Parallel Recognition of Roads from Urban Maps on Generation/Verification Paradigm of Hypotheses

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Abstract

In this paper, we address a method to apply the refinement process of road information based on the generation and verification mechanism of hypotheses to our parallel map recognition, which is organized by the bottom-up approach. First, the hierarchical structure is organized between generation task and verification task with a view to making the mechanism applicable, and then a generation task in the upper layer controls the corresponding verification task in the lower layer. If available processors should be managed effectually, it is possible to improve the recognition ratio by means of the cooperative interpretation among related hypotheses. Also, we implemented the prototype system on the parallel computer in order to make the effectiveness of our approach clear.

1 Introduction

The parallel processing is applicable to improve the processing performance in the recognition of urban maps. T.Oshitani, et al. proposed the map recognition method based on information propagation mechanism on the multi-layers partitioned blackboard model[1, 2]. This method is organized as the bottom-up approach for constructing road information, which transforms stepwisely from map images to road networks. Since the bottom-up processing is too strongly dependent on the local features of image data, the extraction of road fragments may be disturbed by noises or other map elements such as character strings, map symbols and so on. In addition, in case that image data are divided into the sub-data in order to apply the data parallelization, the extraction procedure applied locally among neighboring sub-data may not work sufficiently to traverse the road configuration globally. Namely, it is not always successful for the bottom-up processing to extract road information completely.

In the sequential processing, the progressive methods which extract first road information by the bottom-up processing and then refine it by the top-down processing or cooperative processing have already been proposed[3, 4, 5]. These methods adopt the generation and verification paradigm of hypotheses: road fragments are looked upon as hypotheses, which are inferable for initially extracted road information with heuristics about road configuration. If this framework could be applied to the parallel map recognition, the following merits will be hopeful: 1) to generate and verify many hypotheses at the same period; and 2) to interpret cooperatively many hypotheses. To generate and verify hypotheses in parallel makes the processing performance efficient. Moreover, the

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cooperative interpretation among hypotheses using many processors at once may improve the recognition ratio[6, 7]. However, it is necessary to adjust between generation tasks and verification tasks in parallel. In order to make cooperative parallel processing among hypotheses successful, it is important to control processors effectively.

In this paper, we address an advanced parallel road extraction method, based on the top-down processing and cooperative processing. Our objective is to apply the generation and verification paradigm of hypotheses with a view to making the processing performance sufficient and the recognition ratio high. In addition, the multi-layers partitioned blackboard model, which is an enhanced version of the traditional blackboard model, is used as a whole framework for data parallelization and procedural parallelization. The generation and verification tasks of hypotheses are applied between upper and lower layers. Hypotheses are generated from the top layer and then are verified in the lower layer: if the hypotheses cannot be sufficiently validated, the related hypotheses may be newly generated for the lower layer. This generation and verification process is repeatedly applied in parallel between mutually related upper and lower layers, until the hypothesis could be confirmed or not.

2 Framework

Our procedure for extracting road information is basically derived from the method of T.Hayakawa, et al.[3, 4], and method of M.Nishijima, et al.[5]. In these methods the recognition result is a road network which represents connective relationships among road fragments topologically: the nodes are characteristic points such as intersections, terminal points, connective points between road fragments; and the edges are road fragments. This extraction process is composed of two different phases: the first is to compose a road network as the basic resource to be interpretatively evaluated in the following phase, in the bottom-up approach; and the second is to refine the initially composed road network step by step in the top-down and bottom-up approaches by interpreting hypotheses with heuristics about road configuration or in the cooperative approach by interpreting several hypotheses at once. Figure 1 represents the processing flow.

In the bottom-up phase, the road fragments and intersections are extracted from urban map images, the road fragments are connected by looking upon intersections as starting points for roads, and then the corresponding road network is composed as a topological road structure. Namely, the composition process of road network transforms first from pixel level of urban map images to vector level of line segments, and then to symbol levels of road fragments, intersections, and road network, stepwisely. In order to apply the parallel processing to such a recognition process effectively, we proposed the multi-layers partitioned blackboard model[7]. Our multi-layers partitioned blackboard model is composed of multi-layers partitioned blackboard and processing procedures, as shown in Figure 2. The multi-layers partitioned blackboard constructs a structure of multiple layers to keep various kinds of data. Each layer is divided into sub-areas, and the data, managed in individual sub-areas, are mutually corresponded between upper and lower layers. On the other hand, the processing procedures apply to the data of sub-areas in the lower layer, and generate the data of the corresponding sub-areas in the upper layer.

The application of parallel processing to the refinement phase of road network makes the following terms possible: 1) improvement of processing performance, using parallel execution for generation and verification of hypotheses; 2) accomplishment of high recognition ratio by means of cooperative processing among several processors. The refinement phase for interpreting individual hypotheses independently may be not always applicable to extract road information sufficiently. This is because it is difficult to recognize the global connective relationships among several road fragments even if the road fragments were identified locally. In order to cope with this problem, it is necessary to interpret and verify cooperatively many related hypotheses. As one of advanced strategies, the information exchange among related hypotheses and the cooperative control of processors to which the corresponding hypotheses were assigned should be desirably investigated. We

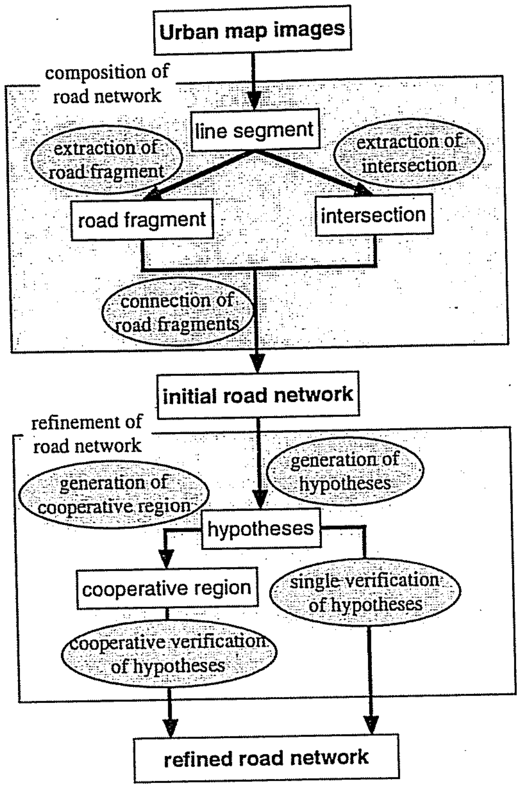


Figure 1: Processing flow for urban map recognition

define the cooperative region for enforcing to manage cooperatively related hypotheses. These hypotheses are mutually verified in this cooperative region.

In order to integrate effectually both the generation of hypotheses and cooperative interpretation/verification of them, the hierarchical structure is organized by two different tasks: one is to infer road information on the basis of multi-layers partitioned blackboard; and another is to verify the infered road information. The generation task, which infers road information, generates hypotheses and cooperative regions from road network, and creates newly cooperative region tasks. In the cooperative region, the related road fragments are infered and verified cooperatively among hypotheses. In the hypothesis verification phase, the line segments and the pairs of parallel line segments, which satisfy features of inferable road fragments, are found out from the processing data in the lower layer. Thus, the cooperative region task generates verification task, and sends the verification request to the lower layer. Figure 3 illustrates a relationship among tasks in the layer structure.

3 Generation and Verification of Hypotheses

3.1 Hypotheses

In urban maps, the intersections are almost cross-points and the road fragments are connective to others. The inference is started from intersections or disjointed points of road fragments, as shown in Figure 4.

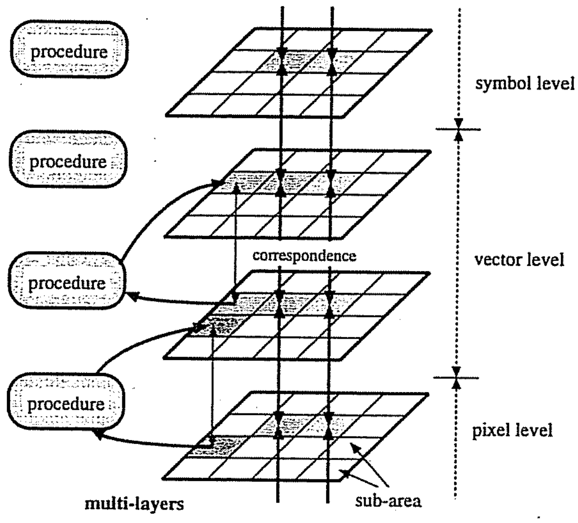


Figure 2: Concept of multi-layers partitioned blackboard model

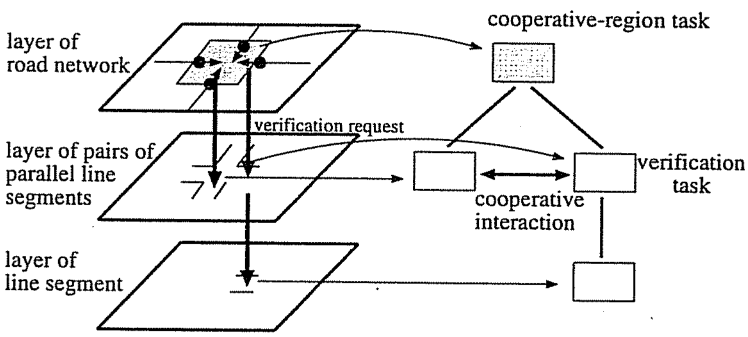


Figure 3: Top-down and cooperative processings based on hierarchical structure of tasks

- Intersection (in Figure 4(1-a))
  In urban map images the intersection is almost +-junction. Under the assumption that the intersection is +-junction the new road fragment is infered for the direction of connective road fragments.
- Disjointed point of road fragment (in Figure 4(1-b))
  The disjointed points of road fragments are terminal nodes in the road network. In general, it is sure that the road is extensible from this disjointed point since the road fragment is connected to others, except L-junction, T-junction and so on.

We define the above infered road fragments as hypotheses. The hypotheses are composed of the starting points, directions and widths of infered road fragments, and are search areas with information which satisfies infered road fragments. Figure 4 shows them. The starting point is an intersection or a disjointed point of road fragment and is a critical point for verifying the infered road fragment. The direction of road is defined as the extensible direction of road fragment. The width of road is the width of road fragment,

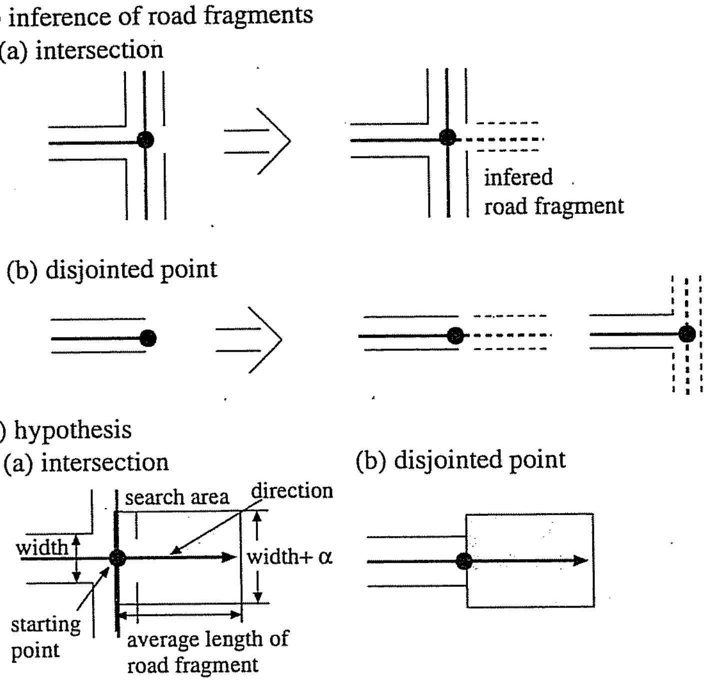


Figure 4: Hypothesis

found in the reverse sides along the direction of currently searched road fragment in case that the hypothesis was generated from intersection, and is the width of another closely related road fragment in other cases. In addition, when the hypothesis was generated from disjointed point, its own width is applied. The search area is a rectangular one to find out pairs of parallel line segments, line segments or pixels, and the size is:

$(widthOfRoad + \alpha) \times averageRoadLength$,

where α is a heuristic value. Also, this search area is used when the cooperative region is generated to interpret and verify cooperatively related hypotheses.

3.2 Cooperative Interpretation of Hypotheses

The road network is refined by verifying generated hypotheses. Although it is possible to extract locally road fragments in order to verify hypotheses individually, it is difficult to find out the global connective relationships among several road fragments. Therefore, it is necessary to interpret and verify related hypotheses cooperatively. The cooperative region is a rectangular area which contains search areas of related hypotheses. Of course, the hypotheses which are not contained into the cooperative region are verified independently by themselves: this is called a single hypothesis.

In case that several hypotheses are in the cooperative region, the road information is infered. As shown in Figure 5(c), the relationship between hypotheses is *crossing* or *facing*. In the facing, the road fragments are connected, while in the crossing the intersection is newly generated from two different road fragments.

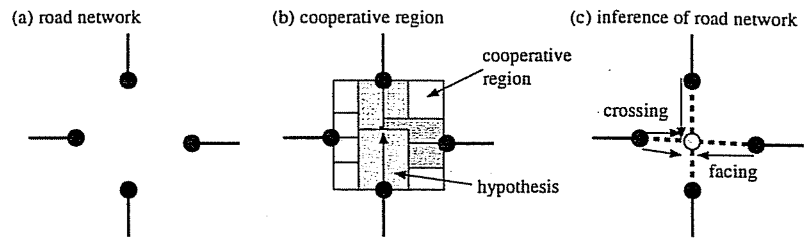


Figure 5: Cooperative interpretation of hypotheses

3.3 Verification of Road Network

(a) single hypothesis

In the verification of single hypothses the procedure finds out data which satisfy infered roads in the search area for hypotheses.

(1) Search of pairs of parallel line segments
In the layer of pairs of parallel line segments, the verification request is generated to find out pairs of parallel line segments, concerning with hypotheses. These pairs must satisfy the direction and distance from starting point.

(2) Search of line segments
In case that pairs of parallel line segments could not be found out in (1), line segments are searched. The verification request is generated to find out line segments, which compose roads, in the layer of line segments. In this layer, the request takes a role of finding line segments as a part of pairs of parallel line segments. In case that two different line segments were found, the pairs of parallel line segments are generated and the result is returned to the upper layer. While, in case that only one line segment was found, the renewly generated request is sent to the pixel layer in order to find out the corresponding pixels in the bottom layer.

(3) Search of pixels
In the pixel layer, the requested line segments are found by tracing black pixels. In (2), when only one line segment was found, pixels, in which were by the road width far from the line segments extracted already in the upper layer, are traced along the road direction. On the other hand, when even one line segment was not found in (2), the black pixels, closed to requested line segment, are traced. As a result, newly found line segment is generated and propagated to the upper layer.

(b) hypotheses in cooperative region

The road network infered in the cooperative region is refined by verifying hypotheses at once. The verification of individual hypotheses is the same as that of the previous single hypothsis. However, the hypotheses in the cooperative region are mutually related, and the verified results of hypotheses and processing data, which are additionally generated in the processing process, are effective for the verification of another hypothesis. Thus, these information is reused among hypotheses in the cooperative region.

- Case that relationship between two hypotheses is facing (in Figure 6(a))
Generally, the possibility that facing road fragments share the same road is high. Thus, among these hypotheses the verified results and additionally generated processing data are exchanged. If pairs of parallel line segments are acquired the hypothesis is regarded as correct one. However, when only one line segment was found

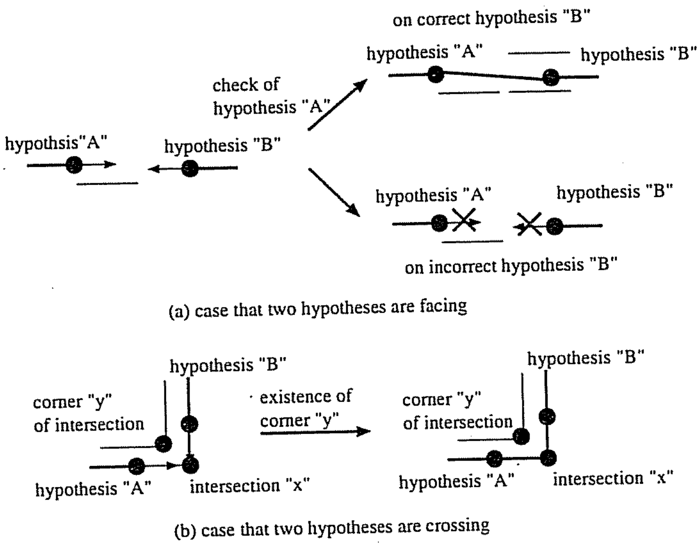


Figure 6: Cooperative verification of hypotheses

out, it is necessary to make use of the verified results of other hypotheses in order to judge whether the current hypothesis is correct or not. Namely, if the already verified result is a pair of parallel line segments or only one line segment, the hypothesis is regarded as correct one.

- Case that relationship between two hypotheses is crossing (in Figure 6(b))
  With respect to these hypotheses the existence of intersection "x" is infered. The existence of intersection's corner "y" related to this intersection indicates that two different hypotheses are connective. Thus, in the verification phase not only pairs of parallel line segments but also the corners of intersections must be searched. The evaluation of hypotheses is done in accordance with the following facts:
  - The hypotheses are correct in case that pairs of parallel line segments are found;
  - When only one line segment has already been found, if newly the corner of intersection is acquired the hypothesis is correct. Otherwise, it is incorrect.
  - If pairs of parallel line segments were not found, the hypothesis is incorrect.

3.4 Modification of Road Network

After the verification of infered road network, the multi-layers partitioned blackboard is updated in order to modify the existing road network. However, the new contradiction may be generated between the already composed road network and the verified result. In Figure 7, first the hypothesis "A" is infered, and then the verified road fragment is added to the existing road network. The contradiction occurrs between hypotheses "A" and "B" when the result of road fragment infered by "B" is incorrect. In this case, the contradiction must be resolved with respect to the verified results:

- Case that pairs of parallel line segments are found
  Generally, the infered road fragments are manipulated as valid facts when pairs of parallel line segments were found in the verification phase of hypotheses. After then,

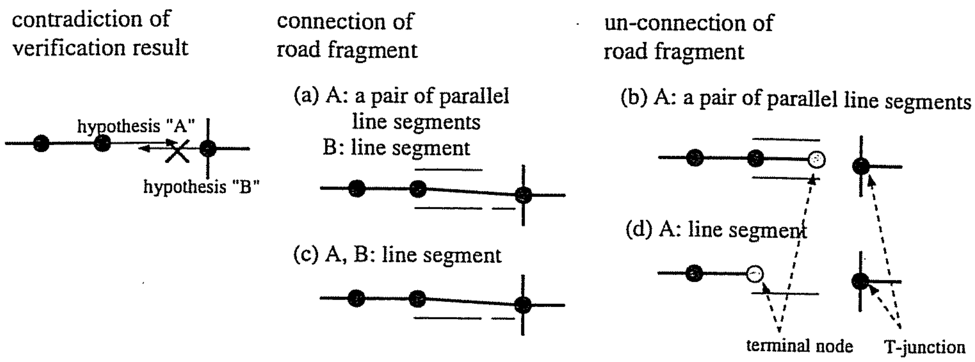


Figure 7: Confliction of verified results

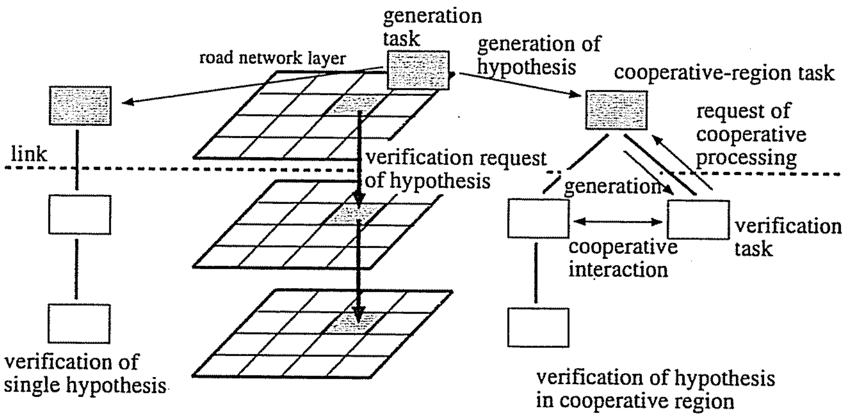


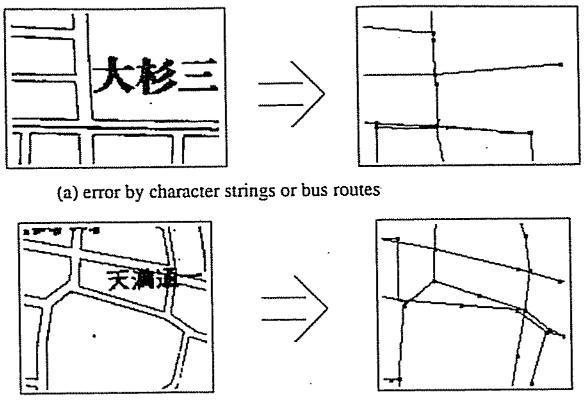
Figure 8: Hierarchical structure of tasks

whether they are connective or not is dependent on other verified results. Namely, two road fragments must be connected when one road fragment has been explicitly detected, as shown in Figure 7(a). On the other hand, when any road fragments cannot be detected they are not connective and are manipulated as terminal nodes, as illustrated in Figure 7(b).

- Case that only one line segment is found
  In this case, it is necessary to judge whether the infered road fragment is correct or not. Namely, when line segments are detected these line segments are connected, as shown in Figure 7(c). However, the infered road fragment is invalid when any line segments are not detected yet.

4 Experiment and Evaluation

We implemented a prototype system for extracting road information in parallel on the distributed-type parallel computer AP-1000. This computer is composed of one host



(a) error by character strings or bus routes

(b) error by mis-inference of road fragments

Figure 9: Example of errors

computer (Host) and 64 cell computers (Cell's). Also, in our experiment we used urban map images with 800 × 800 pixels and 256 gray levels. Moreover, each image was divided into sub-areas of 100 × 100 pixels.

Table 1 shows the experimental result. This result is the average value of 10 urban map images. The improvement ratio of processing performance is a ratio of parallel processing speed to sequential processing speed. Moreover, the recognition ratio is a ratio of correctly extracted road fragments for all road fragments counted in the urban map images, and the error ratio is a ratio of incorrectly extracted road fragments. The processing performance is improved by about 16.87 by means of parallelization. Thus, the effect of parallelization is explicitly observed from our experiments in point of the processing performance and newly detected result of un-extracted road fragments. However, the recognition ratio is inferior in comparison with the sequential processing. This is because the intersections near by the boundaries of sub-areas are not correctly extracted when the road fragments are overlayed on the boundaries. In particular, since our approach searches the road fragments from intersections, and tries to connect them in case that intersections are not distinguished sufficiently, it is difficult to construct the road network and complement it by the inference and verification processing. Thus, it is very important to infer and extract un-extracted intersections with a view to improving the recognition ratio.

On the other hand, concerning with the error ratio, the parallel processing is inferior in comparison with the sequential processing. Figure 8 shows such an example of miss-extracted recognition result. In Figure 8(a), the road information is incorrectly extracted by character strings. This disadvantage is also observed in the sequential processing. In order to improve this disadvantage, it is necessary to separate other information such as characters, bus routes and so on from road information sufficiently. Also, Figure 8(b) is an example that in the inference of road fragments the error estimation is occurred and its error reflects to the whole configuration undesirably. The current prototype system is insufficient in point of the verification method of hypotheses, and it is necessary to improve the method by using heuristics about road configuration.

5 Conclusion

We addressed an experimental parallel processing method for extracting road information from urban map images on the framework of multi-layers partitioned blackboard model. From a viewpoint of parallel map recognition, we introduced the top-down processing

Table 1: Comparison of processing performance

	Processing time	Improvement ratio	Recognition ratio	Error ratio
Sequential processing	564.52 sec.	—	81.05%	0.81%
Parallel processing in bottom-up means	26.31 sec.	21.46	70.79%	0.84%
Parallel processing in top-down, cooperative means	33.47 sec.	16.87	79.51%	0.98%

and cooperative processing into the traditional bottom-up processing. Of course, in order to make the processing performance effective the utilization of many processors is powerful. In our approach, it is possible to make the processing performance sufficient by assigning successively to available processors, because various kinds of tasks are attended with individual processing steps, processing phases and processing methods. Of course, the traditional approach which divides an image into several sub-images and statistically assigns usable processors to the sub-images is not successful, but our approach separates completely processing data and processing procedures from processor, and assigns tasks dynamically, which are generated by the timely-dependent scheduling mechanism, into currently usable processors of the processing data and the corresponding processing procedures. It is so clear that our approach is very successful through some experiments.

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