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Topological Visual Localization Using Decentralized Galois Lattices

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Abstract. This paper presents a new decentralized method for selecting visual landmarks in a structured environment. Different images, issued from the different places, are analyzed, and primitives are extracted to determine whether or not features are present in the images. Subsequently, landmarks are selected as a combination of these features with a mathematical formalism called Galois -or concept- lattices. The main drawback of the general approach is the exponential complexity of lattice building algorithms. A decentralized approach is therefore defined and detailed here: it leads to smaller lattices, and thus to better performance as well as an improved legibility.

1 Introduction

Finding its place in an environment is a difficult challenge today for an autonomous mobile robot. This robot needs to know how to characterize and to recognize a place by itself, to be considered as fully autonomous in terms of orientation and navigation.

The robot here uses visual landmarks to characterize each place of a structural environment. This is therefore a topological approach of localization, that means the robot recognizes the place it is and not exactly its metric position. This approach is thus more qualitative than quantitative. Indeed, metric localization is efficient in a local context, and if and only if objects are not moving. But as soon as the environment is growing up, or as soon as objects could move (typically in a human environment), metric localization is very costly and less stable than the topological approach. Moreover, the use of visual landmarks is justified through advantages of the sensor (a standard webcam in our application): small, cheap, robust, and giving very rich (too much ?) information about the environment.

The formalism used to select landmarks is *Galois* -or *concept- lattice*, and a general approach has been described already in [5]. The authors have developed a general Galois-lattice based landmark selection algorithm. In this paper, we propose to "decentralize" lattices in order to improve performance and legibility.

The learning phase thus consists in building the Galois lattice(s) and landmark extraction, and the generalization phase consists in finding landmarks in images the robot captures to localize itself.

2 Visual Landmarks

Potential features are issued from image primitives, thus to each image is associated a set of features (the process is fully described in [5]). In a practical aspect, a set of images is attached to a place (or site), therefore sets of features are attached to each place of the structured environment. To mine information, an original mathematical formalism, called formal concept analysis, is used by the machine to find landmarks of its environment. Landmarks will be feature combinations extracted from lattices.

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3 Galois Lattice Theory

All information will be described in term of *concepts*, that associate sets of images with sets of feature. All concepts are organized into a hierarchy inside a lattice, and landmarks will be extracted from these "hierarchized" concepts.

The full formalism is described in [1] and [3].

The context in our application being defined with a set of images $\mathcal{O}$ (objects), a set of features $\mathcal{F}$, and a mapping ζ (the presence or not of a feature f in an image o), the general lattice is built (several algorithms exist, see [4]) and landmarks are extracted thanks to the following definition [6]:

Definition 1 *Given a context* $\mathcal{K} = (\mathcal{O}, \mathcal{F}, \zeta)$ *and a subset of objects* $\mathcal{A} \subset \mathcal{O}$. *A subset* $\mathcal{B} \subset \mathcal{F}$ *of features is said to be a* **landmark** *of* $\mathcal{A}$ *if and only if*

- $\mathcal{B}'' = \mathcal{B}$,
- *and* $\mathcal{B}' \subset \mathcal{A}$.

By this way, a landmark is a combination of features of a concept (intent) that describes a set of images (extent) belonging to a specific place.

The main drawback of such an approach is the use of the *general lattice*, *i.e.* the lattice issued from the whole context (all images, all features). Indeed, the complexity of the algorithms is generally exponential *w.r.t.* the size of the context (number of objects, number of features), but for some algorithms is linear in the number of all concepts (modulo some factor polynomial in the input size) [4]. So it would be more efficient to built several smaller lattices rather than one big lattice.

4 The Decentralized Approach

A *decentralized* approach will allow us to have much better performance in terms of number of concepts and time processing. "*Decentralized*" means here that instead of building one general lattice with the whole context, including all places, the machine builds as many lattices as places to describe. A *local lattice* is thus built for each place of the environment, but it is necessary to *modify* the context (and more precisely the mapping) before processing. The modification is done through feature selection.

4.1 Feature Selection

To each site is thus associated a local lattice, that will be eventually modified by removing *undesirable* features in the mapping. One feature is considered as undesirable when it is ”weakly” present in the site, and it is ”strongly” present in any another site.

We define a ”weakly” or ”strongly” present feature by its *rate of appearance* $r_{f,\theta}$ in the considered site. Actually, our heuristic defines a *relative rate* of a feature f in the site θ compared to another site θ^* by the number $\tau_{f,\theta,\theta^*} = \frac{r_{f,\theta}}{r_{f,\theta^*}}$.

For all features, there are two possibilities:

- if $\forall\theta^* \neq \theta$, $\tau_{f,\theta,\theta^*} \gg 1$, feature f is kept in the class θ ;
- if not, the feature f is removed from the site θ.

4.2 Reading Lattices

Once modified local lattices are built, reading them to extract landmarks is easy: it is enough to read intents of the concepts, and more especially the intents of maximal concepts (concepts with minimal cardinality of intents) to get maximal landmarks.

4.3 Decentralized Galois Lattice-Based Algorithm

The algorithm shown Fig. 1 recapitulates the whole process.

1. For each site θ,
2. For each feature f,
3. Calculate the rate of appearance $r_{f,\theta}$
4. For each site θ,
5. For each feature f,
6. For each site $\theta^* \neq \theta$,
7. If $\tau_{f,\theta,\theta^*} \simeq 1$ or $\tau_{f,\theta,\theta^*} \ll 1$
8. Modify local context (*e.g.* Remove f from site θ)
9. Build modified local lattices
10. Extract landmarks from local latticies
11. Detect site landmarks in a new image
12. If there is one or several landmarks linked to one and only one site, the robot is in the corresponding site
13. Else, the robot must move to capture a new image to find landmarks

Figure 1. Decentralized Galois Lattice-Based Algorithm

5 Experimentations, Comparisons and Results

To compare the general approach and the decentralized approach, corresponding algorithms have been developed and tested with square (same number of objects and properties) probabilistic contexts, three classes, sized from 5×5 to 35×35 (Fig. 2).

In this figure, the *”lambda algorithm”* is actually the Carpineto & Romano lattice building algorithm [2], and *”modified algorithm”* means here ”decentralized algorithm”.

The figure shows the interest of decentralizing lattices: for a small 35×35 object/feature context, the total number of concepts is about 1.5 time smaller in the decentralized approach, and above all process is about 20 times faster compared to the ”centralized” approach…

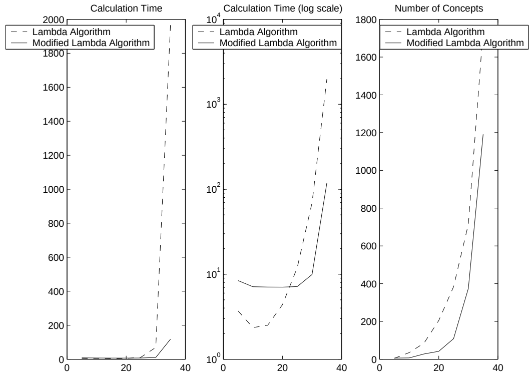

Figure 2. Processing Time and Number of Concepts Comparisons between the Former and the Decentralized Approaches.

6 Conclusion and Perspectives

We do obtain very good results with this new decentralized technique to extract visual landmarks for topological localization. The Galois formalism allow the robot to select them in a structured environment. This formalism is very close to the notion of landmark, by associating features that describe a set of objects and only this set.

The previous methods using global lattice has been improved in terms of processing time and legibility of lattices, and the decentralized approach is much more easy and efficient to use.

The next step is to introduce probabilities inside Galois lattices, in order to give probabilistic landmarks attached to each place. More over, a “semi-supervised” learning process is about to be developed to allow the robot to build, by itself and only by detecting transitions, a topological map in a fully autonomous process.

Finally, the incremental lattice building algorithms allow us to think about a fully real-time process, thanks to the distributed approach developed in this paper and incremental algorithms. Galois lattices will therefore become dynamic distributed entities with dynamic interactions to give the robots abilities of autonomous localization and navigation.

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