# PATTOLOGY: the Science of Patterns and its Applications

# Editorial

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***Abstract*—In this special session we introduce the term *PATTOLOGY* to be the science of patterns and its applications. Over the centuries those with inquisitive minds have observed and pondered the existence of beautiful patterns arising naturally in the universe. Perhaps it is more surprising to encounter such beauty in science as it is natural in art, and as science is our inclination then it is the focus of pattology, while also encouraging a multidisciplinary flavour. This track presents contributions related to temporal patterns based around Allen's interval algebra and multi-pattern matching architectures.**

***Keywords*–*Algorithmic patterns; artificial intelligence; combinatorial patterns; constraint satisfaction; pattology; programming patterns; qualitative reasoning; quantitative reasoning; smart-type reasoning; temporal patterns***

## I. Overview and Perspectives

One of the most classic examples of patterns related to numbers must be the famous Fibonacci sequence, given by the sum of the two preceding numbers. Similarly, Pascal's triangle, a triangular array of the binomial coefficients, exhibits much elegance and symmetry. Fractals, a mathematical set with a repeating pattern, exhibits the pattern at every scale – generated by recursion, fractals are images of dynamic systems. Then there's arithmetic sequences, geometric sequences and patterns, the list goes on. Mathematical patterns have been discovered over the centuries, many independently on different continents – impressive when there was no email! And is it true that our solar system, and others, satisfy the Titius-Bode law?

Combinatorics of words is a much newer discipline in theoretical computer science, studied from the early 1900s, and exhibits many patterned forms such as Lyndon words, Sturmian words, Fibonacci words, and Christoffel words. A word (sequence of letters over an alphabet) is a Lyndon word if it is strictly least in lexicographical order among its set of cyclic rotations. A Sturmian word is a kind of binary infinite word which is not ultimately periodic, or geometrically, a Sturmian word can be defined by considering the sequence of the intersections with a squared-lattice of a specified semi-line. Interestingly, these words are not just deep structurally, but importantly have practical value. For instance, Lyndon words find uses in musicology, bioinformatics, specialized sorting problems and digital geometry. Properties of the Fibonacci word and, more generally, Sturmian words have practical applications in computer imagery (digital straightness) and theoretical physics (quasicrystal modelling). While Christoffel words draw connections with musical scales.

In the field of artificial intelligence, an area particularly rich in patterns is temporal reasoning. Indeed, patterns are often carefully analyzed and utilized in wide-ranging applications, including: planning and scheduling, natural language processing, diagnostic expert systems, behavioural psychology, circuit design, health care and business intelligence.

Allen [1] introduced an algebra of binary relations on intervals (of time), for representing and reasoning about time, see Table I. These binary relations, for example *before or proceeds* depicted $p$, *during* depicted $d$, or *meets* depicted $m$, describe *qualitative* temporal information; frameworks also exist for *quantitative* temporal reasoning. The problem of satisfiability for a set of interval variables with specified relations between them is that of deciding whether there exists an assignment of intervals on the real line for the interval variables, such that all of the specified relations between the intervals are satisfied. When the temporal constraints are chosen from the full form of Allen's algebra, this formulation of the satisfiability problem is known to be NP-complete; however, restricted fragments of the algebra allow for tractability, supporting efficient applications, otherwise heuristic approaches are required.

## II. Special Track Schedule

In reality, all the papers of the conference are relevant to this session on Pattology, however we explore here two partic-

TABLE I.

THE SET $\mathbf{B}$ OF THE THIRTEEN BASIC QUALITATIVE RELATIONS DEFINED BY ALLEN [2]

| Basic Interval Relation | Example | Endpoint Relations |
|---|---|---|
| X precedes Y $(p)$ | $xxx$ | $X^+ < Y^-$ |
| Y preceded-by X $(p \smile)$ | $yyy$ | |
| X meets Y $(m)$ | $xxxx$ | $X^+ = Y^-$ |
| Y met-by X $(m \smile)$ | $yyyy$ | |
| X overlaps Y $(o)$ | $xxxx$ | $X^- < Y^- < X^+ < Y^+$ |
| Y overlapped-by X $(o \smile)$ | $yyyy$ | |
| X during Y $(d)$ | $xxx$ | $X^- > Y^-,\ X^+ < Y^+$ |
| Y includes X $(d \smile)$ | $yyyyyyy$ | |
| X starts Y $(s)$ | $xxx$ | $X^- = Y^-,\ X^+ < Y^+$ |
| Y started-by X $(s \smile)$ | $yyyyyyy$ | |
| X finishes Y $(f)$ | $xxx$ | $X^- > Y^-,\ X^+ = Y^+$ |
| Y finished-by X $(f \smile)$ | $yyyyyyy$ | |
| X equals Y $(\equiv)$ | $xxxx$ $yyyy$ | $X^- = Y^-,\ X^+ = Y^+$ |

ular instances arising in the science of patterns: applications of temporal patterns and, from a rather different angle, pattern-matching algorithms.

We commence with the artcile *Temporal Patterns: Smart-type Reasoning and Applications* by Dineshen Chuckravanen, Jacqueline W. Daykin, Karen Hunsdale and Amar Seeam. Recent research [3] proposed that the Fishburn-Shepp inequality [4] [5] be applied in scheduling type problems to guide the scheduling strategy. This inequality expresses a pattern of correlation in a poset (partially ordered set), equivalently a directed acyclic graph. The Fishburn-Shepp inequality is an inequality for the number of extensions of partial orders to linear orders, expressed as follows. Suppose that $x, y$ and $z$ are incomparable elements of a finite poset, then

$$P(x < y)P(x < z) < P((x < y) \wedge (x < z))$$

where P(*) is the probability that a linear extension has the property *.

Three potential application areas with quite distinct flavours are presented as candidates for applying this inequality. First, temporal issues arising in the Internet of Things centered around smart homes (see [6]). Secondly, applications of Allen's interval algebra in the context of intelligent conversational agents which enable natural language interaction with their human participant (see ([7]). Thirdly, the relation of Allen's temporal interval framework to the complex decision-making processes involved in human physiology during physical exertion, and the consequences of associated scheduling (see [8]). Some common smart-type threads are drawn between these problem scenarios.

The second paper, *Trie Compression for GPU Accelerated Multi-Pattern Matching*, by Xavier Bellekens, Amar Seeam, Christos Tachtatzis and Robert Atkinson considers computations of patterns, namely pattern matching, an activity at the heart of so many applications arising in diverse fields such as: bioinformatics, the Internet of Things, desktop search, cyber-security, text editors, image analysis, and information retrieval.

This paper seeks to exploit the massively parallel capabilities of Graphical Processor Units while mindful of the need for compression in the context of multi-pattern matching. The trie data structure is utilized, namely a tree for storing strings in which there is one node for every common prefix – hence this structure also exhibits the well-known tree pattern. The authors propose a trie compression algorithm for massively parallel pattern matching, which is significantly more space efficient than the original highly efficient parallel failure-less Aho-Corasick version (see [9]), while providing impressive throughput – also verified experimentally. Indeed, this research is oriented in the right direction in this era of big data.

## III. REFLECTIONS

The success of the series of the PATTERNS conferences, nine to date, is testimony to the value of the scientific exploration and invention of patterns. Notably, this platform brings together many distinct, yet inter-related themes, such as: patterns at work, classification patterns, medical and facial image patterns, tracking human patterns, action recognition patterns, colour and texture patterns, ubiquity patterns, software patterns, security patterns, system management patterns, discovery and decision patterns, communications patterns, domain-oriented patterns, and even antipatterns. Observe that this fascinating list of patterns is focused around computer science interests while abundant patterns will also arise in disciplines such as economics, chemistry, geography, and as previously discussed, mathematics, physics and astronomy (see Section I).

In summary, the world is a beautiful and intriguing place - both the observable and the abstract, the tangible and the esoteric, and not only the patterns but the randomness too!


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