The NPC Framework for Building Information Dissemination Networks

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Abstract. Numerous systems for dissemination, retrieval, and archiving of documents have been developed in the past. Those systems often focus on one of these aspects and are hard to extend and combine. Typically, the transmission protocols, query and filtering languages are fixed as well as the interfaces to other systems. We rather envisage the seamless establishment of networks among the providers, repositories and consumers of information, supporting information retrieval and dissemination while being highly interoperable and extensible.

We propose a framework with a single event-based mechanism that unifies document storage, retrieval, and dissemination. This framework offers complete openness with respect to document and metadata formats, transmission protocols, and filtering mechanisms. It specifies a high-level building kit, by which arbitrary processors for document streams can be incorporated to support the retrieval, transformation, aggregation and disaggregation of documents. Using the same kit, interfaces for different transmission protocols can be added easily to enable the communication with various information sources and information consumers.

1 Introduction

The purpose of digital libraries is the archiving of electronic documents and the support of their retrieval and dissemination. We observe digital libraries as “information dissemination networks” (IDNs), the nodes of which are information providers, such as authors and publishers, repositories (e.g. libraries, technical report servers), and information consumers. The links among them may be short-term, as in the case of a literature recherche, or long-term, as for the subscriptions to alerting services and the mirroring of repositories. Such networks must support various document and metadata formats, transmission protocols, and heterogeneous query languages and filters.

In this work, we present a unifying framework for the construction of IDNs. It consists of a simple conceptual model and an event-based mechanism for dissemination and retrieval of information. An implementation of our “NPC” framework provides a building kit consisting of Nodes, Ports and Channels.

Our NPC framework captures the features and functionalities of the many information system types that have emerged to support individual requirements
of information dissemination and retrieval. In its role as an *unifying* framework for heterogeneous functionalities, it must provide the following features:

*Openness and extensibility:* our framework is generic in the sense that support for arbitrary document and metadata formats, as well as support for a wide range of query and filtering languages, transmission protocols, and manipulations of document streams can be plugged in.

*Interoperability* with existing systems is a consequence of the extensibility with various transmission protocols.

*Protocol Transparency:* As Franklin and Zdonik put it in [FZ97], “the character of a link should be of concern only to the nodes on either end”. This means that the model treats different protocol characteristics such as push/pull or periodic/aperiodic in a transparent way. Moreover, different and even mixed models should be supported simultaneously as in the case of a mailing-list server (push) with integrated archive (pull), or in the case of a document repository (pull) offering a notification service for its catalog (push).

*Modularity* is achieved by offering a building kit of elements that can be freely combined to build networks.

*Evolution and Management:* IDNs must be able to adapt to changing demand and supply of information by providing for dynamic reconfiguration. The information dissemination mechanism lends itself naturally to transport the necessary administrative information. NPC ports are able to inspect and to change the configuration of their parent nodes in reaction to events or external requests.

*Filtering, document conversion, (dis)aggregation:* Ports may arbitrarily process the document streams passing through them. This includes the deletion of selected documents (filtering), arbitrary transformations of single documents, combination of documents into aggregated documents (such as archives) as well as disaggregation of documents into multiple documents.

*Scheduling:* Many applications require the scheduled and periodic delivery of information. This is supported in our framework by means of time events.

*Coordination of Demand and Supply:* To support demand-driven delivery of information, the information demand and its termination must be propagated across a network from consumers to information providers. The complementary requirement is the advertisement of information offers to potential consumers.
Security is crucial in all distributed systems. Our model supports the implementation of a large range of security policies. The use of existing authentication and encryption protocols is supported through its extensibility with various transmission protocols and the support for arbitrary document conversions.

Contents The rest of the paper is organized as follows: we present the conceptual model of NPC in Sec. 2. The central protocol for communication between nodes and their ports is presented in Sec. 3. Then we demonstrate in Sec. 4 several applications of the NPC approach. In Sec. 6 we discuss related work. Some extensions of our model are discussed in Sec. 5. We conclude and give an outlook in Sec. 7.

2 Conceptual Model

The principal components of the NPC framework are Nodes, Ports and Channels. Intuitively, documents are transferred between nodes across communication channels, whereby a node may have more than one communication port. To capture the functionalities of an IDN in a generic way, a more elaborate data model is required, though, which is presented in Fig. 2 as an UML class diagram. As can be seen in the left side of the figure, a node may have documents, ports and subnodes (to be explained later) attached to it by means of Entries. Nodes are contained within Servers that are located on physical hosts. Channels are modeled as associations between ports and Resources which specialize into Ports and ExternalResources. The latter may be any external software system offering a well-defined communication protocol; e.g., a Web server/browser, a file system, a database server etc. A Port communicates with its parent node by exchanging Events (c.f. Sec. 2.3) that are archived in an eventHistory. It communicates with resources on other servers via Gateways (c.f. Sec. 2.3). We stress that each node, port, and gateway in an NPC network may have an individual implementation which enables the support for heterogeneous document and metadata formats, protocols, conversions, and filter languages.

Example 1. (Forwarding) A simple NPC application forwards all new documents from a “provider node” to a “consumer node” via a channel. A new document entry is inserted by posting an Insert event to the provider node. A “provider port” at this node consumes the Insert event and communicates its contents to a “consumer port” at the consumer node (via suitable gateway objects understanding a common communication protocol). The consumer port inserts the document by emitting a corresponding Insert event. In addition, the provider port may delete forwarded document entries by emitting Remove events for them.

2.1 Nodes

Each Node stores a set of Entries that are uniquely named within the node. Each entry belongs to a single node and consists of: (i) a metadata record describing
the content of the entry, (ii) the proper content of the entry, which may be either a Document, a Node, or a Port. Hence we speak of document entries, node entries, and port entries. Node entries enable the construction of node hierarchies similar to directory trees in file systems. We require that each server has a unique root node. Then each entry can be uniquely addressed by a URL that consists of the host address of the server and a sequence of entry names describing the path from the root node via a chain of subnodes to the entry.

2.2 Events

Events describe state changes in a node. The state of a node is its content, i.e., its set of entries. Each node keeps a history of events ordered by creation time. Every event posted by a port is received by its node, recorded in the event history, and delivered to all other ports. The two most basic types of events produced by ports are Insert and Remove events. An Insert event causes the node to insert a new entry specified by the event. Similarly, a Remove event causes the node to delete the entry named by the event. Newer events may cancel older events in the event history. For instance, a Remove event for an entry may delete the preceding Insert event for this entry. In addition, a node may have some policy for discarding old events.

Example 2. (Replication) Example 1 can be extended to support mirroring of repositories by transmitting not only Insert events, but also Remove events. Thus both insertions and deletions at the provider node are propagated to the consumer node where they are mirrored. By adding a back channel, bidirectional
mirroring can be achieved. To distinguish originals from replicas each entry is
tagged with its originating node. More complex replication schemes such as the
I2-DSI architecture DBM99 can be supported as well.

Entries can be accessed through the events referring to them. In particular,
the contents of a removed entry may be still accessible through the event
describing its removal, depending on the node implementation. In addition to
EntryEvents referencing an entry, there are further event types such as FlowEvents
for flow control and TimeEvents for scheduling (c.f. Fig. 2).

2.3 Gateways

Each server hosts a number of Gateways which are in charge of communication
with (gateways at) other servers or external resources. Each gateway implements
a specific communication protocol. The communication between the ports form-
ing a channel is routed via gateways as illustrated in Fig. Gateways and ports
communicate via a protocol-specific API. Incoming connections may indicate to
the gateway which port they want to contact by specifying its URL.

![Fig. 3. Implementation of a channel.](image)

2.4 Ports

Ports are persistent processes that enable the communication between nodes
and resources, including the ports of other nodes, via gateways. Most ports are
unidirectional in- and out-ports. In-ports transform an incoming data stream
into a stream of events that are posted to the parent node. Conversely, out-ports
consume an event stream and turn it into an outgoing data stream.

*Example 3. (Filtering, Conversion, Aggregation)* The ports involved in Exam-
ple may be designed to forward/accept only documents matching certain fil-
tering criteria. The ports may convert the forwarded documents, for instance by
applying XSL stylesheets to XML documents. The provider port may even pack
several documents into archive files which are unpacked by the consumer port.
Properties of a Port: (i) Ports may be in-ports, out-ports, or bidirectional. (ii) Their operation may be periodic or a-periodic. (iii) The communication with the external resource may follow the push-, pull-, or a mixed model. We call the combinations in-port + push and out-port + pull externally driven, the combinations in-port + pull and out-port + push internally driven.

Example 4. (Push vs. Pull) Example can be implemented using either push- or pull-mode communication. In aperiodic push-mode, the provider port is triggered by the Insert events posted to the event history of the provider node. For each Insert event the provider port feeds the new document to the consumer port. In periodic pull-mode, the consumer port is triggered by time events at the consumer node to poll the provider port for new documents. Only if triggered by the consumer port does the provider port request the next insert events from the provider node and transmit the referred documents to the consumer port. An application of this scheme would be to periodically fetch new metadata records from an OAI repository.

Event filters. For security and efficiency reasons, ports need not receive all events nor should they be able to emit arbitrary events. Each port entry contains as metadata two filter expressions, the input and the output filter. They are interpreted by the node to restrict which events the port may receive and produce, respectively. Proper in-/out-ports can be enforced by blocking output/input filters. Different node implementations may support different filter languages of varying expressiveness. Filter conditions may reference properties of events as well as metadata and content of the entry an EntryEvent refers to.

Metaports. Ports that are restricted to receive or generate Insert or Remove events for document entries only are called plain ports. All other ports we call metaports. Only metaports are allowed to inspect, insert, or delete port entries and subnode entries. Metaports provide a reflexive and introspective mechanism for evolution and remote management of NPC networks. Metaports are called admin ports if their filters allow arbitrary events to pass. For security reasons, communication with metaports (and admin ports in particular) should be protected by suitable authentication and encryption techniques.

Security Policies have to be enforced by choosing appropriate input/output filters. Basic objectives of such a policy are to ensure that plain ports can only read or write document entries and that meta ports cannot insert port entries which violate the security policy. Further objectives may be to hide certain entries from certain ports or to restrict which ports can delete certain entries.

2.5 Channels

NPC channels are unidirectional communication relationships between nodes. A channel transmits a stream of data items from a source node to a target node via a port and a gateway at each end of the channel (c.f. Fig.[3]). A channel may also connect a node to some other external resource. Bidirectional streams between nodes are implemented as pairs of channels.
Document channels transmit streams of documents. Document channels are generalized by entry channels that copy entries from the source node to the target node. Entry channels allow to transmit also non-document entries. Event channels generalize entry channels further by transmitting arbitrary event streams which may also propagate deletions of entries.

Ports may be created without being part of a channel and they may survive the termination of the channel they are participating in. Ports are intended to participate in no more than one channel at a time, except in cases like bidirectional ports. Instead of multiple channels ending in the same port, the advisable method is to create a dedicated port for each new channel.

To establish a new channel between a source node and a target node, a source port and a target port need to exist. One of these ports contacts the other port (via suitable gateways). Ports may delegate incoming connections to other ports and may even create new ports to this purpose. Thus a node can support arbitrary numbers of incoming or outgoing channels with dedicated ports. Various policies for connection pools can be implemented as well this way.

3 Unifying the Push- and Pull-Model

The communication between a node and its ports via the event history is illustrated in Fig. 4. This diagram depicts an in-port that currently deletes entry 1 by writing a delete event and an out-port that is just reading an earlier event describing the insertion of entry 2. Both ports are communicating with external resources. The details of the interaction between a port and the event queue are specified by the node/port protocol that is introduced in the sequel of this section.

As argued in the introduction, information dissemination frameworks need to support various communication models. In the NPC framework, both push-model and pull-model communication are generalized into the node/port communication protocol. The communication between a node and its ports is entirely event-based. A port can only post events to its parent node that pass its output filter. On arrival at the node, events may trigger state changes such as insertion or removal of entries. By default, every event is entered into the node's event history. FlowEvents control the delivery of events to a port.

The sequence diagram in Fig. 5 illustrates the flow control in the node/port protocol. Each port entry stores a receive flag to indicate whether the port is currently accepting input events. The port may set this flag by issuing a Receive event which is not added to the event history (1). After the receive flag has been set, the node starts delivering events from the event history to the port (2). Only events passing the input filter of the port entry are delivered to this port. Each port entry also contains a cursor pointing into the event history to keep track of the events already delivered. The node implementation should guarantee a fair delivery of events, i.e., eventually every interested port will receive every event. Nodes may also implement delivery policies that honor Quality-of-Service requirements stated in the metadata of port entries.
A port may suspend the delivery of events temporarily by issuing a Suspends event which clears its receive flag (3). After having issued a Resume event (4) the receive flag is set again and the port continues to receive events (5). After the cursor of a port has reached the end of the event history, the node issues a Suspends event to the port which clears its receive flag (6). If the port wants to wait for future events, it has to emit again a Resume event (7). If the cursor is still at the end of the event history at this time, the Resume event is posted to the event history which may trigger interested in-ports to post events matching the input-filter of the out-port (8). Only those events that actually pass the input-filter are delivered to the out-port. A port can terminate the delivery of events by issuing a Close event (9). This cancels any preceding Resume events and is received by interested in-ports which in turn may stop event delivery.

An important advantage of the node/port-protocol is its support both for the push and pull communication model: In the push-model external producers send data to in-ports of a node which post it in form of Insert events. Out-ports of this node receive these events and forward the data to external consumers, including in-ports of other nodes. Thus information can be pushed from providers to consumers across a NPC network.

The pull-model requires more coordination: An external consumer connected to an out-port causes it to emit a Receive event. After having received all historic events the out-port issues a Resume event which is received by all interested in-ports (c.f. Fig. 5). These in-ports may retrieve data from external producers and
post it in form of Insert events that are received by all out-ports with matching input filters, including the out-port that has triggered the import. This enables consumers to pull information from providers across a NPC network. In-ports may achieve finer flow control by also monitoring Suspend and Close events.

4 Applications

In this section we present some example applications and how they can be implemented using the NPC approach.

Mailing Lists. A mailing list can be implemented using a single node (Fig. 6). An active “administration” in-port periodically fetches (un-)subscription messages via some gateway from an external mail server. The administrator port transforms each (un-)subscription message into an insert (remove) event of a “subscriber” out-port. A “submission port” periodically fetches submissions from the mail server. For each received message it emits an Insert event which is received by the subscriber ports and sent to each subscriber using a gateway to the external mail server. Subscriber ports may convert messages into a format preferred by the subscriber and bundle several messages into message digests.

All messages are archived in the mailing list node (unless a “garbage collector” port is deleting old messages). In paragraph “Simple Document Server” below we explain how to add a Web interface for this archive.
Alerting Systems. The mailing list application can be easily extended to build alerting systems that filter the incoming documents on behalf of their subscribers. Each subscriber port uses its input filter (and possibly internal post-processing) to forward only those documents the subscriber is interested in. To handle a large number of subscriptions efficiently, the node may index the input filters of its subscriber ports to deliver incoming events only to matching subscriber ports (c.f. [YGM94]).

Hierarchical Document Classification. Documents can be classified into a subject hierarchy by modeling the subject hierarchy as an NPC network as depicted in Fig. 7. Each node represents a subject class, its subnodes represent its subclasses. For each subnode there exists an out-port that forwards messages to an in-port of the subnode. This out-port implements a classifier that permits only those documents belonging to the class represented by the subnode. Note that classifiers need not necessarily be automated, they may as well prompt a human expert for advice.

![Fig. 7. A classification hierarchy for document filtering.](image)

Incoming documents are fed into the root node of this hierarchy and are distributed to those nodes representing the classes they fit.

Simple Document Server. A node storing a document collection can act as a simple (HTTP) document server. A document request from a client is received by an admin-port via a HTTP gateway which inserts a dedicated “request port” into the node. The request port specifies the name of the requested document in its input filter. After receiving the recorded Insert event for the requested document entry, the request port reads the document stored in this entry and sends it to the client. For a missing document the request port receives a Suspend event instead and sends an error message to the client. In both cases, the port removes itself from the node by emitting a Remove event for itself.

Information Retrieval. Information retrieval from a document repository is a generalization of the simple document server application mentioned above. Instead of request ports we speak of “query ports” in this context. Instead of a single document, a query port may return a set of documents.
The input filter of a query port preselects potential result documents. The query port post-processes the events passed by the filter depending on the expressiveness of the node’s filter language. Each matching document is returned to the client. A node may maintain an internal index for its event history and use it when evaluating new filter expressions against existing events.

The query port may also collect and order the matching documents according to some relevance measure. The query node receives a **Suspend** event after the event history is exhausted. It then delivers the result as a ranked list to the client either in one part or in several portions of fixed size.

**Query Mediation.** In networked information retrieval, a query from a client against a mediator is processed by forwarding it to several source repositories. Wrappers translate between the mediator query language and the heterogeneous source query languages. They also convert the returned results into a common format. The mediator returns the combined results to the client.

In NPC, a query mediator can be implemented as follows: Each query port entry states its query in its metadata. For each source repository there exists a “query translator port” in the mediator node which monitors the **Receive** events posted by query ports, analyzes each query and decides whether to delegate it to its source repository. In this case it inserts a “wrapper port” supplied with the name of the query port repository-specific translation of the query. The query port name is also stored in the wrapper port metadata. The wrapper port queries its source repository, posts the received results (tagged with the query port name), and finally removes itself from the node.

The query port subscribes to **Insert** events for document entries tagged with its own name, removes them from the node, and returns the documents to the client. It may also filter, collect, sort, and group the results before returning them. The query port also monitors insertions and removals of wrapper ports to check whether all wrapper ports for the query have terminated.

If the client aborts the query, the query port removes all wrapper ports for this query. Each wrapper port is notified of its own removal by a **Remove** event which triggers it to propagate the abort to its repository and then to terminate. Finally, the query port removes itself and terminates as well.

**Further application areas** include workflow management (using a document-flow centered view), hierarchical document filtering, network management, Web-caching, and peer-to-peer information dissemination networks.

## 5 Extensions

### 5.1 Exclusive consumption of events

In certain applications it is important to deliver an event exclusively to a single port. When a node receives an event, it returns a flag that determines whether the event is consumed by the port or delivered to further ports. By attaching a priority to each port, a partial ordering for the event delivery is introduced. Ports of equal priority may be ordered in a nondeterministic way.
5.2 External Security Policies

In the NPC model presented so far, every port is free to communicate with arbitrary resources via suitable gateway objects. Input and output filters control only the information exchange between nodes and ports. The right place to control the communication between ports and external resources or ports is at the gateway objects.

External security policies which restrict this communication may be defined as sets of firewall rules similar to those used by typical firewall software. Such security policies may be either global or are attached as metadata to port or subnode entries. A security policy attached to a subnode entry applies to all ports in the tree rooted in the subnode entry and is subject to refinement by security policies in nodes or ports deeper within this tree.

This approach can be extended to control intra-server communication by requiring that all communication between ports on the same server has to be routed as well through gateway objects.

5.3 Dynamic subscriptions

The input filter of a port serves a twofold purpose: it reflects the security policy of the node and the interests of the port. While the security policy can be considered to be static, the interests of the port may change over time. Moreover, a port may want to maintain several subscriptions for the event queue that it can control independently (via receive, suspend, resume, close events).

For instance, a port may initially subscribe to a future time event and only after receiving this time event it will subscribe to other events.

To cater these needs we propose to change the node/port protocol as follows: two parameters are added to receive events, a filter expression and a subscription name chosen by the port. The subscription name is used to reference the subscription in suspend, resume, and close events. Subscription names need to be unique only within each port.

In the example, the port would first emit a receive event specifying a filter condition for a future time event. After receiving this time event, the port would emit a close event for this first subscription and a receive event specifying the second subscription.

6 Related Work

Message-oriented middleware such as the Java Messaging Service (JMS) standard [Mic99], IBM MQ-Series [MQ-02], Oracle Advanced Queuing [Ora02], and Talarian SmartSockets [Sma00] offer message queues and topics to connect supplier and consumer clients. Extra client-side programming is needed to connect queues or topics to a larger network. Clients may specify filter-expressions on the message header fields in a simple and fixed filter language. The object-based CORBA notification service [CNS] does not have these shortcomings. Moreover
it supports the propagation of demand for and the supply of certain event types. However, this mechanism is external to the event propagation mechanism and it does not allow the propagation of more complex queries as in NPC. All mentioned systems are missing introspective means for management and evolution as in our model. Channels in our model could be based on these systems.

Siena [CRW01] is a push-model publish/subscribe system for alerting within a wide-area network. It offers scalability by distributing filters over servers within the network and saving bandwidth by filtering close to the event sources and bundling similar subscriptions. Siena is modular and offers sophisticated filtering mechanisms including dynamic configuration and distribution. It lacks openness, document stream transformation, and scheduling.

Elvin4 [SAB+00] is an alerting system based on a client-server-client architecture. It is open for different transport, security, and marshalling mechanisms. Elvin4 is not intended to scale to wide-area networks or to go beyond publish/subscribe systems. Its quenching mechanism prevents the publication of events for which there exists no consumer. This is similar, but less general than the query-propagation mechanism offered by our model.

The Information and Content Exchange (ICE) protocol [ICE00] is an XML-and HTTP-based standard for content syndication that could be supported by our framework. Providers advertise information delivery offers which consumers may subscribe to. Both push- and pull-delivery is supported.

Alerting systems based on Continual Queries such as CQ [LPT+99] and WebCQ [LTBP02] have been developed to track changes in databases and on Web sites. The focus here is on efficient detection and meaningful summarization rather than on openness or modularity. CQ systems could be used as information providers within the NPC framework.

For a survey on further event-based systems, see [RK98].

7 Conclusion and Outlook

The NPC approach presented here offers an unifying framework for building a wide range of information dissemination networks built from nodes, ports, and channels. It is open for heterogeneous protocols, filtering languages, document and metadata formats by allowing different node and port implementations within the same IDN. Moreover, existing document processing technology can be easily incorporated into nodes and ports which enables all kinds of filtering operations, format conversions, and (dis)aggregation operations. Due to its openness, NPC is also interoperable with a wide range of existing IDS. By using a general event-based node/port communication protocol, the heterogeneity of the underlying port/port communication protocols is hidden. In particular, it supports both supply-driven (push-model) and demand-driven (pull-model) information dissemination across an IDN. Other important features are dynamic and reflexive configurability, support of scheduling, and of security policies.
The generality of the NPC approach supports various applications, from newsgroups to query mediation, and facilitates the development of innovative information dissemination applications.

Due to space limitations several interesting extensions had to be omitted, e.g., complex events, exclusive consumption of events, dynamic subscriptions, and external security policies. A Java implementation of the node/port protocol is available at [Fau03]. We are currently extending it to a full-fledged IDN construction kit.

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