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Structured Writing with Granular Computing Strategies

Yiyu Yao
Department of Computer Science, University of Regina
Regina, Saskatchewan, Canada S4S 0A2
Email: yyao@cs.uregina.ca URL: http://www.cs.uregina.ca/∼yyao

Abstract— **Granular computing unifies structured thinking, structured problem solving and structured information processing. In order to see the flexibility and universal applicability of this trinity model, we must demonstrate its effectiveness in solving real world problems. In this paper, we apply the basic ideas, principles, and strategies of granular computing to the specific problem solving task known as structured writing. Results from languages, human knowledge organization, rhetoric, writing, computer programming, and mathematical proving are summarized and cast in a setting for structured writing. The results bring new insights into granular computing.**

I. Introduction

In many talks on granular computing, a few questions are always asked. What is granular computing? Is granular computing simply a reformulation of the existing theories and methods, for example, clustering, with a new set of terms? The answers to those questions cannot be given satisfactorily if one restricts the discussion to the computational perspective. We need to move beyond a narrow and literal interpretation of the word *computing* as well as computer based implementations of computing models [4], [5], [23], [29], [30], [31], [32], [33], [34], [35], [36], [38].

Granular computing must be viewed from three perspectives: the philosophy, the methodology, and the computation [35], [36]. The scope of granular computing is a study of heuristics, strategies, theories, methods, and tools for real world problem solving by both humans and machines. The three perspectives may be ordered as the philosophy, the methodology and the computation to reflect the change from human-centered problem solving to machine-centered problem solving. Granular computing extracts the common domain-independent principles, strategies and heuristics that have been applied either explicitly or implicitly in many disciplines, and describes them using a common language so that they can be used by more people consciously for problem solving [36].

The promise of granular computing lies in its focus on human-centered and knowledge intensive problem solving tasks, where multiple levels of information and knowledge granularity play an important role. As a new field of research, granular computing must prove itself by demonstrating its effectiveness in solving a wide range of real world problems. Moreover, these problems cannot be easily or effectively solved by using other computational methods.

To demonstrate the potential of granular computing, we consider the problem of writing. There does exist a precisely defined procedure for writing. Many aspects of writing may not be quantified, nor formalized, at least in the near future. We demonstrate that strategies of granular computing can be applied to structured writing. By consciously using strategies and heuristics of granular computing, a scientist has a better chance to produce a clear, structured, and comprehensible document. Markup language based computer systems can be designed and implemented for readers to explore and make full use of granular structures of scientific documents. The philosophical and methodological perspectives of granular computing are more instructive to the writing process. The computational perspective is more relevant to the design and implementation of computer systems for supporting structured writing and reading.

II. The Trinity Model of Granular Computing

The trinity model of granular computing integrates three perspectives, namely, the philosophy, the methodology and the information processing mechanism, based on granular structures [36]. The three perspectives are the three vertices of the granular computing triangle. With an emphasis on structures, granular computing leads to structured solutions to real-world problems.

A. Granular structures: multilevel and multiview

Granules are the primitive notion of granular computing. Each granule represents a specific aspect of a real-world problem at a particular level of detail. We adopt the results from systems theory [1], [3], [6], [16] for the study of granular computing. In particular, a problem or a system may be interpreted as a whole consisting of parts. Each part is called a granule. Granular computing explores the composition of parts, their interrelationships, and connections to the whole. It represents a problem in a structured way through the notions of granules, levels, and hierarchies [35], [36].

A granule plays dual roles, depending on our viewpoints. When it is viewed as a part of another granule, the granule is interpreted as a single element of the other granule. Alternatively, it may be viewed as a whole consisting of a family of granules. This part-whole relationship suggests a partial ordering of granules, which leads to a hierarchical structure. A hierarchy consists of a family of interacting and interrelated granules, and each of them can be, in turn, a

hierarchical structure. Trees and lattices are typical examples of hierarchical structures. We may view a hierarchy as a structure of (partially) ordered multiple levels. Each level is made up of a family of granules. Hierarchical structures not only make a complex problem more easily understandable, but also lead to efficient, although perhaps approximate, solutions.

A hierarchical structure is built through a vertical separation of levels and a horizontal separation of granules at the same hierarchical level. It is based on the principles of approximations and a loose coupling of parts [6], [27]. Each level may be viewed as a representation of a problem at a specific level of granularity. The relationship between levels can be interpreted in terms of abstraction, control, complexity, detail, resolution etc.

A hierarchy represents a problem from one particular angle or point-of-view with multiple levels of granularity. A complete understanding of the problem requires the use and comparison of multiple hierarchies, namely, multiview. Depending on different contexts of applications, we may have granular data structures, information structures, and knowledge structures [36].

B. The granular computing triangle

The scope and issues of granular computing are given by the granular computing triangle consisting of three perspectives [35], [36]. The main ideas are summarized below.

Philosophy: Structured Thinking. Granular computing, as a way of structured thinking, draws results from two complementary philosophical views dealing with the complexity of real-world problems, namely, the traditional reductionist thinking and the more recent systems thinking. It combines analytical thinking for decomposing a whole into parts and synthetic thinking for integrating parts into a whole. Granular computing stresses the importance of the conscious effects in thinking with hierarchical structures that models a complex system in terms of the whole and parts.

Methodology: Structured Problem Solving. Granular computing, as a method of structured problem solving, promotes systematic approaches, effective principles, and practical strategies for solving real-world problems by exploring granular structures. This involves three basic tasks: constructing granular structures, working within a particular level of the structures, and switching between levels. By solving the same problem at different levels of complexity, abstraction, or detail, in an incremental level-wise manner, we may be able to obtain more insights into the problem, simplify the problem solving process, and find approximate, but practically useful and low cost solutions.

Computation: Structured Information Processing. Granular computing, as a paradigm of structured information processing, focuses on implementing knowledge-intensive systems based on granular structures. Two basic issues are the representation and process [20]. A representation is a formal system that makes explicit certain entities or types of information and a specification of how the system achieves it. A process may be interpreted as actions or procedures for carrying out information processing tasks. Processes of granular computing may be broadly divided into the two classes: granulation and computation with granules [30], [35]. Granulation processes involve the construction of the building blocks and structures, namely, granules, levels, and hierarchies. Computation processes explore the granular structures. This involves two-way communications up and down in a hierarchy, as well as switching between levels.

III. Granularity in Scientific Documents

A scientific document may be viewed as a product of a research process and a writing process. The prerequisites for producing a good document is an understanding of the human cognitive process and the structures of documents in terms of the form and content. Both aspects are closely related to the principles and strategies of granular computing, namely, multiple levels of the thinking process and organization.

A. Granular structures as an effective means of communication

According to Flower and Hayes [8], writing is a complex cognitive process, a strategic action and a thinking problem. It is reasonable to assume that writing somehow depends on our cognition skill and ability to organize ourselves, our environment, and our perceptions of the physical world into structures. Writing as a means of communication needs to fully consider granular structures. This is supported by the following results.

In his influential paper on the magical number seven, Miller [21] made a convincing argument regarding our limited capacity of short-term memory. More specifically, short-term memory holds around seven units of information. In order to cope with a large amount of information, the chunking principle is applied so that individual pieces of information are chunked together to form one larger unit. One may successively obtain a sequence of chunks so that the number of units are within the capacity of the short-term memory. This suggests that a hierarchical structure is obtained through chunking so that the number of units at each level is about seven. Each chunk may be viewed as a granule and hence hierarchical granular structures are a solution to the bottleneck of the limited human information processing capacity.

Human thought and knowledge is normally organized in hierarchical structures, where concepts are ordered by their different levels of specificity or granularity. For example, Reif and Heller [26] suggested that the knowledge about a quantitative science such as mechanics in physics specifies descriptive concepts and relations at different levels of abstraction that is organized in a hierarchical manner. A plausible reason for such organizations is that they reflect truthfully the hierarchical and nested structures abundant in natural and artificial systems.

As a basic tool for recording and communicating human knowledge, languages, either natural or artificial, employ hierarchical structures. For example, words are composed of letters, and phrases and sentences are composed of words. The hierarchical structures of languages make it much easier

to describe our hierarchical understanding and perception of the real world.

In summary, hierarchical granular structures with multiple levels of abstraction are required, in some sense, by the limited capacity of our short-term memory and are consistent with our perceptions of the world and our knowledge about the world. It is not difficult to convince ourselves that the granular structures must be explored in writing for effective communication.

B. Granular views of a scientific document

Given that granular structures are necessary for effective and efficient communication, one would expect to find such structures in scientific documents. This is in fact the case. Many scientific documents employ a structured form of presentation that clearly shows a hierarchical organization. Broadly, two nested hierarchical structures can be observed.

A low-level structure reflects the hierarchical structures of a language. Words are made up by letters, phrases and clauses by words, sentences by phrases and clauses, and paragraphs by sentences [27]. A high-level structure reflects the organization of a document. Subsections are made up by paragraphs, sections by subsections, and a document by sections. A book is made up by chapters and each chapter is made up by sections.

From a reader's point of view, the multiple levels of granularity in a document are essential for understanding. For example, a reader may simply glance at a document to extract the high-level hierarchical structures which gives a birds-eye view of the document. Many documents in fact explicitly support this task by providing the table of contents. In some books, multiple tables of contents are used: a) a simplified version without mentioning units at lower levels of granularity (e.g., subsubsections), and b) a detailed version including the lower levels. For example, Luger in a text book on artificial intelligence used two versions of the table of contents called, respectively, the *Brief Contents* and the *Contents* [19]. Between the levels of table of contents and the full text, some books contain another level of granular description that discusses briefly the materials.

Schematically, one may make explicit the nested hierarchical structure of a document by using a numeric labeling system such as the Dewey Decimal Classification and proper indentation. Numbers representing units at different levels are connected together by a "." and each lower level is indented. This scheme is used by Wikipedia (http://en.wikipedia.org/wiki) to present the document structures and is also used to present structured mathematical proofs [15]. As an example, the hierarchical structures of this article are discussed.

The title provides the coarsest description of the paper and is expanded with finer granularity in six sections:

Structured Writing with Granular Computing Strategies:
1. Introduction
2. The Trinity Model of Granular Computing
3. Granularity in Scientific Documents
4. Structured Writing as Granular Computing
5. An Example
6. Concluding Remarks

A reader can easily infer the following two points. First, Sections 2 and 3 discuss the topics of granular computing and granular structures in scientific documents. Second, Section 4 explores principles of granular computing and granular structures for structured writing, and Section 5 illustrates the ideas through an example.

At the next level, Section 2 can be divided into two subsections:

2. The Trinity Model of Granular Computing
   2.1. Granular structures: multilevel and multiview
   2.2. The granular computing triangle

One immediately grasps the two basic components of granular computing: granular structures and the granular computing triangle. Regarding the latter, Subsection 2.2. is again divided into three subsubsections:

2.2. The granular computing triangle
   2.2.1. Philosophy: Structured Thinking
   2.2.2. Methodology: Structured Problem Solving
   2.2.3. Computation: Structured Information Processing

At this level, the three perspectives of granular computing become clear to a reader.

The complete hierarchical structure of this paper is given by:

1. Introduction
2. The Trinity Model of Granular Computing
   2.1. Granular structures: multilevel and multiview
   2.2. The granular computing triangle
      2.2.1. Philosophy: Structured Thinking
      2.2.2. Methodology: Structured Problem Solving
      2.2.3. Computation: Structured Information Processing
3. Granularity in Scientific Documents
   3.1. Granular structures as an effective means of communication
   3.2. Granular views of a scientific document
   3.3. Structured documents and markup languages
4. Structured Writing as Granular Computing
   4.1. Structured writing guided by granular structures
   4.2. Writing process as constructing granular structures
5. An Example
6. Concluding Remarks

The explicit representation of the hierarchical structures leads to a granular understanding of a document, which is useful to the writer and the reader. In particular, we have four granular views of the paper, namely at levels labeled by "n.", "n.n.", "n.n.n.", and the full text, respectively. The granular structures are beneficiary to both both the writer and a reader. The stepwise decomposition in terms of granularity is very natural for a writer to organize ideas. A reader may have a good grasp of the main ideas at different levels even without reading the entire paper.

C. Structured documents and markup languages

An area of research that exploits the granular structures is the study of structured documents and markup languages [2],

[11], [12]. A structured document focuses on a high-level representation of a document based on its logical organization. That is, a document is no longer treated as a stream of characters in a linear order. Typically, a markup language is used to label and to tag different parts of a document and, furthermore, to link different parts by hyperlinks.

Many studies of structured documents and markup languages are concerned mainly with the preparation, processing, retrieval, presenting, and understanding of a document by machines automatically. The principle of the separation of the form and the contents is applied so that a machine is in charge of the form and helps a writer to prepare the contents. Such form-oriented approaches can be easily used to support a writer and a reader.

It is important to highlight the hierarchical structures for writing and reading structured documents. Markup languages make this a relatively easy task. Based on the numbering system, it is easy to produce granular views of a document at a particular level without considering the irrelevant details of lower levels. For example, a granular view can be generated at the first level labeled by "n." without irrelevant details of subsequent lower levels. If more detail is required, a finer granular view can be generated at the second level labeled by "n.n.". In particular, a granular view can be generated for a particular section. This strategy has proved to be effective in managing and viewing file directory structures in a computer. It would be equally effective in managing and reading a scientific document. For example, many authors provide readers with a table of contents of a document by using bookmarks in a PDF file.

IV. Structured Writing as Granular Computing

We consider the following three related writing tasks:

- write an English prose;
- write a computer program;
- write a mathematical proof.

Although the final products are different, the process for producing them are remarkably similar. Moreover, one applies similar methods and strategies. Human concept formation and learning determine, in principle, the ways to produce easily-understandable solutions to a problem. For example, the chunking principle underlying human memory [21] suggests a hierarchical structure used in writing [13], [22]. The hierarchical structures of complex systems [27] are applicable to the process of writing if one considers an article to be a complex system that has evolved through time [37]. The styles of programming [14], [17] are influenced by the styles of writing English prose [28]. Structured programming in turn offers solutions to structured mathematical proofs [10], [18].

In the rest of this section, we focus our attention on writing a scientific document. From the previous discussion, it is evident that we must make full use of granular structures in writing. For clarity, we only touch on levels at and above the labeled units such as subsubsections. This allows us to examine the structures of a document without getting lost in too much detail at the sentence and paragraph levels. One may consult books that cover sentence and paragraph writing, as well as styles of writing [9], [24], [28].

The discussion of this section is influenced by the following studies:

- Simon [27]: the architecture of complexity;
- Flower [7], Flower and Hayes [8]: problem-solving strategies for writing;
- Young, Becker and Pike [37]: rhetoric as process;
- Minto [22]: the pyramid principle for writing;
- Horn [13]: structured writing;
- Ledgard, Gueras and Nagin [17]: structured programming.

We focus on a brief discussion and synthesis of the ideas, principles, heuristics, and strategies from those studies in the light of granular computing for structured writing. A reader may find it more informative and instructive to read the original works of those authors.

A. Structured writing guided by granular structures

According to the magical number seven hypothesis, one can only comprehend about seven ideas at any one time. It is necessary to organize a document in a structured way to facilitate writing and reading. Specifically, a simple idea is described by a paragraph consisting of several sentences. A point-of-view is jointly described and supported by several ideas. A theme of a document emerges from different points-of-view and perspectives [36].

Two related issues need to be examined: a) the choice of different types of units, i.e., granules of different sizes, in a document, and b) the relations connecting those units, i.e., granular structures. Horn [13] promotes a strategy for grouping information into small and manageable units (i.e., labeled chunks) called information blocks and information maps. Young, Becker and Pike [37] refer to them as units of experience. Minto [22] suggests that one can sort ideas into a pyramid so that one orders ideas from the top down and thinks from the bottom up. Flower and Hayes [8] discuss a strategy of treeing ideas so that issues addressed by a document are arranged into an issue tree. Young, Becker and Pike [37] suggest that a document may be viewed as a complex system evolved through time. Hence, the hierarchical architecture of a complex system [27] can be applied, so that a document can be modeled as a hierarchically structured system of units of experience.

A granular structure serves several purposes. First, it helps a writer to clarify and organize ideas. A granular structure gives multiple views at different levels of granularity. This conceptual map of contents of a document enables a writer to answer many fundamental questions, such as: What is new? What is different? Is an argument convincing? Second, by providing an explicit hierarchical structure through titles of various units, a document is more comprehensive to a reader. In this case, the magical number seven works for readers. The granular structure allows a reader to quickly and correctly share the experience of the writer and hence grasp the main ideas of a document. In some sense, the structure establishes easy connections between the writer and readers. Thus, structured writing guided by granular structures is a

powerful methodology for adapting writing for the needs of readers [7].

In summary, structured writing is guided by hierarchical granular structures. It explores the power of structures for producing organization, understanding, and insights. Structured writing leads to clarity and comprehensibility of a scientific document.

B. Writing process as constructing granular structures

Writing may be viewed as a problem solving process [7], [37]. An essential task is the construction of a granular structure representing the final document.

In constructing a granular structure, there are several issues, such as the vertical separation of levels and the horizontal separation of granules (i.e., units) in each level [27]. As suggested by Minto [22], the vertical dimension concerns the relationships between points and subpoints, and the horizontal dimension concerns the relationships within a set of subpoints. To achieve clarity and readability, it is desirable that units and levels are internally consistent and externally independent. The internal consistency can be achieved by applying the relevance principle [13]. That is, each unit contains only information that relates to one main point. The external independency is obtained by exploring the near-decomposability [27], so that the interactions among units, either vertically or horizontally, are weak.

The construction of a granular structure can be either top-down or bottom-up. While the bottom-up approach may be suitable for synthesizing scattered ideas at an early stage, the top-down approach may be effective for analyzing the results at a later stage. One may combine both strategies.

The construction is also an iterative process. It is important to backtrack in order to obtain the most informative and effective granular structure. The magical number seven again plays a crucial role. For example, if we are in a situation where too many issues are discussed in a unit, it may be better to introduce new levels or regroup different units. In many situations, writing and researching are two closely tied tasks. In the process of writing, we need to research new topics, and the new findings may lead to rewriting certain portions of a document.

In the context of structured programming, Ledgard, Gueras and Nagin [17] summarize concisely the main characteristics of the top-down programming approach. We simply adapt them for structured writing:

1. **Writing in levels.** A level consists of a set of units. At higher levels, only a brief description of a unit is provided. The details of the unit are to be refined, divided into smaller units, and developed in lower levels. The labeling of units should follow this principle. For example, titles of subsections should be more specific than the parent section.
2. **Initial language independence.** At initial levels, one focuses on relevant ideas without worrying too much about the choices of words. As suggested by Flower and Hayes [8], one may use private cue words. This strategy is particularly helpful if one writes in a foreign language. It is important to separate the main issues of organizing and developing ideas from the language barrier.
3. **Postponement of details to lower levels.** The initial levels concern critical broad issues and the structure of the document. The details are postponed to lower levels.
4. **Formalization and verification of each level.** Before proceeding to a lower level, one needs to obtain a formal and precise description of the current level. This will ensure a full understanding of the structure of the current sketched version. Furthermore, each level must be verified so that errors pertinent to the current level will be detected. One cannot expect a good structure at a lower level if the structure at the current level is unsuitable. Errors in structure may be amplified in lower levels.
5. **Successive refinements.** Structured writing is a successive refinement process. Starting from the top level, each level is redefined, formalized, and verified until one obtains a full document.

Heuristics and strategies similar to those have been discussed in detail by many authors for writing [7], [8], [13], [22], [37]. These works articulate the next level of details.

V. An Example

Many writers learn to write by reading published works as examples [25]. The effectiveness of granular structures and the principles of structured writing with granular structures are illustrated with an example.

We choose the paper by Flower and Hayes [8] on problem-solving strategies for writing. For this paper, we have the following granular structure:

Problem-Solving Strategies and the Writing Process:
1. Writing as a Form of Problem Solving
   1.1. Strategies for writing: inspiration, prescription, and writer's block
   1.2. A problem-solving strategy for writing
2. A Heuristic Strategy for Analytical Writing
   2.1. Part one: planning
      2.1.1. Plan
         2.1.1.1. Set up a goal
         2.1.1.2. Find operators
   2.2. Part two: generating ideas in words
      2.2.1. Play your thoughts
         2.2.1.1. Turn off the editor and brainstorm
         2.2.1.2. Stage a scenario
         2.2.1.3. Play out an analogy
         2.2.1.4. Rest and incubate
      2.2.2. Push your ideas
         2.2.2.1. Find a cue word or rich bit
         2.2.2.2. Nutshell your ideas and teach them
         2.2.2.3. Tree your ideas
         2.2.2.4. Test your writing against your own editor
   2.3. Part three: constructing for an audience
      2.3.1. Ends
         2.3.1.1. Identify a mutual end you and the reader share

2.3.1.2. Decide on your own specific ends
2.3.2. Roadblocks
2.3.3. Means
2.3.3.1. Develop a rhetorical strategy
2.3.3.2. Test your rhetorical strategy
3. Teaching and Using Heuristics
3.1. The process as a whole
3.2. Teaching

This granular representation of the paper is very informative. It concisely summarizes the main steps and issues of a writing process. The full paper of 13 pages may be considered as a refinement of this structure with more details on the next level of granularity. In addition, the 210-page book by Flower [7] is yet another level of refinement of the same thesis with more details and examples.

VI. Concluding Remarks

If various units of a document are interpreted as granules at different levels, we can immediately apply principles and strategies of granular computing to the writing process. Conversely, results from writing can help us to gain more insights into granular computing. This paper is written for both objectives. On the one hand, we want to demonstrate the power of granular computing by its application to structured writing. On the other hand, we want to draw results from the study of writing to enrich granular computing.

Structured writing is both a thinking process and a problem solving process. From the examination of the complex task of writing, we obtain further evidence to support the trinity model of granular computing. The philosophy and methodology of granular computing are instructive to a writer in the writing process. The computation paradigm of granular computing may lead to markup language based systems that support full explorations of granular structures and granularity in scientific documents.

It is perhaps fair to say that many concrete models of granular computing, for example, clustering, fuzzy sets, and rough sets, are insufficient to solve the complex problem of writing, although their results are applicable at a more abstract level. A study of granular structures based on the trinity model may offer new insights into human problem solving and unique solutions for knowledge intensive computer systems.

It may be argued that the basic ideas of exploring different levels of granularity have in fact been used implicitly by many authors. However, they have not been made explicit and, hence, are not available to many more people. One of the objectives of the study of granular computing is to make such *implicit* principles *explicit* [36]. This paper is a call for making *conscious effects* using granular structures in writing.

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