Robust and Tuneable Family of Gossiping Algorithms

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Abstract

We present a family of gossiping algorithms whose members share the same structure though they vary their performance in function of a combinatorial parameter. We show that such parameter may be considered as a “knob” controlling the amount of communication parallelism characterizing the algorithms. After this we introduce procedures to operate the knob and choose parameters matching the amount of communication channels currently provided by the available communication system(s). In so doing we provide a robust mechanism to tune the production of requests for communication after the current operational conditions of the consumers of such requests. This can be used to achieve high performance and programmatic avoidance of undesirable events such as message collisions.

1 Introduction

The main character in this text is a family of algorithms for distributed gossiping whose members differ in the strategy adopted to discipline the right to transmit. That strategy can be expressed as a permutation of the indices of the participants. In [7] a formal model for this family of algorithms was introduced and the performance of some of its members was analyzed. In the cited paper in particular it was shown how the choice of the structure of the permutations controlling these algorithms translates in different requirements on the underlying communication system—namely, different amounts of concurrent send and receive requests.

The focus of this paper is not on the functional properties of the gossiping algorithms but rather on the non-functional characteristics exhibited by them with the change of the adopted permutations. Building on top of our past research, here we first show that by assigning different classes of permutations to the participants it is possible to scale dynamically the amount of communication requests triggered by the execution of our algorithm. In other words, this enables the expression of a spectrum of codes each characterized by a different algorithmic parallelism.

Secondly, we show here how this can be used to reach an optimal match with the contextual (that is, physical) parallelism provided by the deployment platform and networks. Such an optimal tuning allows the avoidance of shortcoming and excess of algorithmic parallelism. While in the former case one would under-utilize the available resources, in the latter case one would issue a number of requests higher than the available communication resources, which could lead to undesirable conditions such as overloading of request queues and packet collisions.

In what follows we first define our family of algorithms and concisely recall its characteristics in Sect. 2. Next, in Sect. 3 we introduce hybrid gossiping—a strategy to tune the algorithmic parallelism in function of the physical parallelism characterizing the current context. Section 4 explains how that strategy can be used to design autonomic evolution engines exploiting hybrid gossiping. State of the art is then briefly summarized in Sect. 5. Our conclusions follow in Sect. 6.

2 A Family of Gossiping Algorithms

In this section we recall the main features of a family of gossiping algorithms firstly introduced in [7]. We refer the reader to the cited paper for a thorough discussion of the features of those algorithms. Introductions to gossiping, which may be concisely defined as all-to-all pairwise interprocess communication, may be found e.g. in [12] [2] [11].
In what follows we define a formal model for such family of
algorithms and we highlight the characteristics of two of its
members.

2.1 Formal Model

Let $t$ represent time and $N > 0$ be an integer. We shall
consider a set of $N + 1$ communicating processes. We as-
sume that such processes may be uniquely identified via in-
tegers in $\{0, \ldots, N\}$. Processes are deployed in processing
nodes linked together via one or more communication net-
works. We shall refer to the set of nodes and networks as to
“the system”. Nodes are equipped with a limited number of
communication ports. Likewise, networks provide a limited
number of independent full-duplex point-to-point communica-
tion lines. At any time $t$ a new communication can only be
initiated if a free port and a free line are available in the
system. If that is not the case, the requesting process is put
in a wait state. Due to resource competition, the number of
ports and that of lines vary dynamically. Depending on the
available ports and lines, at any time $t$ at most $N(t)$ send
and at most $N(t)$ receive requests may be allowed to exe-
cute. Communication is synchronous and blocking.

Processes own some local data they need to share (for in-
cidence, to execute a voting algorithm as in [9] or [3]). In
order to do so, each process broadcasts its local data to all
the others through multiple consecutive send requests, and
receives the $N$ data items owned by its fellows via multi-
ple consecutive receive requests. A discrete time model is
assumed—events occur at discrete time steps, and during
any time step any process can be involved in only one such
event. More specifically, on a given time step $t$ process $i$
may be:

1. sending a message to process $j$, $j \neq i$; this is repre-
sented as $i S^t j$;
2. receiving a message from process $j$, $j \neq i$; this is
shown as $i R^t j$;
3. blocked, waiting for messages to be received from any
process; symbol “\( \rightarrow \)” will be used to mean this case;
4. blocked, waiting for a message to be sent, i.e. for an
addressee to enter the receiving state. Symbol “\( \leftarrow \)”
will be used for this.

A slot is defined as a process’ temporal “window” one
time step long. On each given time step $t$, $N + 1$ slots are
available within the system. Process $i$ makes use of slot $t$ if
and only if $\exists j (i S^t j \lor i R^t j)$; on the contrary, process $i$
is said to waste slot $t$.

By the term “run” we shall refer in what follows to the
the collection of slots required to execute the above algo-

Let us define the following four state templates:

$WR$ state. A process is in state $WR_j$ if it is waiting for
the arrival of a message from process $j$. Where the
subscript is not important it will be omitted. Once in
$WR$, a process stays there for one or more time steps,
corresponding to the same number of “\( \rightarrow \)” actions.

$S$ state. A process $i$ is in state $S_j$ when it is sending a
message to process $j$. After one time step $i$ leaves state $S_j$.
This corresponds to one $i S^t j$ action.

$WS$ state. A process $i$ waiting to send process $j$ its mes-
gage is said to be in state $WS_j$. Where the subscript is
not important it will be omitted. Once in $WS_j$, process
$i$ stays there for one or more time steps, corresponding
to the same number of “\( \leftarrow \)” actions.

$R$ state. When process $i$ is receiving a message from pro-
cess $j$, it is said to be in state $R_j$. This state transi-
tion also lasts one time step and corresponds to action
$i R^t j$.

Let $P_1, \ldots, P_N$ represent a permutation of integers
$0, \ldots, i - 1, i + 1, \ldots, N$. Then the above state templates

Figure 1 shows the finite state automaton that solves dis-
tributed gossiping for process $i$, which we obtained by ex-
ecuting Alg. 1. The first row is the condition that has to be
reached before process $i$ is allowed to begin its broadcast: a
series of $i (WR, R)$ couples.

Once process $i$ has successfully received $i$ messages, it
acquires the right to broadcast. Broadcasting is performed
according to the rule expressed in the second row of Fig. 1
process $i$ orderly sends its message to its fellows, the $j$-th
message being sent to process $P_j$.

The third row of Fig. 1 instructs the reception of the re-

In [7] it was shown how, irrespective of the value of $P$,
such FSA’s implement a distributed deadlock-free gossiping
algorithm. As intuition may suggest, the choice of which
permutation to use has indeed a deep impact on the over-
all performance of the algorithm—together with the physi-
cal characteristics of the system. In fact, different permuta-
tions translate in different amounts of communication par-
allelism; when such algorithmic parallelism is backed up
by contextual parallelism—that is, by a sufficiently large
number of independent communication ports and lines in
the system, modeled as dynamic system $N(t)$—then there
is an optimal match between the algorithm and the deploy-
ment platform.

In order to evaluate the above impact we shall make use of
the following “quality metrics”:

Algorithm 1: Compose the FSA solving gossiping

for process $i \in \{0, \ldots, N\}$

\begin{algorithm}
\Input{A $\equiv (i, N, \mathcal{P})$}
\Output{FSA(A)}
1 \Begin
2 \Comment{emit the initial state}
3 \textbf{FSA}($A$) := \textsc{START}
4 \For{$j := 0$ \textbf{to} $i - 1$}
5 \Comment{operator “←” appends a new state to the FSA}
6 \textbf{FSA}($A$) $\leftarrow$ \textsc{WR}
7 \textbf{FSA}($A$) $\leftarrow$ \textsc{R}
8 \Enddo
9 \For{$j := 1$ \textbf{to} $N$}
10 \textbf{FSA}($A$) $\leftarrow$ \textsc{WS}$\mathcal{P}_j$
11 \textbf{FSA}($A$) $\leftarrow$ \textsc{S}$\mathcal{P}_j$
12 \Enddo
13 \For{$j := i + 1$ \textbf{to} $N$}
14 \textbf{FSA}($A$) $\leftarrow$ \textsc{WR}
15 \textbf{FSA}($A$) $\leftarrow$ \textsc{R}
16 \Enddo
17 \Comment{emit the final state}
18 \textbf{FSA}($A$) $\leftarrow$ \textsc{STOP}
19 \End.
\end{algorithm}

Average slot utilization. This is the average number of used slots per time step in a given run. It will be indicated as $\mu_N$, or simply as $\mu$. $\mu$ can be interpreted as the average degree of parallelism expressed by the algorithm—hence it will be referred to also as the “algorithmic parallelism”. $\mu$ can take any real value in $[0, N + 1]$.

Length. This is the number of time steps in a run. It represents a measure of the time needed for the distributed algorithm to complete. $\lambda_N$, or more simply $\lambda$, will be used for lengths.

For any time step $t$, we shall call $\nu_t$ as the number of slots that were used during $t$. The $\lambda$-tuple $\vec{\nu} = [\nu_1, \nu_2, \ldots, \nu_\lambda]$, orderly encoding the number of used slots for each time step in a run, shall be called “utilization string.”

In [7] several cases of $\mathcal{P}$ were introduced and discussed. In particular in the above cited reference it was shown how varying the structure of $\mathcal{P}$ produces quite different values of $\mu$ and $\lambda$. This fact, coupled with physical constraints of the system as modeled by $\mathcal{N}(t)$, determine the overall performance of our algorithm.

In what follows we focus on two particular cases representing the minimal and maximal algorithmic parallelism.

2.2 Identity Permutation

As a first case, let $\mathcal{P}$ be the identity permutation:

\[
\begin{pmatrix}
0, \ldots, i - 1, i + 1, \ldots, N \\
0, \ldots, i - 1, i + 1, \ldots, N
\end{pmatrix},
\]

i.e., in cycle notation [17], $\mathcal{P} = (0) \ldots (i-1)(i+1) \ldots (N)$.

This means that, once process $i$ acquires the right to broadcast, it first sends its message to process 0 (possibly having to wait for it to become available), then it will do the same with process 1, and so forth up to process $N$, obviously skipping itself. This is shown in Table 1 for $N = 5$. In what follows we shall refer to tables such as Table 1 as to “run-tables.”

In [7] it was shown how it is possible to characterize some properties of the quality metrics of the member corresponding to the identity permutation. Among such properties particularly useful here are the following two ones:

- The algorithm makes use of $O(N^2)$ time—more precisely, $\lambda_N = \frac{1}{3}N^2 + \frac{2}{3}N + \frac{1}{3}[N/2]$. 
- The asymptotic value of algorithmic parallelism, that is $\lim_{k \to \infty} \mu_k$, equals $\frac{8}{3}$. 

2.3 Pipelined Permutation

We now consider a second case—the one corresponding to permutation

\[
(0, \ldots, i-1, i+1, \ldots, N, i+1, \ldots, N, 0, \ldots, i-1).
\]

(2)

Note how permutation (2) is equivalent to \(i\) cyclic logical left shifts of the identity permutation.

When \(P\) as in (2), then process \(i\) first sends its message to process \(i+1\), then to process \(i+2\), and so on until it reaches process \(N\). After that, \(i\) wraps around and sends from process 0 to process \(i-1\). This is shown in Table 2 for \(N=8\). As can be seen from that table, (2) maximally overlaps the processes’ broadcast sessions the same way as machine instructions are being overlapped in pipelined microprocessors [13]. This similarity brought to the name of “pipelined permutation” for (2) [7].

In [7], some of the quality metrics of the member corresponding to the pipelined permutation were also characterized. In particular it was shown that:

- The algorithm makes use of \(O(N)\) time, and more precisely \(\lambda_N = 3N\).
- Algorithmic parallelism linearly depends on the amount of involved processes: \(\forall k > 0 : \mu_k = \frac{2}{3}(k+1)\).

3 Tuning Algorithmic Parallelism through Hybrid Gossiping

The two cases introduced in the previous section represent two “extremes” in the spectrum of possible permutation structures: the identity permutation and the pipelined permutation respectively translate in very low and very high algorithmic parallelism. These emerging behaviors characterize homogeneous gossiping—gossiping that is in which all processes make use of the same permutation. A useful property of our family of algorithms is that it also supports hybrid gossiping: in this case the gossiping processes make use of a permutation selected (with some predefined logic) from two or more classes, as depicted in Fig. 2. A noteworthy assignment logic is the one that schedules the pipelined permutation to a certain percentage of the processes and the identity permutation to the rest. By doing so we experimentally found that the ensuing algorithmic parallelism grows after the percentage of pipelined permutations assigned to
Analyze means checking whether \( \mu_N \) matches the estimated value of \( N(t) \).

Plan is a “meta-algorithm” (also known as “evolution engine”) \( Q \) responsible for choosing how to evolve the system.

Execute is the execution of the meta-algorithm and the corresponding evolution of the managed system.

In what follows we assume the availability of a monitoring function called sense. A reflective system such as the one introduced in [5] or [8] could be used to provide transparent access to the number of currently available ports and lines—that is, \( N(t) \). The “Analyze” step is merely the assessment of how close the current value of \( H_N \) is to the estimated value of \( N(t) \). The system would evolve only in case of two conditions: overshooting, that is a value of \( H_N \) overabundant with respect to that of \( N(t) \), and undershooting—namely, a value of \( H_N \) that would translate in a suboptimal exploitation of the available contextual parallelism. In case the system would indeed require adaptation, several
meta-algorithms may be selected for the Planning step depending on e.g. the characteristic of the mission and the system assumptions: in fact complex planning is likely to call for non-negligible amounts of system resources, which could interfere e.g. with real-time requirements. A possible cost-effective solution for the meta-algorithm could then be to make use of look-up tables providing for several values of $N$ the algorithmic parallelism corresponding to some sampling of $\mathcal{H}_N$. Figure 4 shows 200 samples of $\mathcal{H}_{200}$, which could be computed off-line and stored in one such look-up table. Algorithm 2 could then be used for the “Execute” step. Alternatively, should performance penalties be deemed preferable to the memory penalty to store the look-up table, one could compute the curve best fitting the sampling of $\mathcal{H}_N$ at run-time.

Another possibility is for instance the one described in Algorithm 3. In this case we define $\mathcal{M}_N$ as an associative map, that is, a growing set of domain-to-value associations that link known values of $\mathcal{H}_N$ to corresponding known values of $\mu_N$. A system such as the one described in [4] could implement such a map. The specific difference with respect to a look-up table lies in the dynamic nature of $\mathcal{M}_N$, as it is possible to add new associations to it at all times. It is assumed that $\mathcal{M}_N$ is initialized at least with the associations corresponding to the identity and the pipelined permutations.

The strategy followed in this case is to return a best match with the entries currently available in $\mathcal{M}_N$, and to add new entries to refine dichotomically the list. The current linear strategy may be replaced by a more efficient one designed after the non-linear nature of $\mu$. Figure 5 graphically depicts the working of Algorithm 3 under the following conditions: $N = 200$; $\mathcal{M}_{200}$ initially includes only the identity and pipelined permutations; $\mathcal{N}(t) = 13$ for all values of $t$. At the eighth iteration $|\mathcal{M}_{200}| = 9$ and the selected best value for $\mu$ is $13.11$.

5 State of the Art

In this section we briefly report on methods and strategies to tune the characteristics of a software system so as to achieve high performance e.g. through the expression and
Concerns such as this normally are not localized in a single physical module (e.g. a function) or logical component (e.g., a formal parameter, as it is the case for our gossiping algorithms); on the contrary, they often span through several modules and require the joint evolution of multiple correlated variables. In other words, the expression of parallelism is a typical cross-cutting concern. A typical way to tackle such concerns is through the usage of Aspect Oriented Programming (AOP) [16]. In AOP the source core consists of two separate “blocks”: the functional code dealing with the business logic and the aspect code to express one or more cross-cutting concerns. The actual source code is the result of a merging process called weaving where the functional code is rearranged, instrumented, and patched, according to what prescribed in the aspect code. This allows software systems to be effectively evolved so as to maximize one or more target concerns—including e.g. the expression of algorithmic parallelism [18]. Widely used in industry and academia, AOP proved in many cases to be able to manage effectively the complexity of software evolution.

The general problem of guaranteeing the emergence of certain expected features or behaviors in a system—software or otherwise—was termed by Jen [14] as “robust evolvability”. In the cited paper the author defines evolvability as an entity’s ability to “alter their structure or function so as to adapt to changing circumstances” and discusses a system’s capability to retain certain characteristics of interests (e.g. maximizing algorithmic parallelism) despite exploitation of algorithmic parallelism.

Algorithm 2: Tune algorithmic parallelism after contextual parallelism

\[ \text{Input: } \mathcal{N}(t), N, \text{ look-up table } M_N; \text{ Output: } H_{\text{best}} \]

1. \begin{align*} &\text{begin} \\
&\text{/* } \text{cp holds the current contextual parallelism */} \\
&\text{/* Function now returns current time */} \\
&cp \leftarrow \text{sense}(\mathcal{N}(\text{now}())) \\
&H_{\text{best}} \leftarrow \min\{h : M_N(h) \geq cp\} \\
&\text{return } H_{\text{best}} \\
&\text{end.} \end{align*}
changes in its composition and deployment environment. Such capability is called by Jen as robustness: feature persistence under specified and unforeseen perturbations, obtained by switching among multiple strategic options such that those changes are dynamically tolerated or even exploited. Interestingly enough, Jen distinguishes two classes of evolvable systems.

- Phenotypically plastic systems. Such systems retain their structure and organization throughout adaptations and only achieve evolution by switching among a few, preordained, structurally equivalent configurations that depend on some internal parameter. Obviously this is the case for our gossiping algorithms.

- Phenotypically dynamic systems programming system, which are able to assume different structures and organizations by mutating the topology, the role, and the number of their components. An example of this is given by AOP systems.

A deeper discussion and some examples of systems matching the above classes may be found e.g. in [6].

We believe as worth mentioning here the case of FFTW, an evolvable software system that tunes its logics so as to maximize performance on a given target platform. FFTW (whose name stands for “Fastest Fourier Transform in the West”) is a code generator for Fast Fourier Transforms that defines and assembles blocks of C code that optimally solve FFT sub-problems on a given machine [10].

Finally we observe how nowadays it is common practice designing software for families of target platforms, which selectively enable or disable target-specific optimizations. One such software is the mplayer video player [1], which explicitly states such optimizations with messages such as “Using optimized IMDCT transform” or “Using MMX optimized resampler.” The same software also permits to instruct the use of a number of threads that matches optimally the amount of parallelism available on a multi-core target machine.

6 Conclusions

We presented the properties of a family of algorithms which retain their structural characteristics though vary their operation depending on a combinatorial parameter. We showed how such “phenotypically plastic” system [14, 6] may be used to meet various changing requirements by tuning dynamically the amount of algorithmic parallelism manifested by the software. This paves the way to enabling robust control on the emergence of several properties and behaviors, e.g. collision avoidance, deterministic upper bounds on energy consumption, and optimal use of the available communication resources. Finally we showed how several evolution engines may be adopted to achieve autonomic context-aware selection of members that best match the current contextual conditions.

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Algorithm 3: Tune algorithmic parallelism after contextual parallelism

Input: $N(t), N$, associative map $M_N$; Output: $H_{\text{best}}$

1 begin
2 $cp \leftarrow \text{sense}(N(\text{now}()))$
3 $H_{\text{best}} \leftarrow \min\{h : M_N(h) \geq cp\}$
4 if $M_N(H_{\text{best}}) = cp$ then return $H_{\text{best}}$ fi
5 /* $M_N(H_{\text{best}}) > cp$ */
6 $sb \leftarrow \max\{h : M_N(h) < M_N(H_{\text{best}})\}$
7 $H_{\text{best}} \leftarrow (M_N(H_{\text{best}}) - M_N(sb))/2$
8 /* compute_µ simulates a run */
9 $µ \leftarrow \text{compute}_µ(H_{\text{best}})$
10 $M_N \leftarrow M_N \cup \{H_{\text{best}} \rightarrow µ\}$
11 return $H_{\text{best}}$
12 end.

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Figure 5. A graphical representation of Algorithm 3 when $N = 200$ and $\forall t : N(t) = 13$. Logarithmic scales are used.
