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Automatic crater detection based on random forests, existing crater map, and spatial structural information from DEM

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State Key Laboratory of Resources And Environmental Information System

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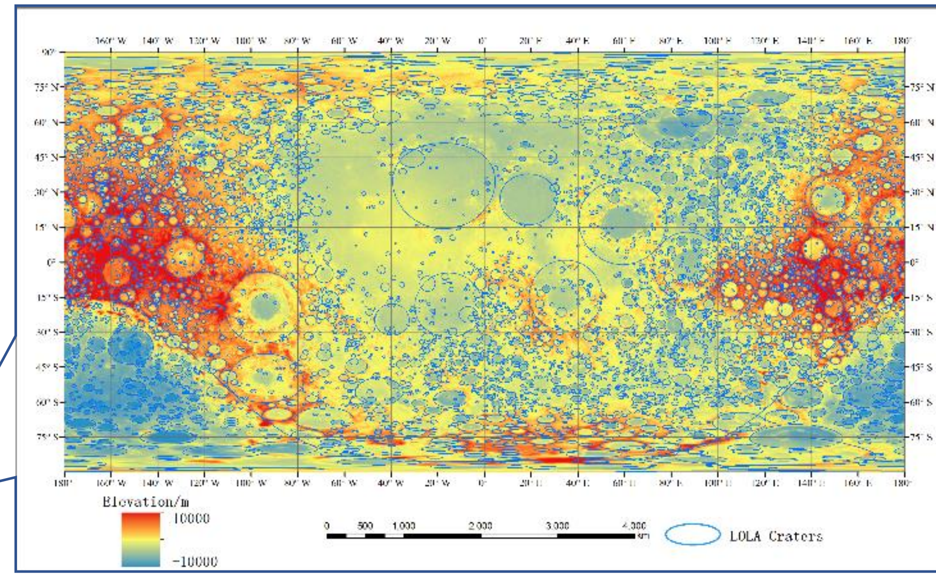
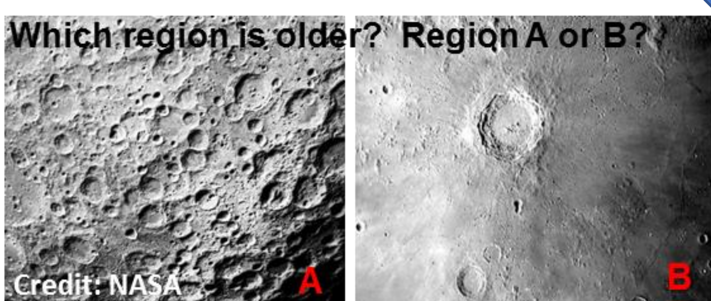
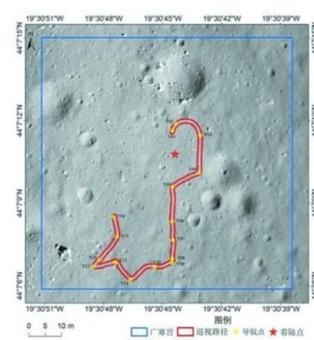
1. Background

Impact crater map is important for

- Research on evolution of stars' surfaces (Neukum et al., 2001)
- Engineering such as probe landing and self-driving







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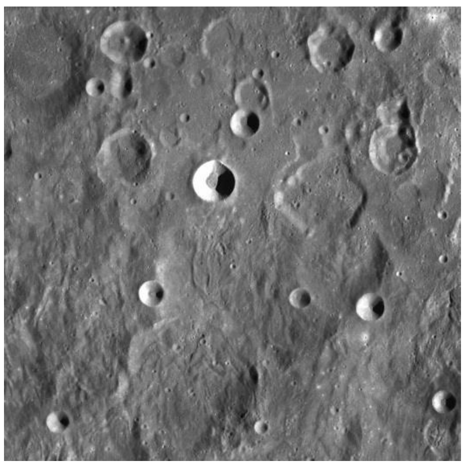
(Neukum et al., 2001; Cheng et al., 2016)

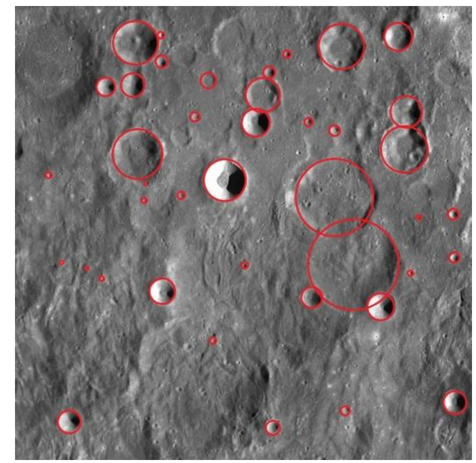
Crater detection

- Traditional way: manual delineation based on visual judgement



Imagery

Domain experts



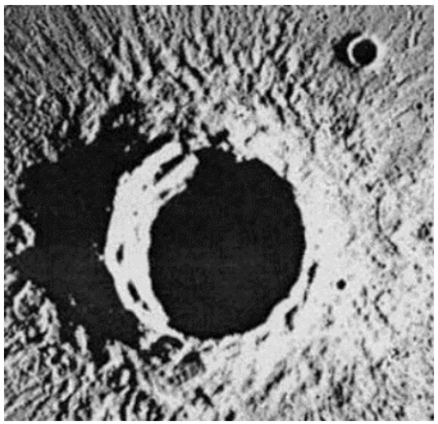
Impact crater map

Shortcomings: labor-intensive, low efficiency, and high cost

Crater detection approaches (CDAs) based on image analysis

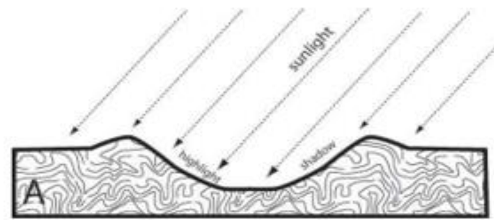
- Image characteristics of craters:

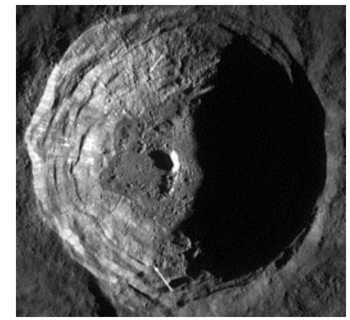
1) Ring-like rim of crater



(Barata et al., 2004; Kim et al., 2005; Salamunićcar & Lončarić, 2008; Salamunićcar et al., 2010; Luo et al., 2011)

2) Pattern of Bright-dark



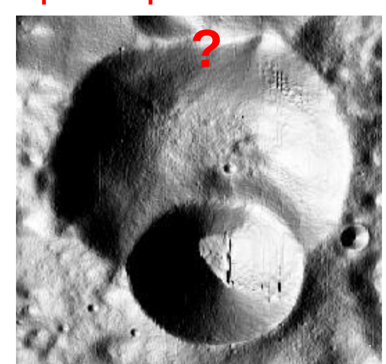


(Sawabe et al., 2006; Urbach & Stepinski, 2009; Ding et al., 2011)

Shortcomings:

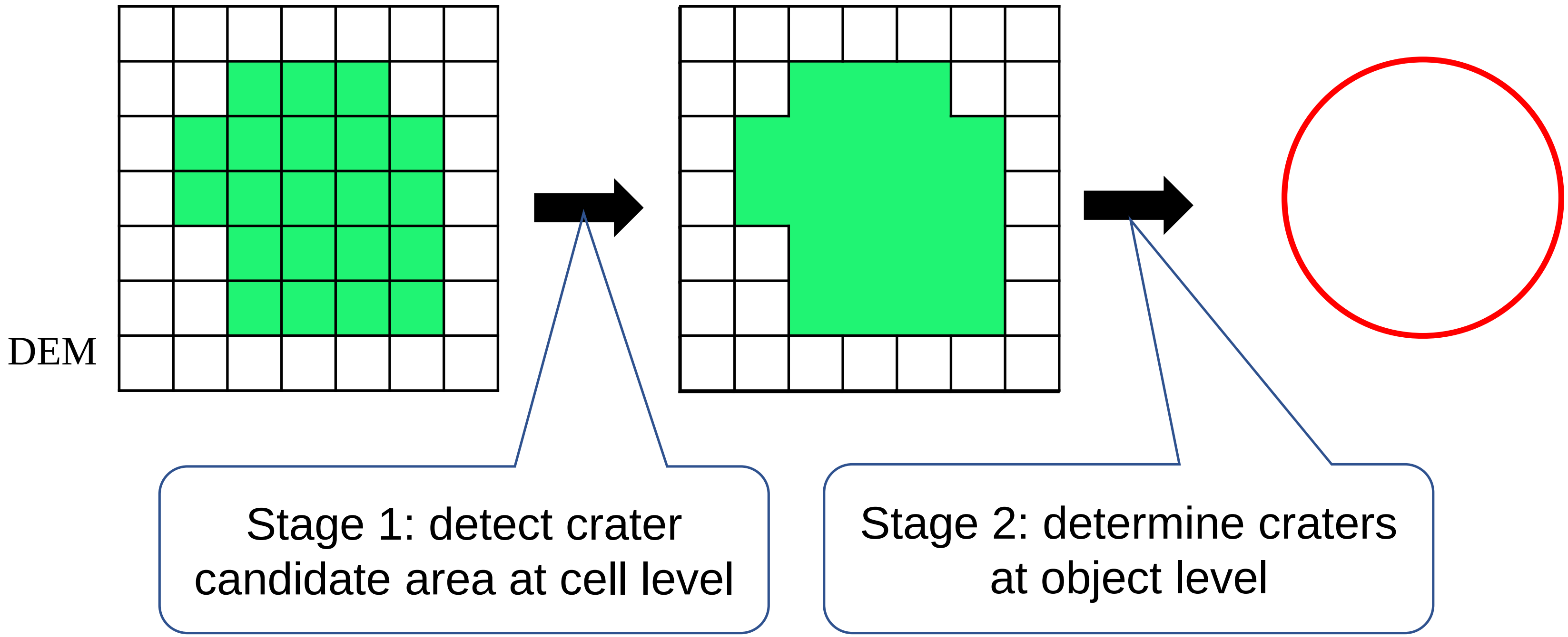
- Image quality issue due to lighting conditions, terrain conditions, etc. (Stepinski et al., 2009)
- 2D image cannot well reflect the spatial structure of craters, especially of those superimposed craters and degraded craters.

superimposed craters



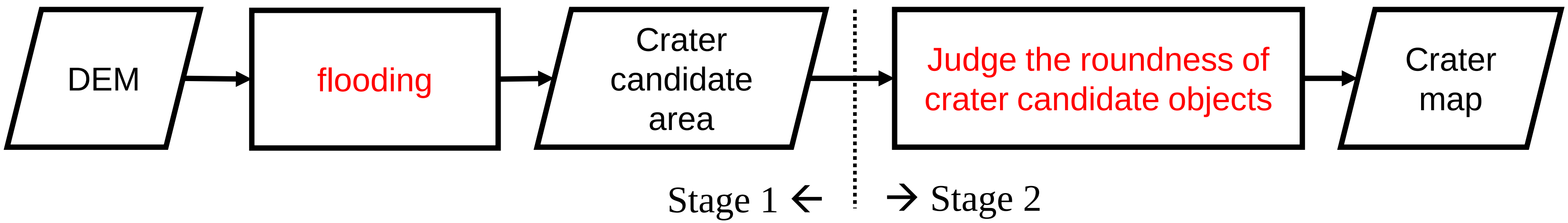
CDAs based on terrain analysis

- Gridded DEM records 3D information of craters and thus could reveal the spatial structure of craters (Stepinski et al., 2009; Wan et al., 2012)
- General workflow: two-stage process
  (Bue & Stepinski, 2007; Stepinski et al., 2009; Stepinski et al., 2012; Wan et al., 2012; Yue et al., 2013; Zuo et al., 2015; Vamshi et al., 2016; Liu et al., 2017)

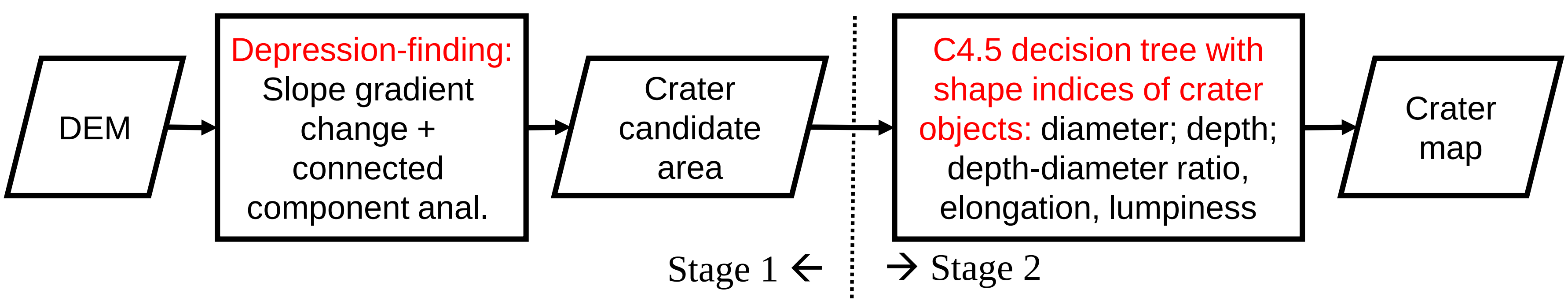


Existing CDAs based on terrain analysis

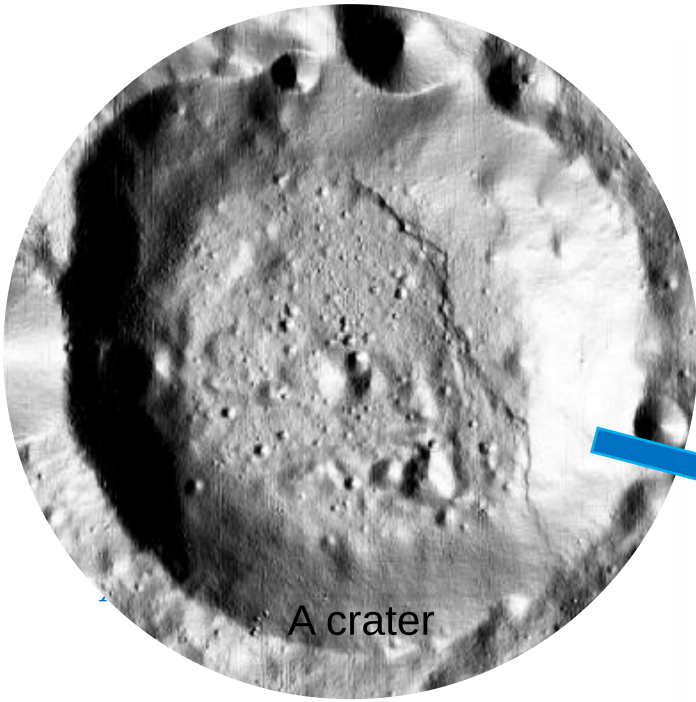
- Type 1: Depression-filling & manually-determined rules on shape (Bue & Stepinski, 2007; Wan et al., 2012; Yue et al., 2013; Zuo et al., 2015; Vamshi et al., 2016; Liu et al., 2017)
  - Shortcomings: View craters as simple round depressions, thus ignore the spatial structural information of craters; limit effectiveness



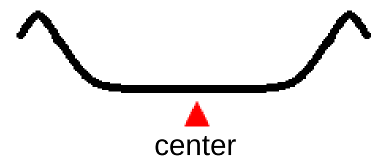
- Type 2: AutoCrat (Stepinski et al., 2009; Stepinski et al., 2012)
  - Shortcomings: Using a set of simple shape indices only partly consider the spatial structural information of craters (not inside craters)



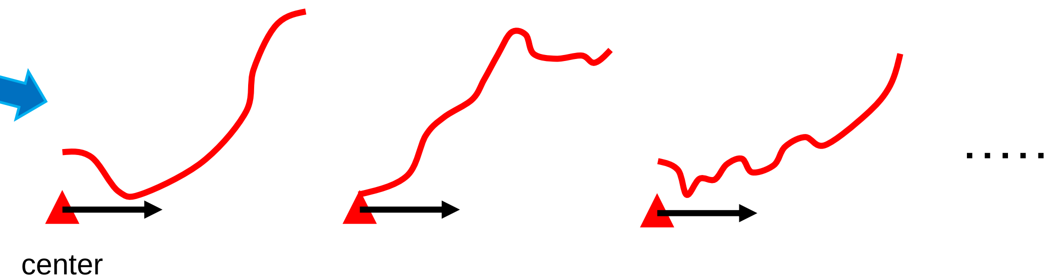
Study issue



- Existing CDAs mainly consider conceptual crater (with simplified shape/spatial structure).



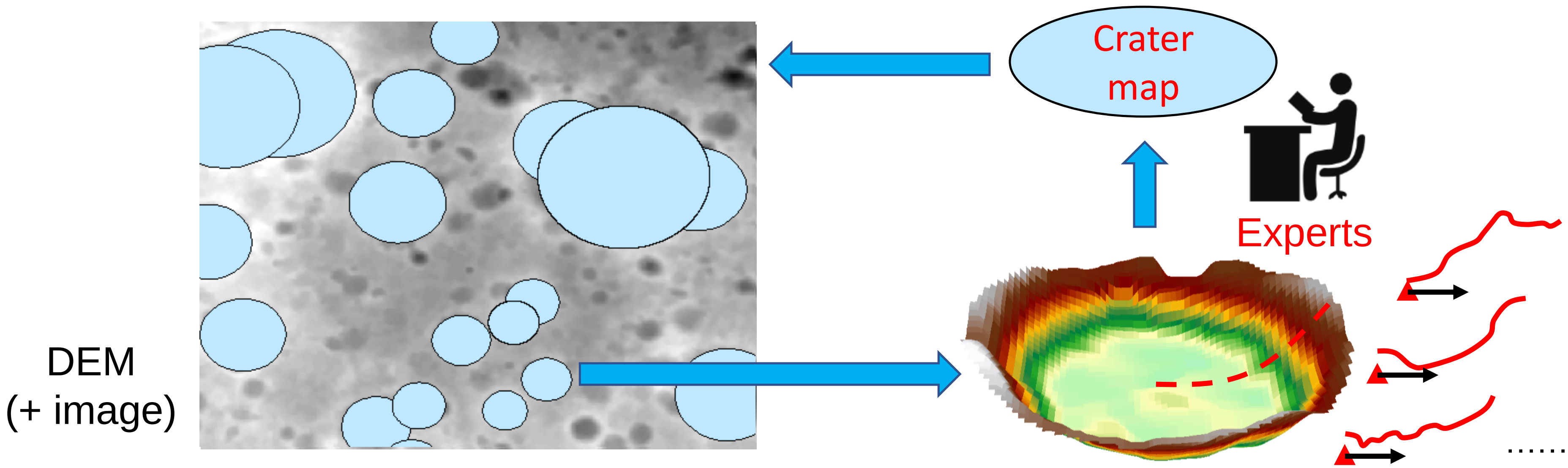
- Spatial structure of real craters is complicated

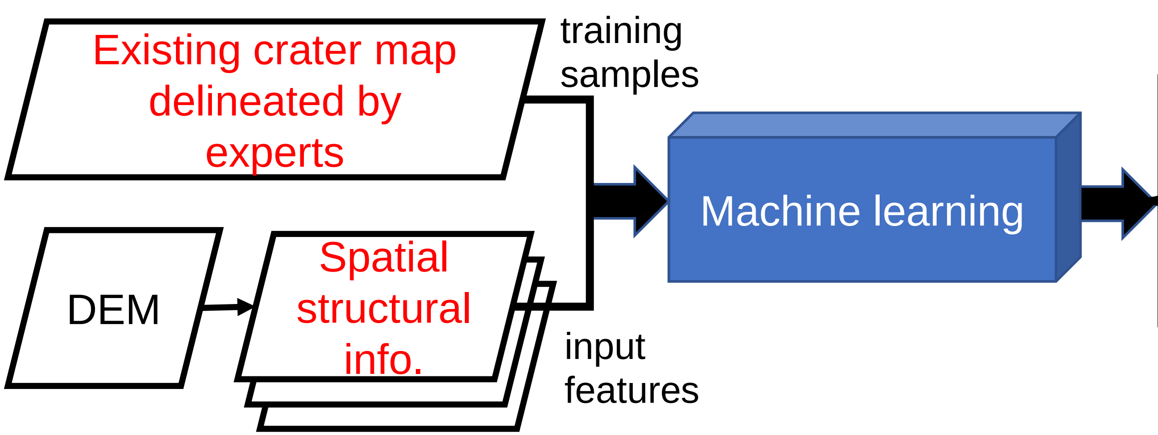


How to design a new automatic approach to detecting craters based on DEM ?

- effectively consider the spatial structural information of real craters

2. Basic idea

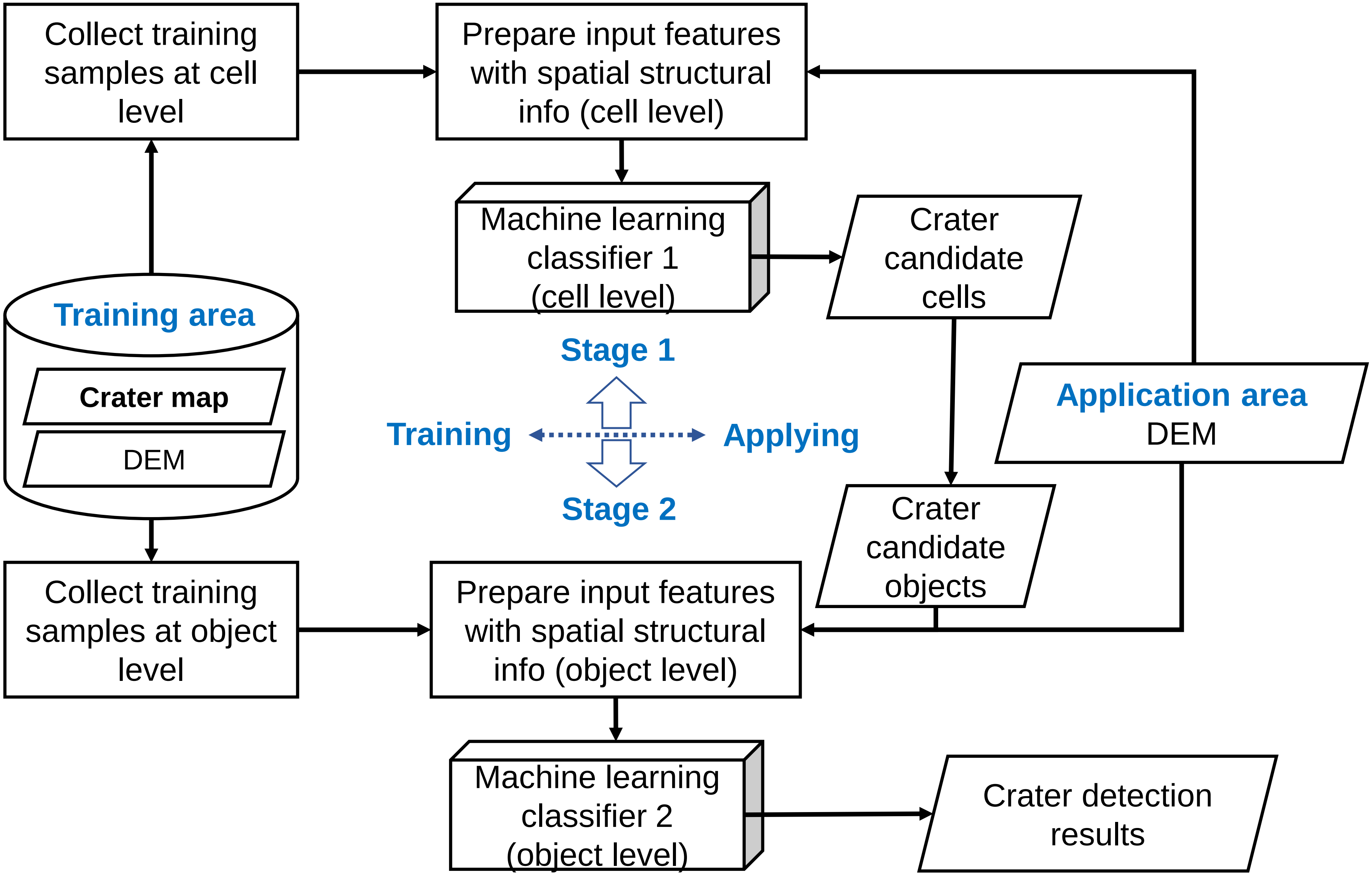




- Mining implicit expert knowledge on spatial structure of real craters;
- and using it to detect craters in other areas with DEM

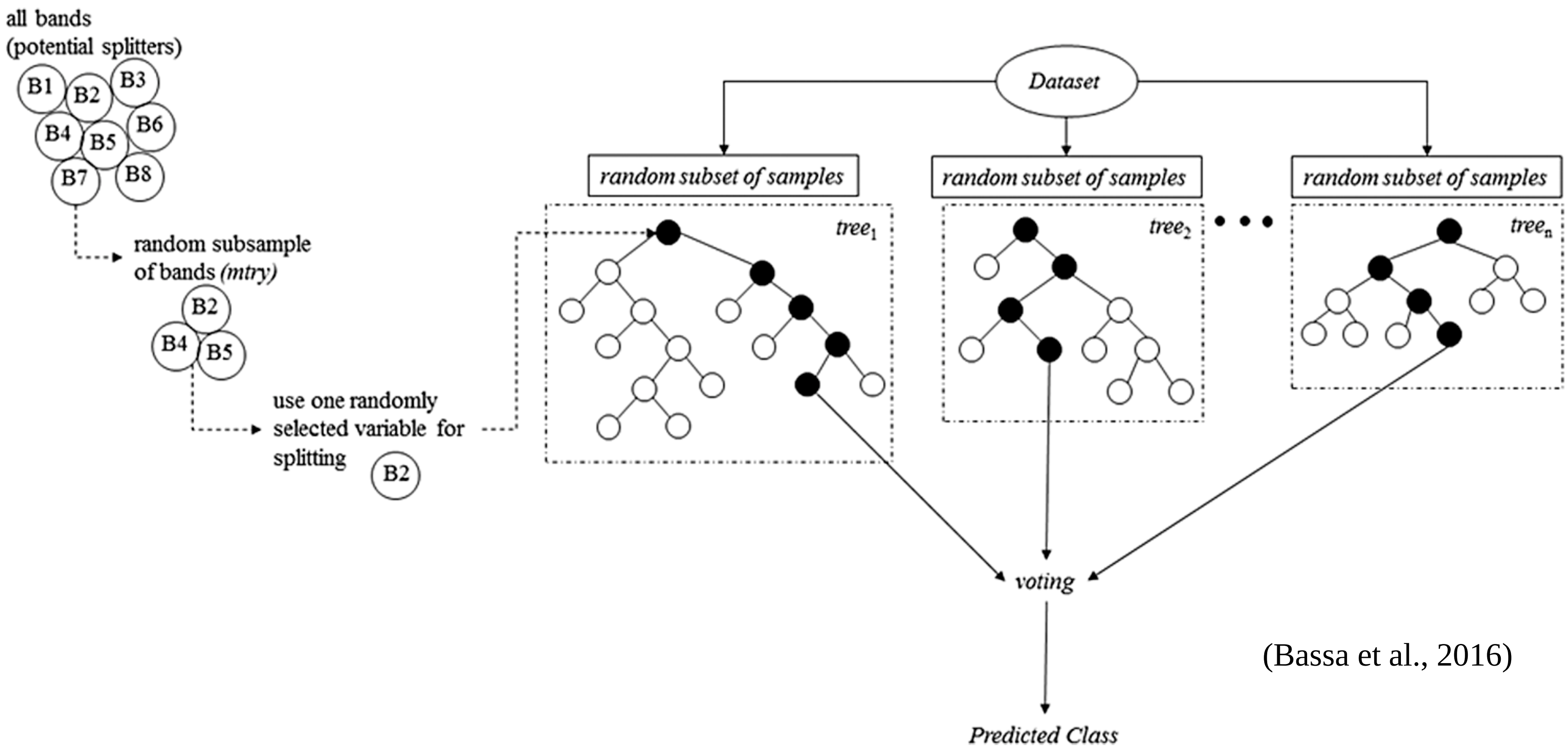
A new automatic approach to detecting craters

Framework of the proposed approach



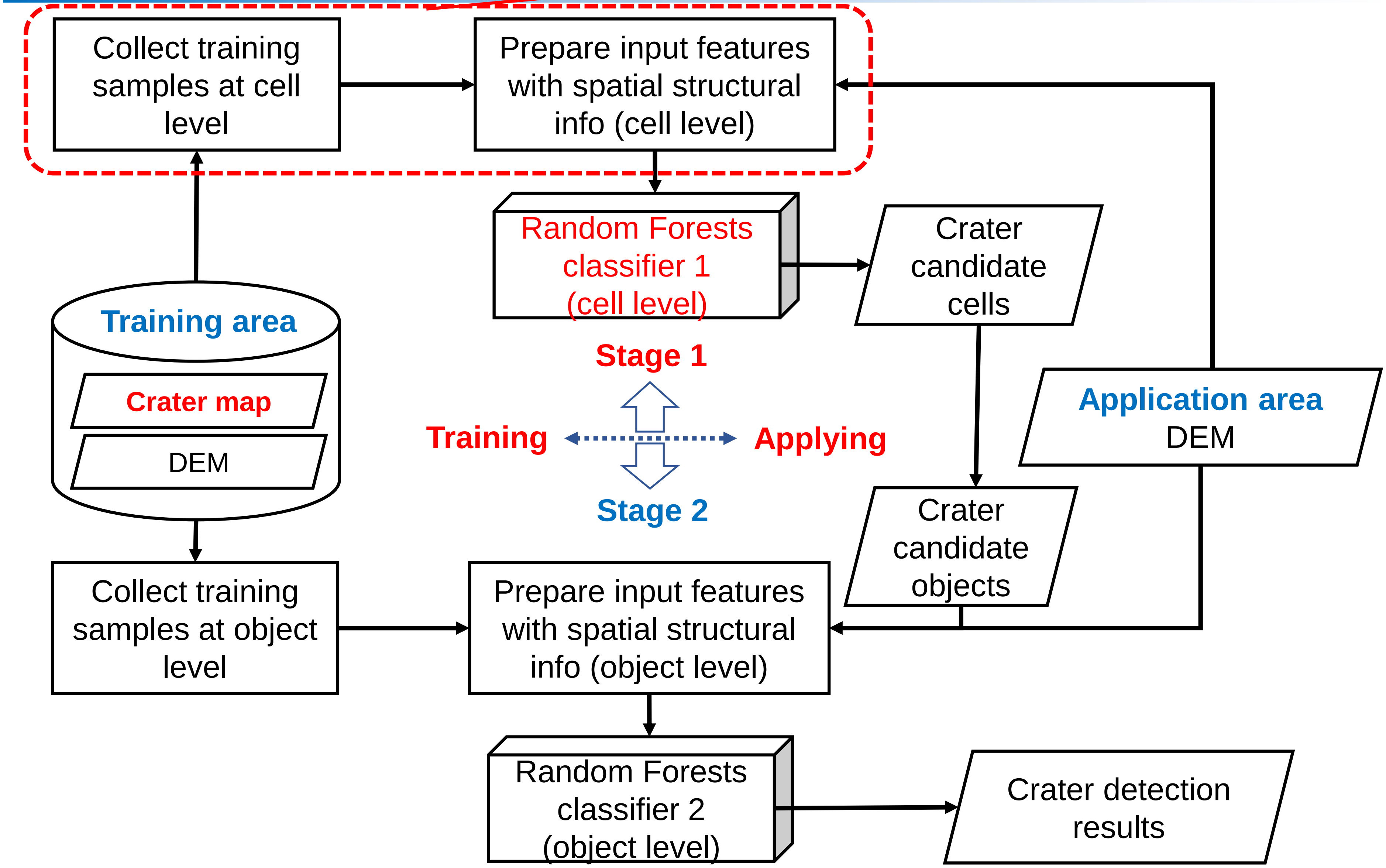
3. Detailed design of the proposed approach

- Machine learning classifier: Random Forests (Breiman, 2001)

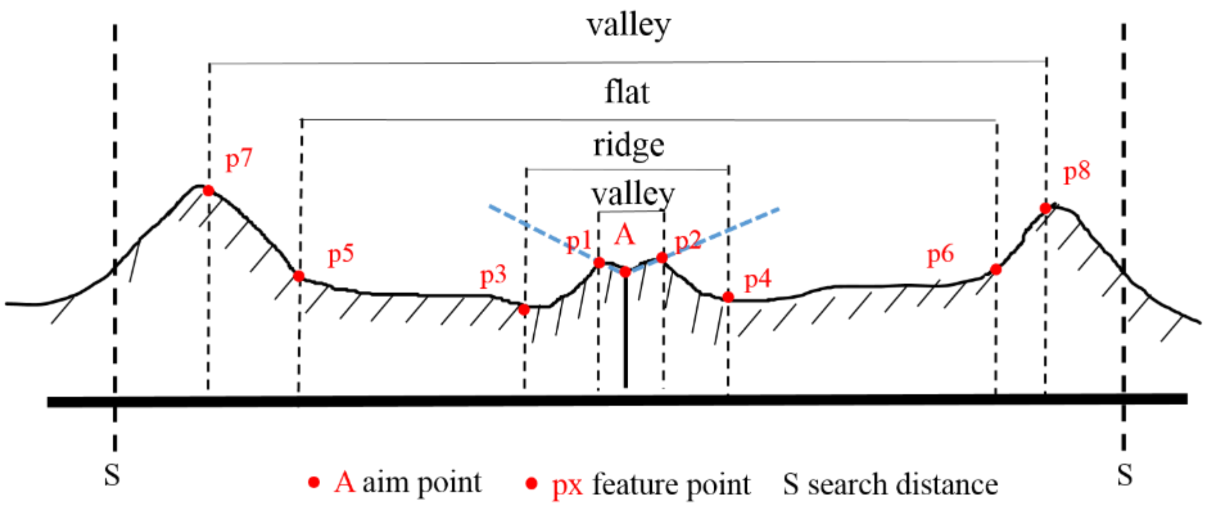


(Bassa et al., 2016)

How to train RF classifier to detect crater candidate cells?

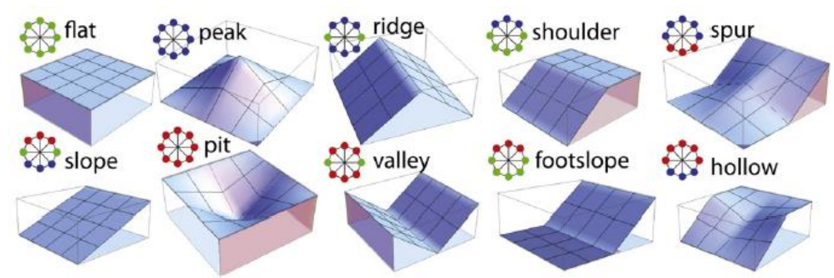


Input features with spatial structural information at cell level



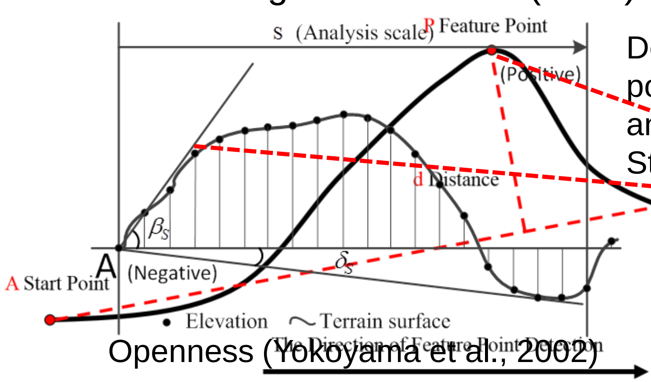
A location with different analysis scale could show different landform element types (Fisher et al., 2004; Deng et al., 2008)

- Multi-scale landform element (Kang et al., 2016)
  - Extend the Geomorphons method (Jasiewicz & Stepinski, 2013), which derives landform element at single analysis scale, to multi-scale
  - Determine feature point at each analysis scale based on Douglas & Peucker (1973)



10-type landform element

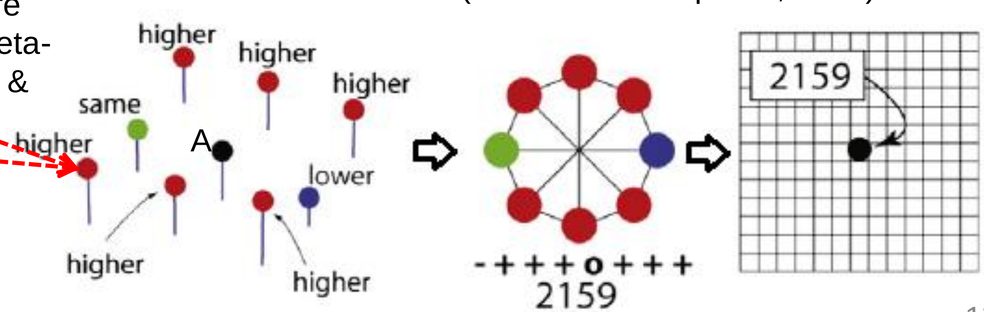
(Jasiewicz & Stepinski, 2013)



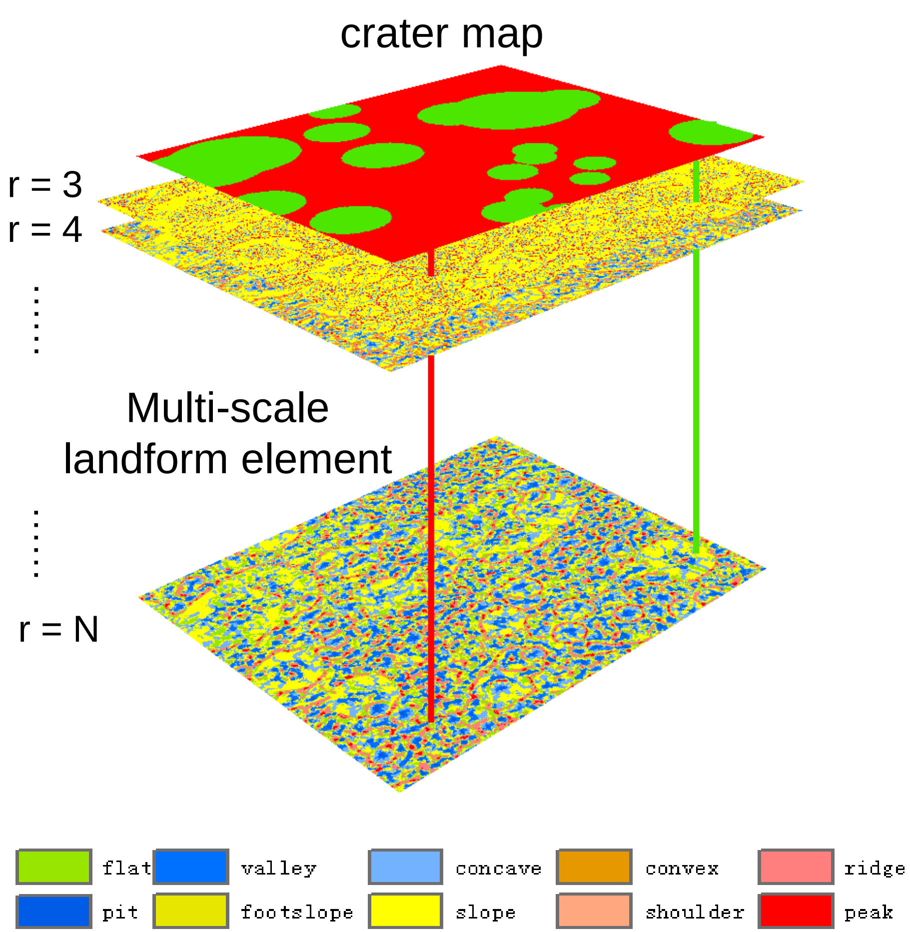
Openness (Yokoyama et al., 2002)

Determine feature point with max beta-angle (Jasiewicz & Stepinski, 2013)

End point: anal scale[1..N]



Training samples with input features for RF at cell level

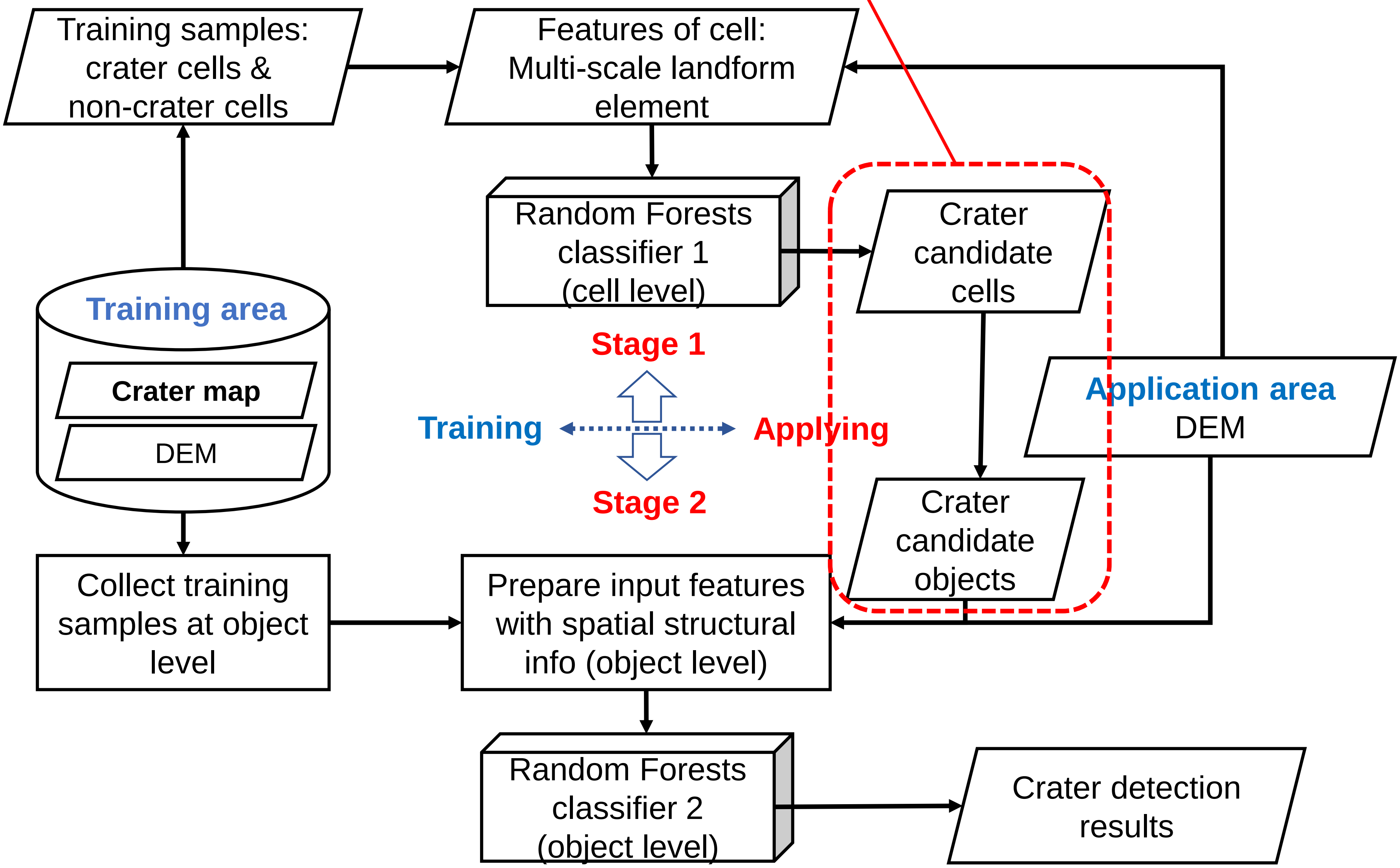


- Positive sample

- Negative sample

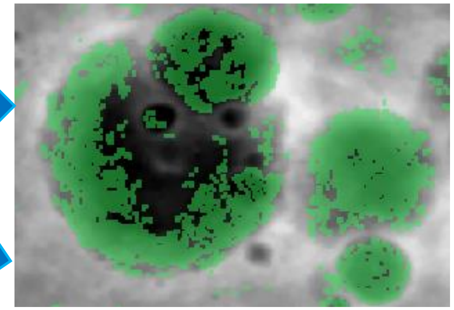
- Input feature: multi-scale landform elements for each sample (i.e., landform element types at a series of analysis scale)

How to create crater candidate objects from candidate cells?



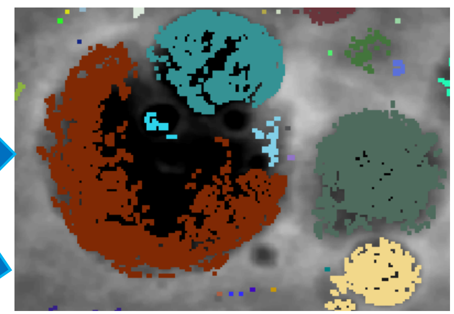
crater candidate cells → candidate objects

Random Forests classifier 1 (cell level)

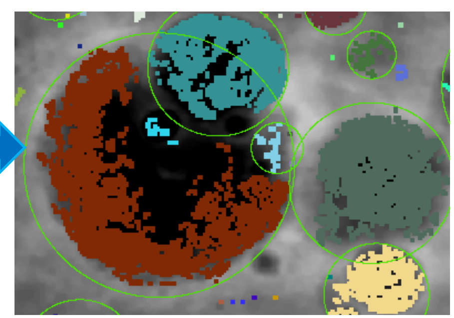


Crater candidate cells

De-noising by mathematical morphology (open op.) + DBSCAN clustering

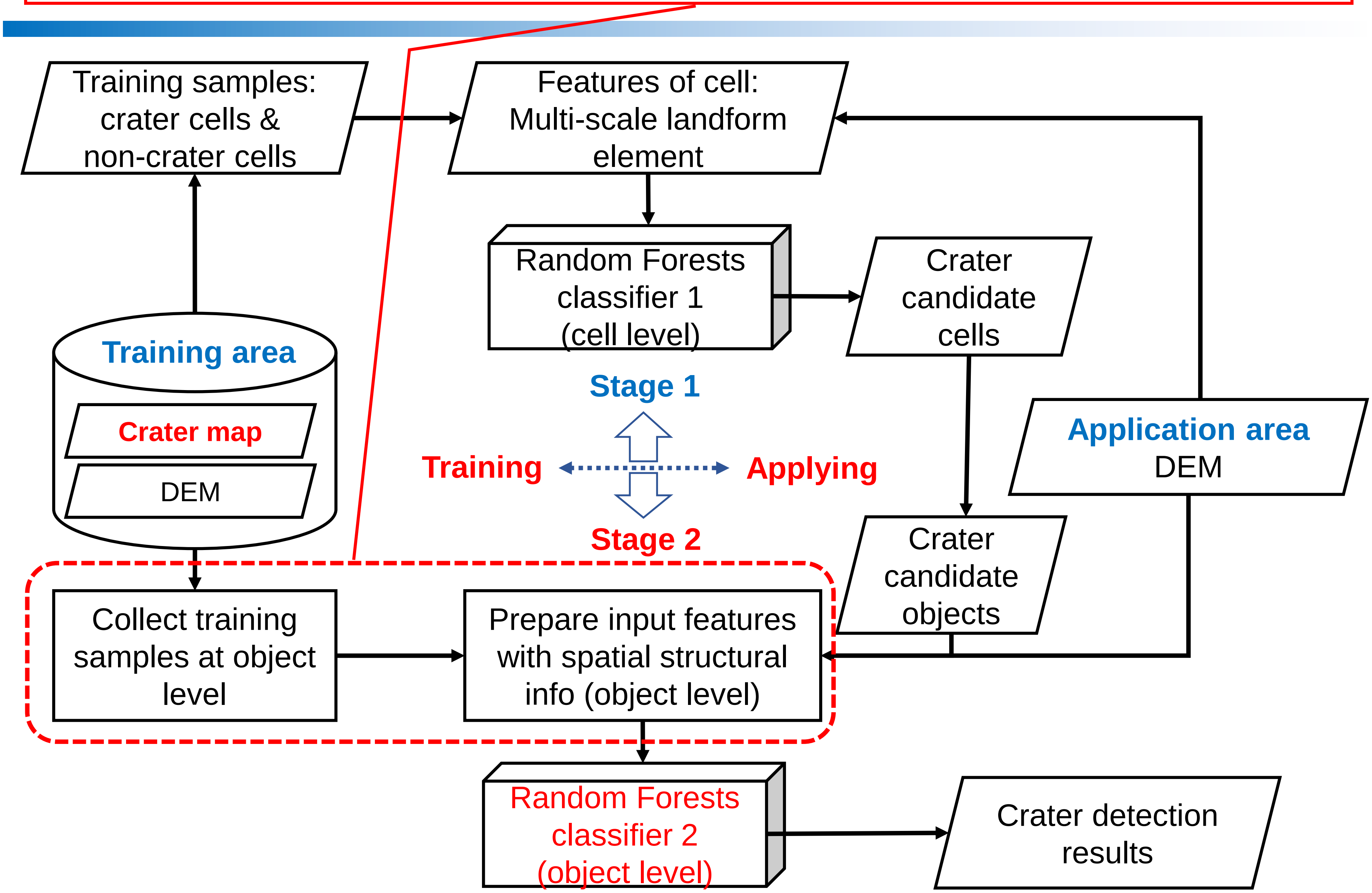


Minimum circumscribed circle → candidate object

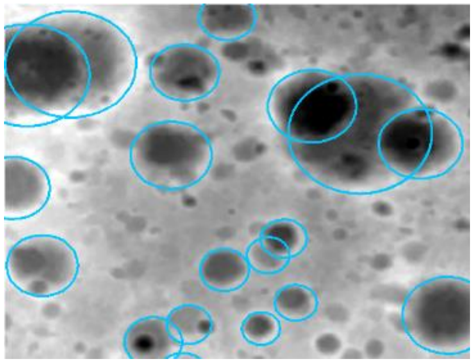


Crater candidate objects

How to train RF classifier to determine craters?

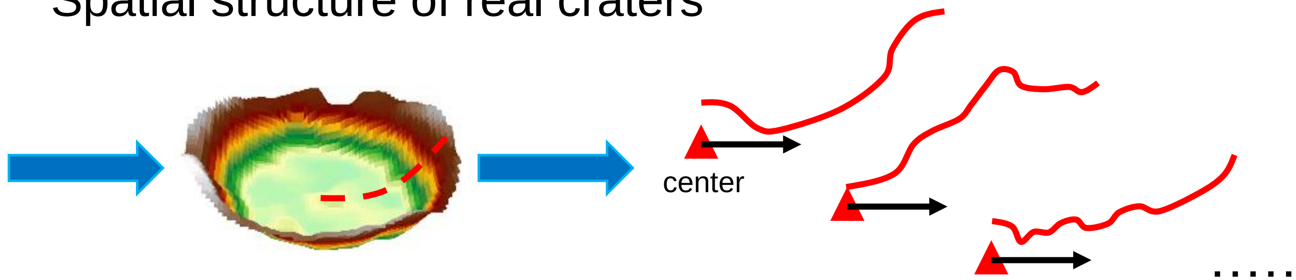


Input features with spatial structural information at object level

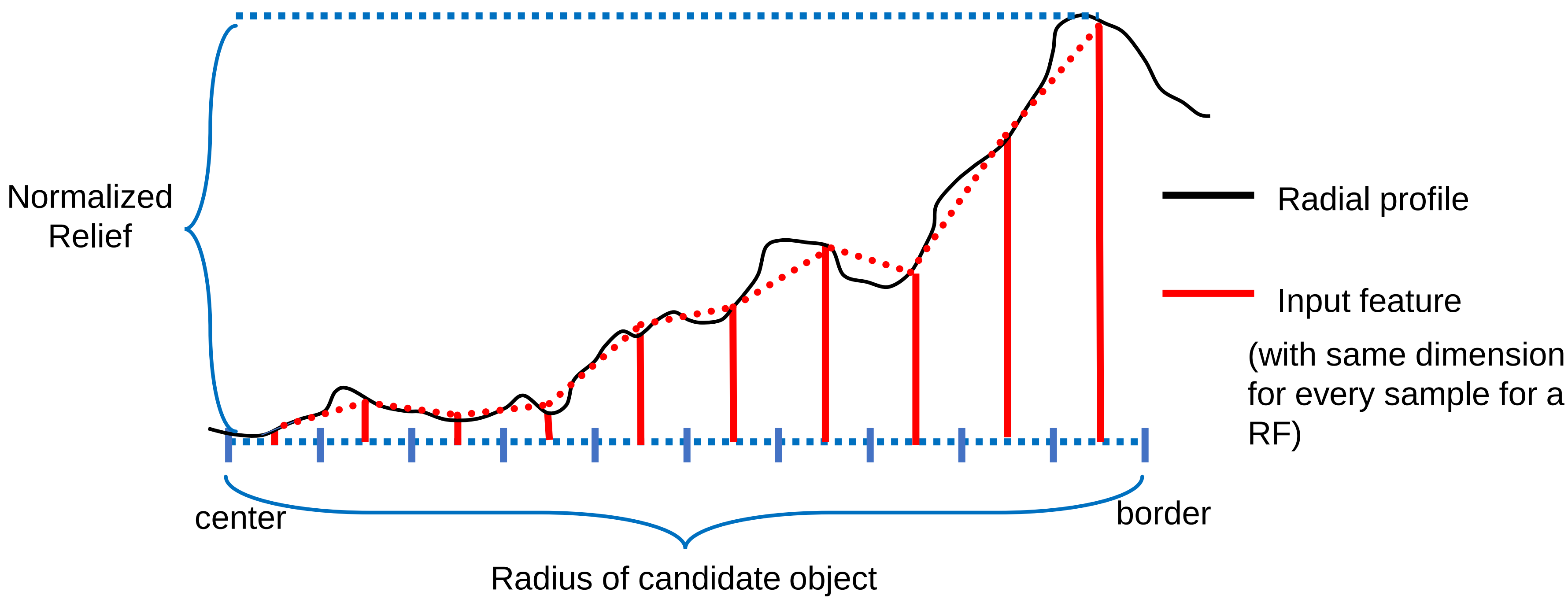


Crater map + DEM

Spatial structure of real craters



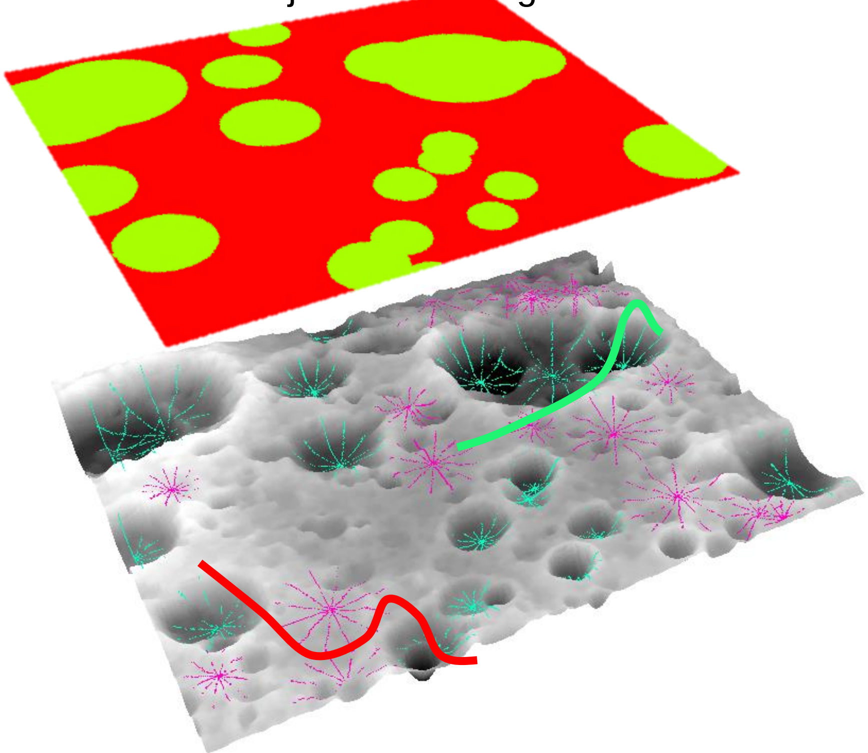
Radial elevation profile



Train the object-level RF classifier to determine craters

- Train the object-level RF with those training samples with features (normalized radial elevation profile) in training area

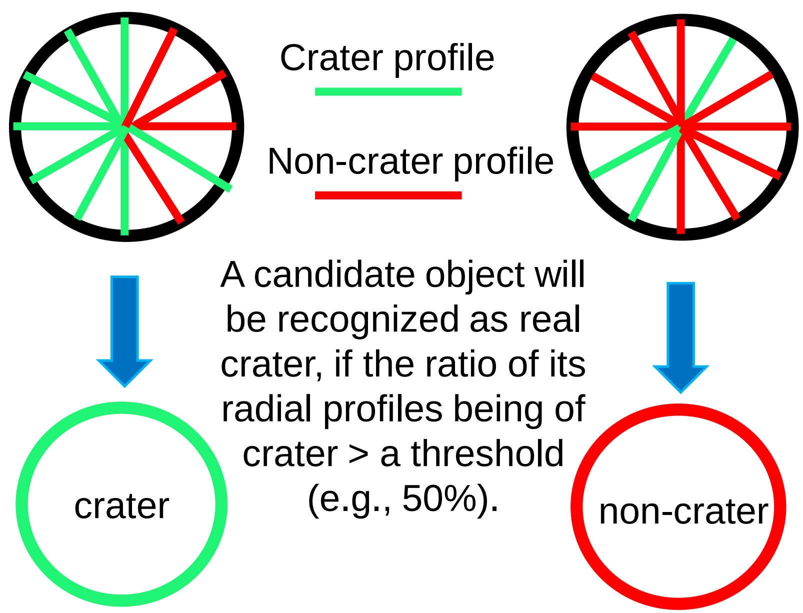
Crater objects in training area



- Positive sample

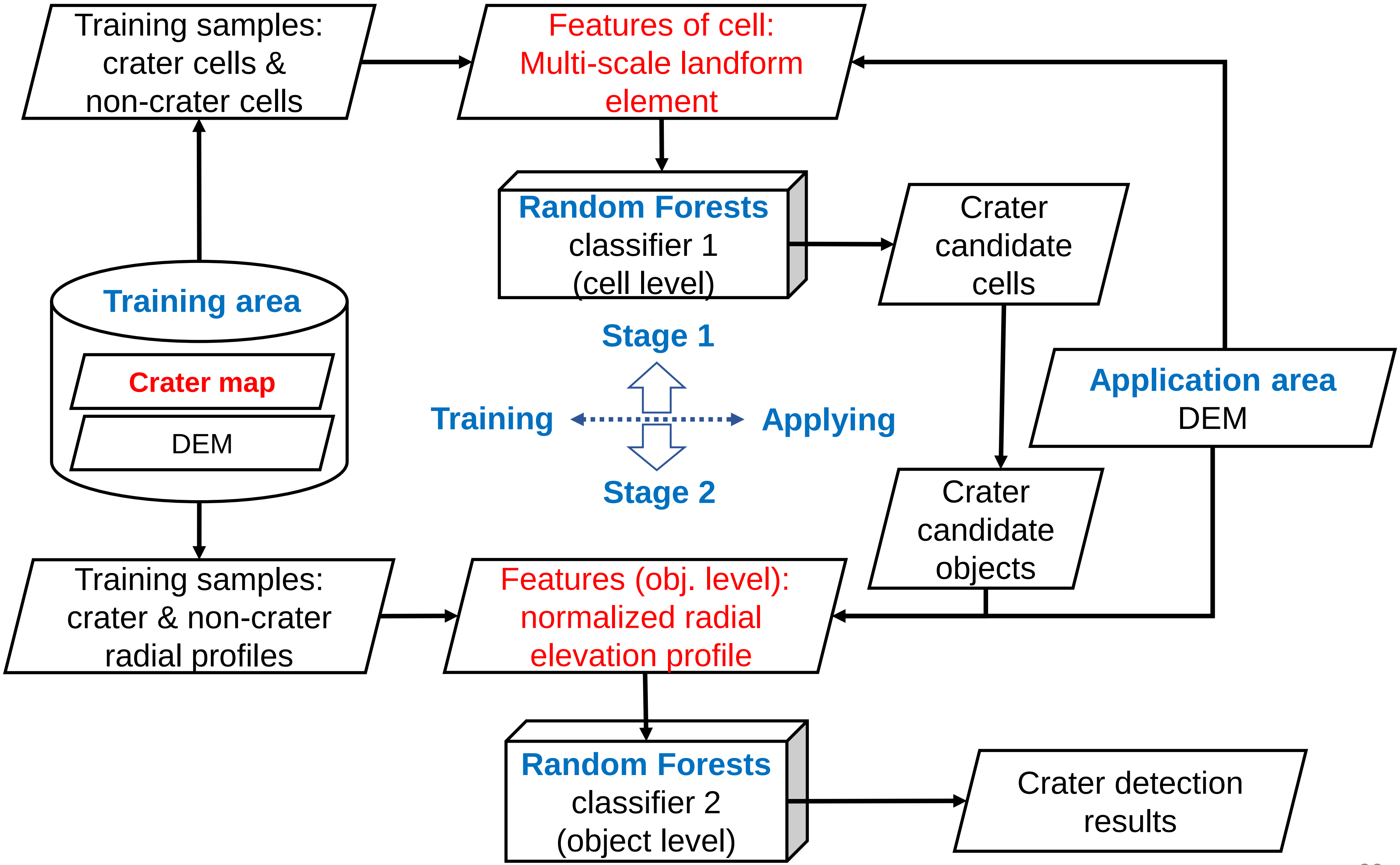
- Negative sample

- The trained RF classifier → Judge the candidate objects in application area



A candidate object will be recognized as real crater, if the ratio of its radial profiles being of crater > a threshold (e.g., 50%).

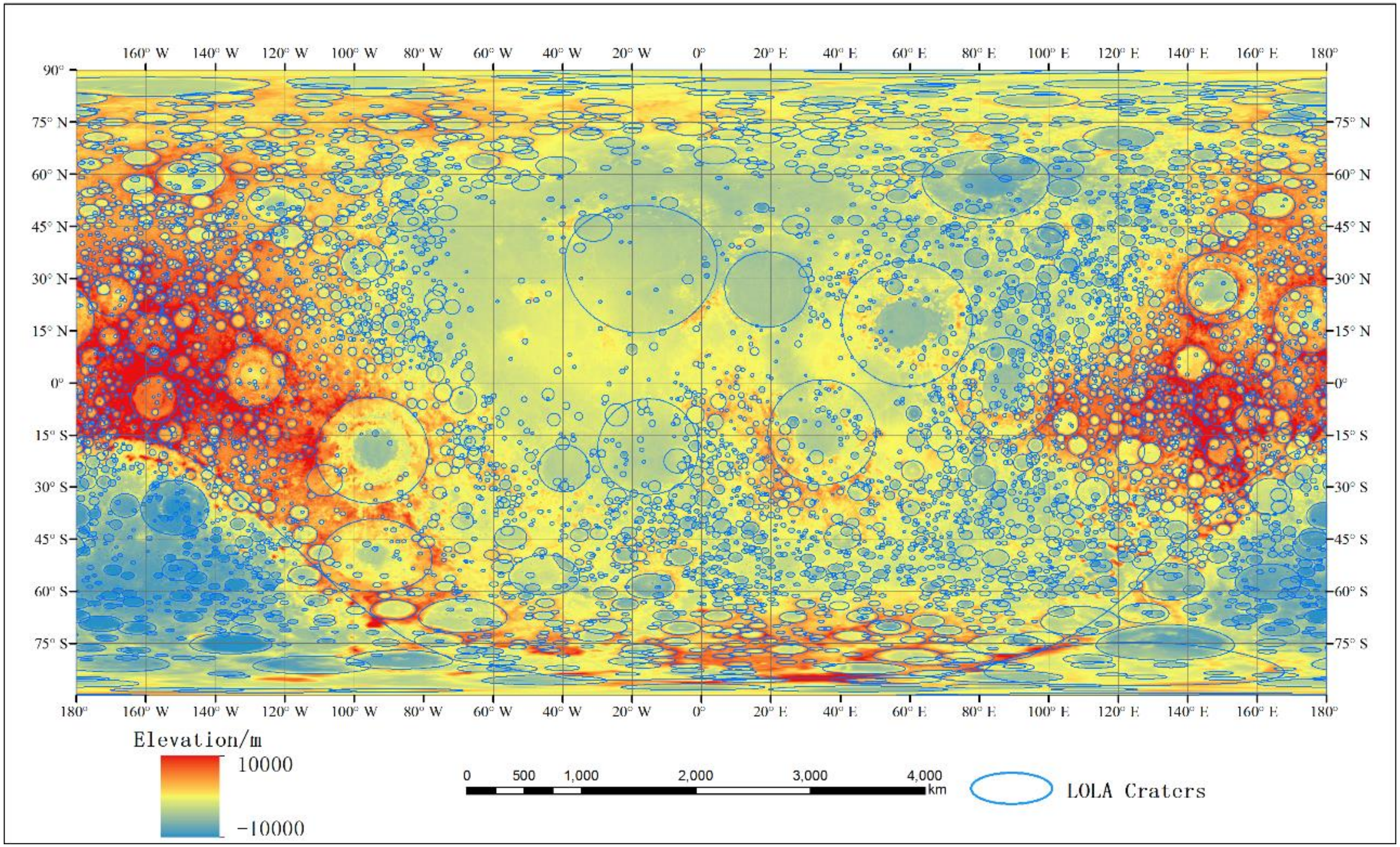
Detailed workflow of the proposed approach



4. Case study: lunar impact craters

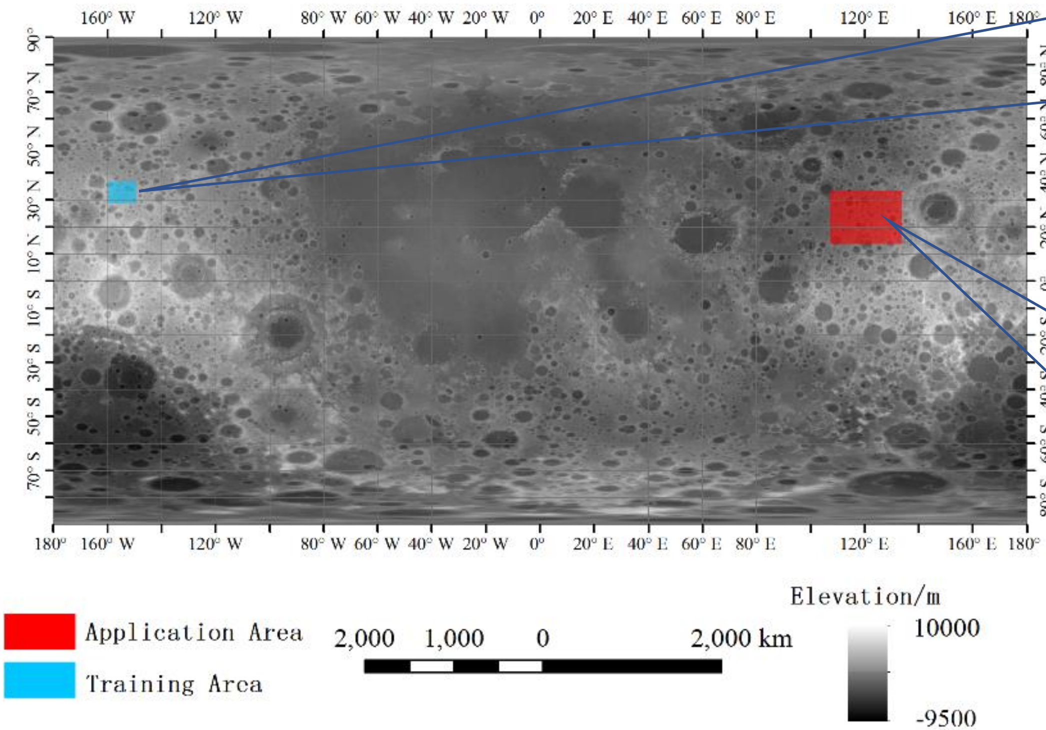
Data source:

- LOLA (Lunar Orbiter Laser Altimeter) crater map (diameter of crater ≥ 20 km) (Kadish et al., 2011)
- Chang'E-1 DEM (resolution: 500 m) (Wu et al., 2011)

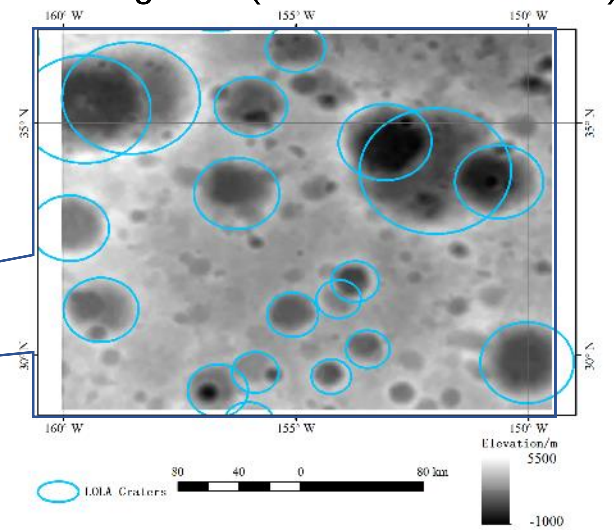


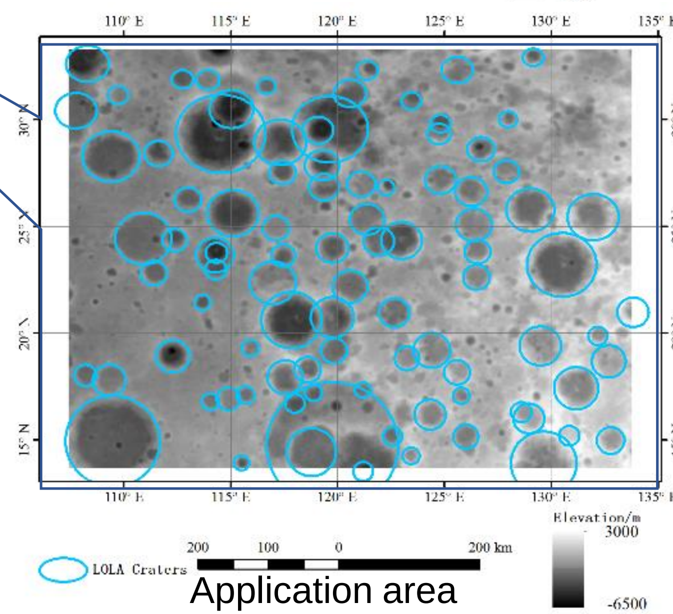
Study area settings

- Training area: 78,000 km^2; 490*640 cells
- Application area: 476,000 km^2; 1190*1600 cells (~6 times of training area)
  - Distance: ~2000 km



Training area (with 18 LOLA craters)





Application area
(with 92 LOLA craters)

Evaluation method

- The reference approach: the state-of-the-art AutoCrat (Stepinski et al., 2009; Stepinski et al., 2012)
  - http://cratermatic.sourceforge.net/

- Quantitative evaluation

  1) Individual correctness index (*C*-value)

  C-value = IntersectionArea(T, D) / UnionArea(T, D)

  (T: the crater in LOLA; D: the crater recognized by the proposed approach)

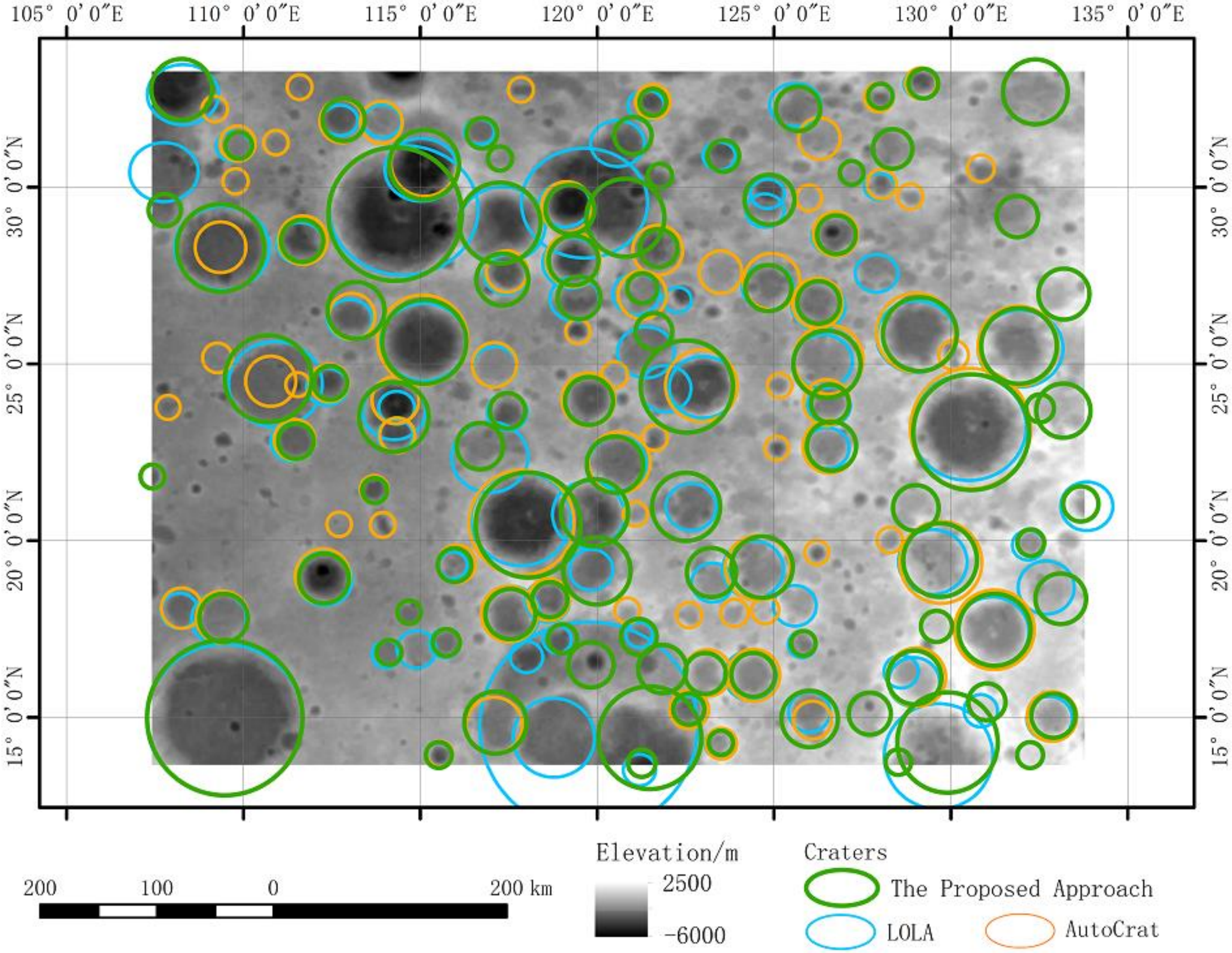
  ✓ A crater is detected "correctly", if the ***C*-value > a user-assigned *C*-threshold** (0.3, 0.4, 0.5, 0.6, and 0.7 were tested in this study)

  2) Matching ratio = Count(craters detected correctly) / Count(LOLA craters) * 100%

4. Evaluation results & discussion

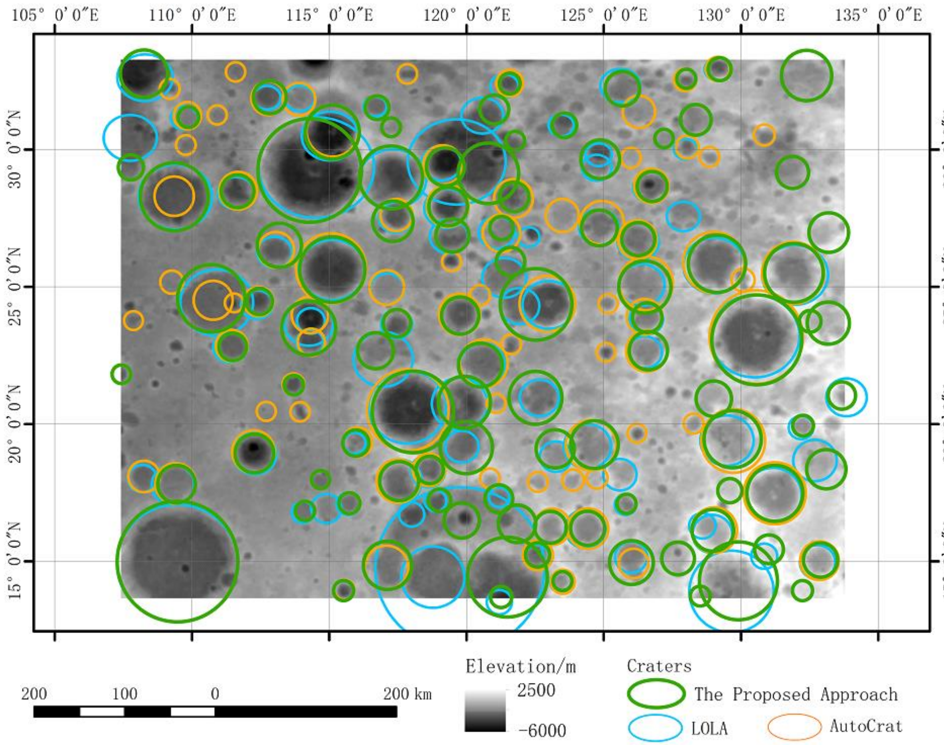
- Crater count in application area

LOLA: 92; **the proposed approach: 94**; AutoCrat: 71



"Correctly" detected craters with different individual correctness threshold

C-threshold	Craters matching to LOLA		matching ratio	
	the proposed appr.	AutoCrat	the proposed appr.	AutoCrat
0.7	43	37	46.7%	40.2%
0.6	56	44	60.9%	47.8%
0.5	62	49	67.4%	53.3%
0.4	68	49	73.9%	53.3%
0.3	71	51	77.2%	55.4%

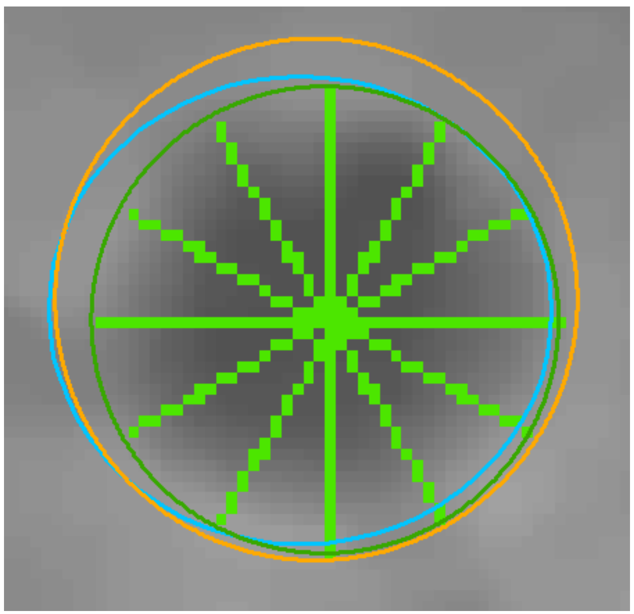


(*C*-value >= 0.5)	craters matching to LOLA	
	the proposed appr.	AutoCrat
craters correctly detected by both appr.	40	
craters correctly detected just by one appr.	22	9
Matching ratio	67.4%	53.3%

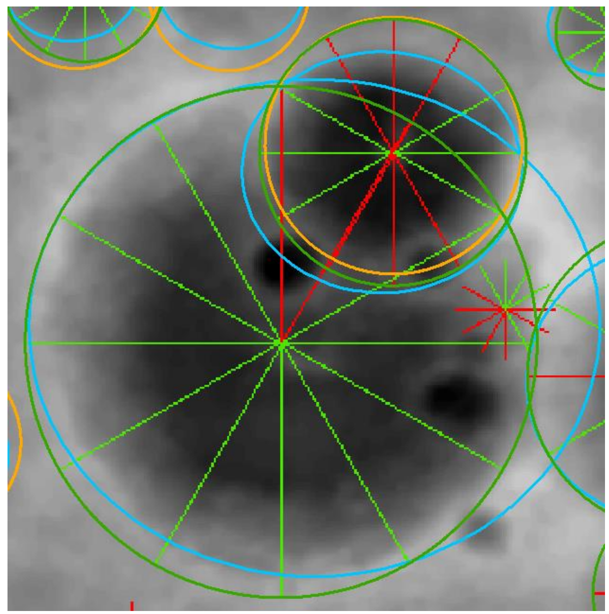
Discussion

Different types of craters detected correctly by the proposed approach

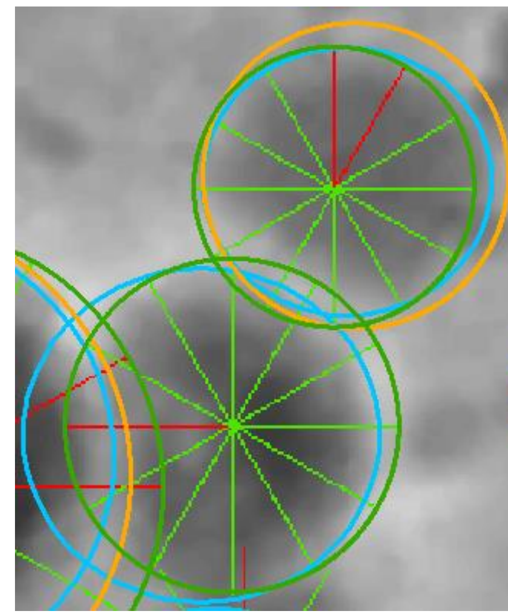
- ✓ Simple craters / degraded craters
- ✓ Superimposed craters
- ✓ Multiple connected craters created probably by one impact event



Simple crater



Superimposed craters

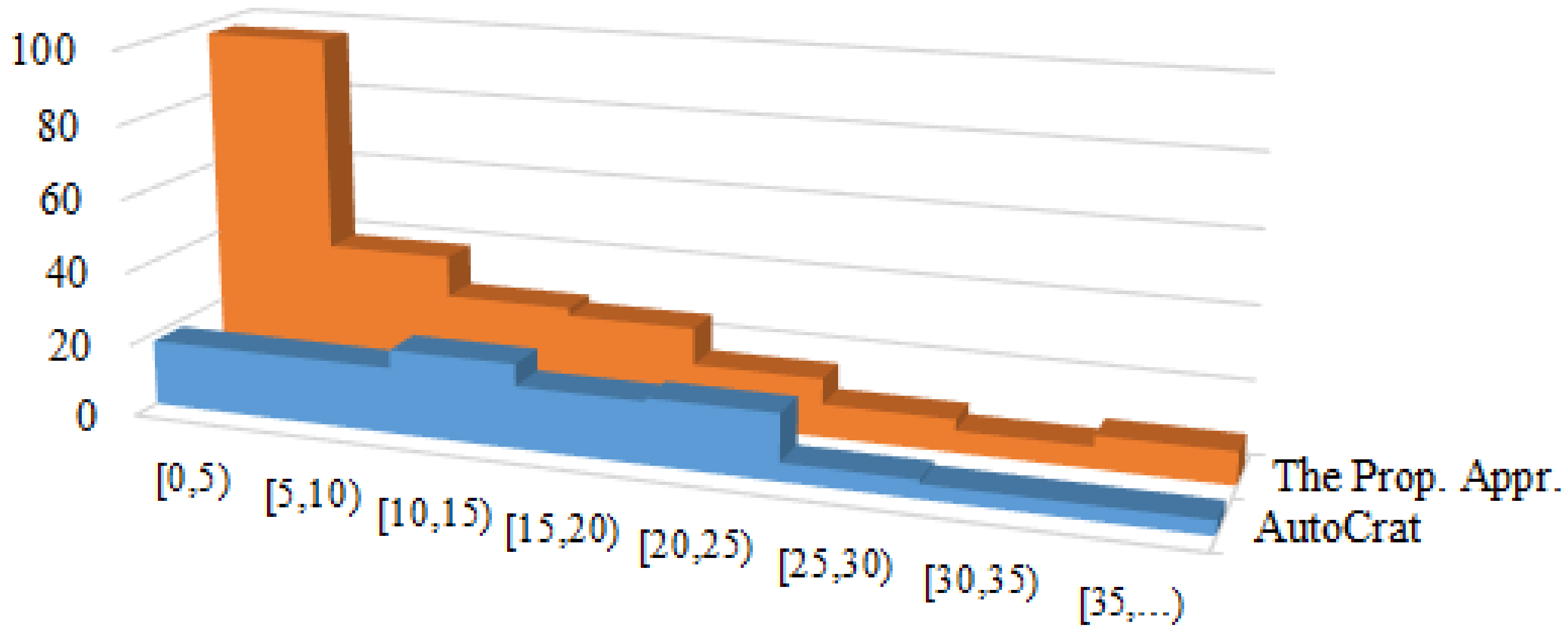


Multiple connected craters

AutoCrat The proposed approach LOLA

Discussion

- Frequency of detected craters with different radiuses



The proposed approach showed reasonable extrapolation performance.

6. Summary

- **An automatic approach to detecting impact crater: Machine learning + existing crater map + spatial structural information from DEM**
  - mine implicit expert knowledge on spatial structure of real craters from existing crater map
  - effectively consider the spatial structural information inside real craters
    - from two levels, respectively (i.e., cell, and object)

- Potential
  - The methodology and framework of the proposed approach could also be applied to mapping other geomorphologic types (e.g., volcanic crater, sand dune, V-shape channel, …).

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