Problem
- Utilize reconstructed 3D models for landmark recognition
- Design effective representation of 3D points in 3D models
- Identify occurrences of 3D points from images

Limitations of existing solutions
- Image-to-Image Matching
  - Sensitive to noises in DB images
  - Lacking robustness to full projective transformations
  - Relying on geometric verification
- 3D-to-2D / 2D-to-3D Matching
  - Utilizing appearance of individual 3D points but ignoring geometric structure among them
  - Relying on geometric verification

Our solution
- Discover 3D Visual Phrases (3DVP) from a 3D point cloud
- Describe appearance and geometric structure of 3DVPs
- Detect 3DVPs to identify landmarks in 2D images

Discovering 3DVPs from a point cloud
(a) 3D point selection
(b) space carving
- Select popular 3D points to spatially cover the model
- Construct 3D surface → triangular facets as 3DVPs

Describing 3DVPs (i.e., 3D point triplets)
- Appearance of 3D points
  - 3D-to-2D re-projection
  - clusters of SIFT descriptors
- Geometry between 3D points
  - cyclic order of vertices
  - scale-distance correlation

Detecting 3DVPs from a 2D image
(a) 3D-to-2D matching
(b) Construct a graph over putative 3DVPs (by linking non-conflicting pairs)
(c) Identify 3DVPs by finding maximal cliques from the graph

Evaluation
- Dataset
  - 10 landmarks, each with ~1.5K DB images + 200 test images
  - Negative test images from Oxford5K dataset
- Overall performance (averaged over 10 landmarks)
  - 3DVP boosts Precision & F-score, even WITHOUT geometric verification

Dataset available at http://landmark3d.codeplex.com