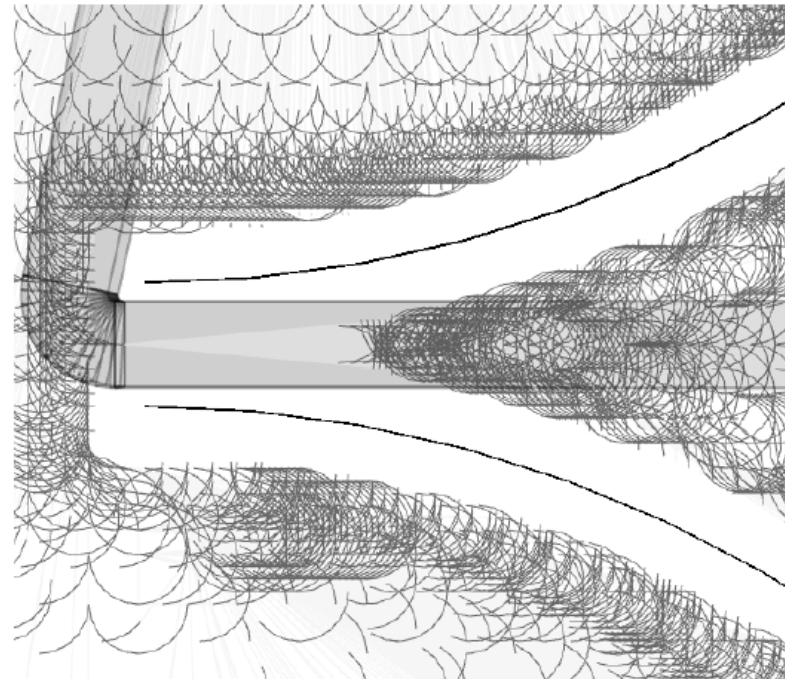


- path specifies motion trajectory for airplane reference point
- airplane dynamics can be converted to **flight envelope elements**:
 - straight
 - horizontal turn
 - vertical turn
 - spiral
- elements parameters are constrained by:
 - minimum horizontal turn radius
 - minimum vertical turn radius
 - maximum airplane pitch angle

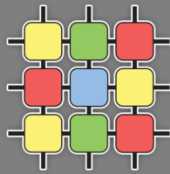
Path Planning Task



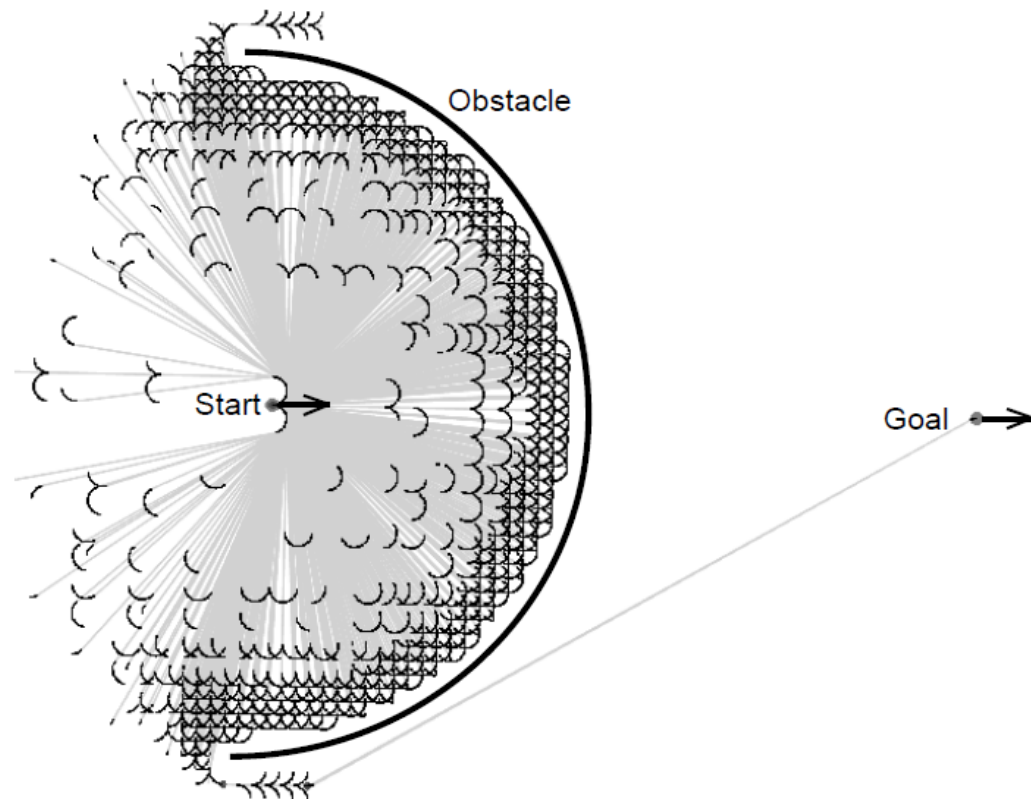
- **free space** is operational area without obstacles
- airplane can fly only within ε -**free space**
- plan is a finite ordered sequence of flight envelope elements from the start to the goal configuration
- validity of the plan:
 - smooth trajectory
 - inside allowed ε -free space
 - dynamics constraints are not violated



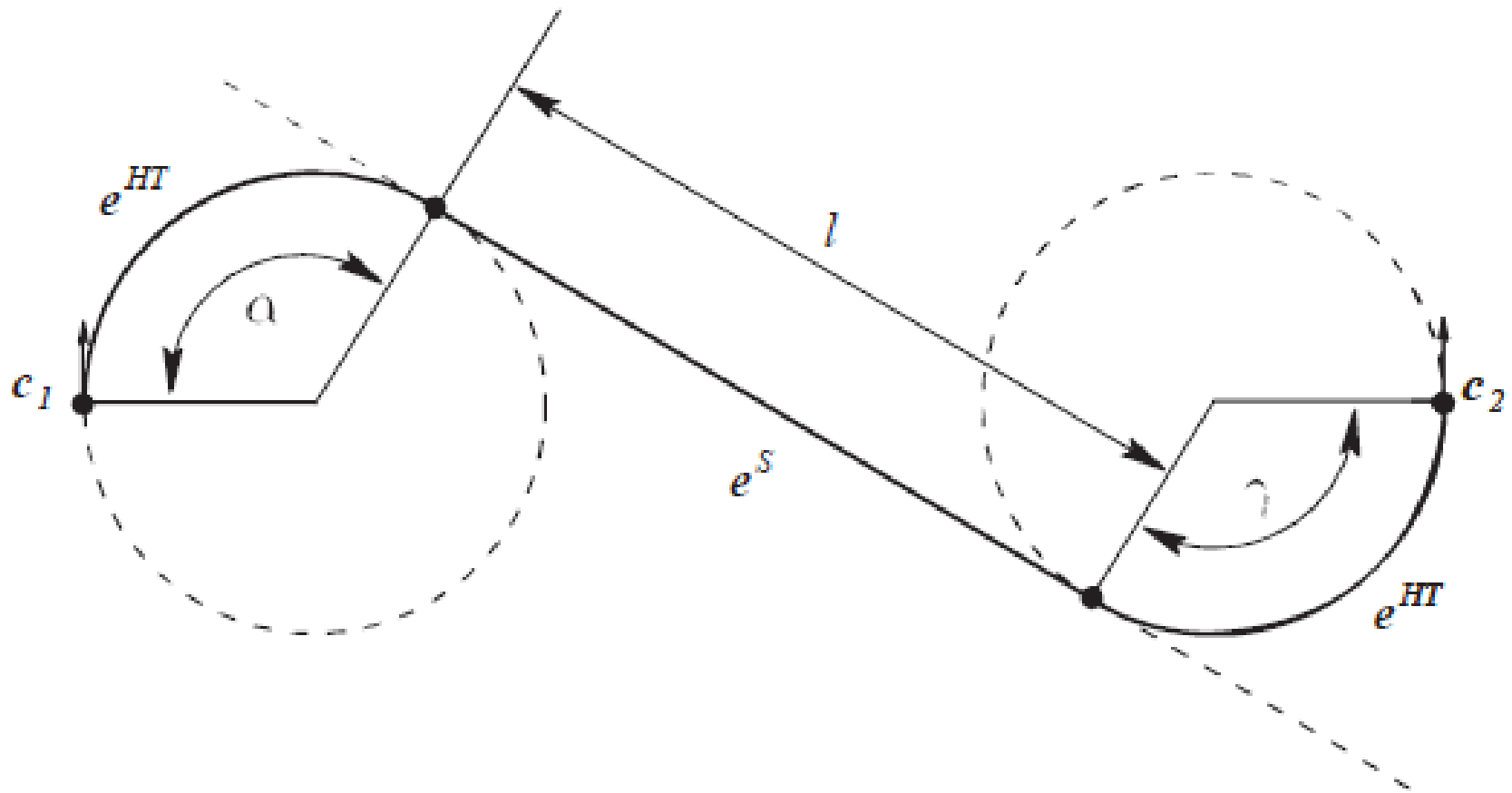
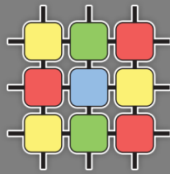
Accelerated A* Algorithm



- **adaptive sampling** – removes the trade-off between speed and search precision
- minimal sampling step – **search precision**
- progressive path smoothing
- similarity check
- heuristics based on shortest connection



Accelerated A* Algorithm

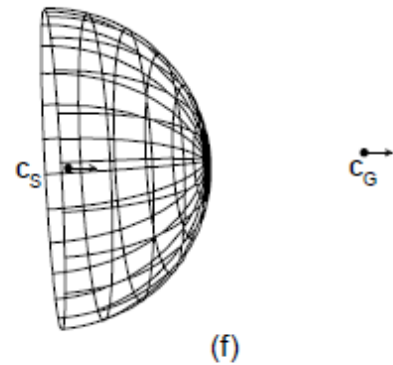
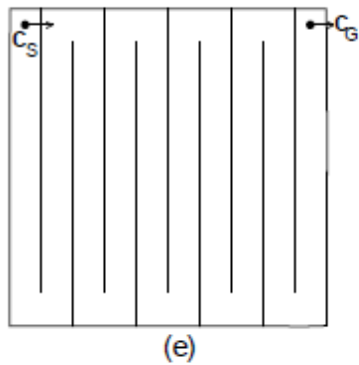
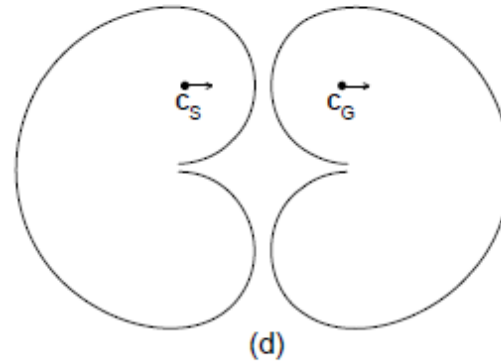
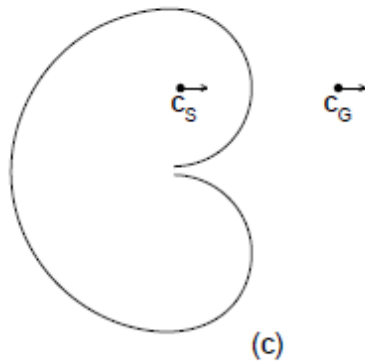
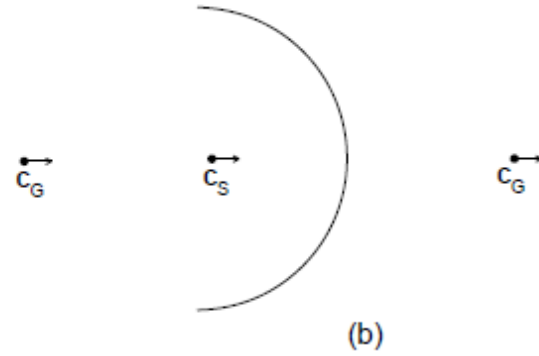
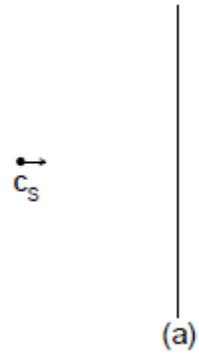
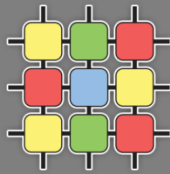


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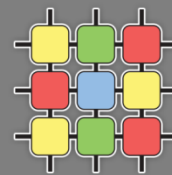
{6}  while  $OPEN \neq \emptyset$  do
{7}     $cur \leftarrow \text{RemoveTheBest}(OPEN);$ 
{8}    Insert  $c^{cur}$  into  $CLOSED$ ;
{9}    if  $s^{cur}$  then
{10}       $cur \leftarrow \langle c_G, -, \text{CONNECTION}, true,$ 
         $g^{cur} + h^{cur}, 0, cur \rangle;$ 
{11}       $cur \leftarrow \text{SmoothPath}(cur);$ 
{12}       $\Phi \leftarrow \text{ReconstructPath}(cur);$ 
{13}      return  $\Phi$ ;
{14}    end
{15}    foreach  $e_i \in \text{Expand}(cur)$  do
{16}       $c^{new} \leftarrow p(e_i, 1);$ 
{17}       $\xi^{new} \leftarrow \text{GetSamplingParams}(c^{new});$ 
{18}      if  $\text{Contains}(c^{new}, CLOSED, \xi^{new})$  then
{19}        continue;
{20}      if not  $\text{IsValid}(e_i)$  then continue;
{21}       $e^{end} \leftarrow \text{Connect}(c^{new}, c_G);$ 
{22}       $new \leftarrow \langle c^{new}, \xi^{new},$ 
         $\text{TypeOf}(e_i), \text{IsValid}(e^{end}),$ 
         $g^{cur} + l(e_i), l(e^{end}), cur \rangle;$ 
{23}       $new \leftarrow \text{SmoothPath}(new);$ 
{24}       $\text{InsertOrReplaceIfBetter}(new, OPEN,$ 
         $\xi^{new});$ 
{25}    end
{26}  end

```


Empirical Evaluation



Results



Experiment Setup			SD	PL	ES
Setup	Algorithm	Search precision			
Wall	A*	1,25	1	731,20 (3)	335 128
	AA*	1,25	0,000 69	733,87 (4)	1 282
Half circle	A*	1,25	1	879,14 (3)	360 999
	AA*	1,25	0,001 95	879,30 (3)	3 767
Single gap	A*	1,25	1	879,14 (3)	359 878
	AA*	1,25	0,002 48	879,30 (3)	3 581
Double gap	A*	1,25	1	1 117,54 (3)	801 752
	AA*	1,25	0,005 911	1 118,09 (3)	12 876
Maze	A*	1,25	1	8 557,30 (19)	1 737 858
	AA*	1,25	0,039 85	8 591,56 (20)	111 525
Half sphere	A*	10	1	880,33 (3)	340 922
	AA*	10	0,182 51	880,90 (3)	75 440