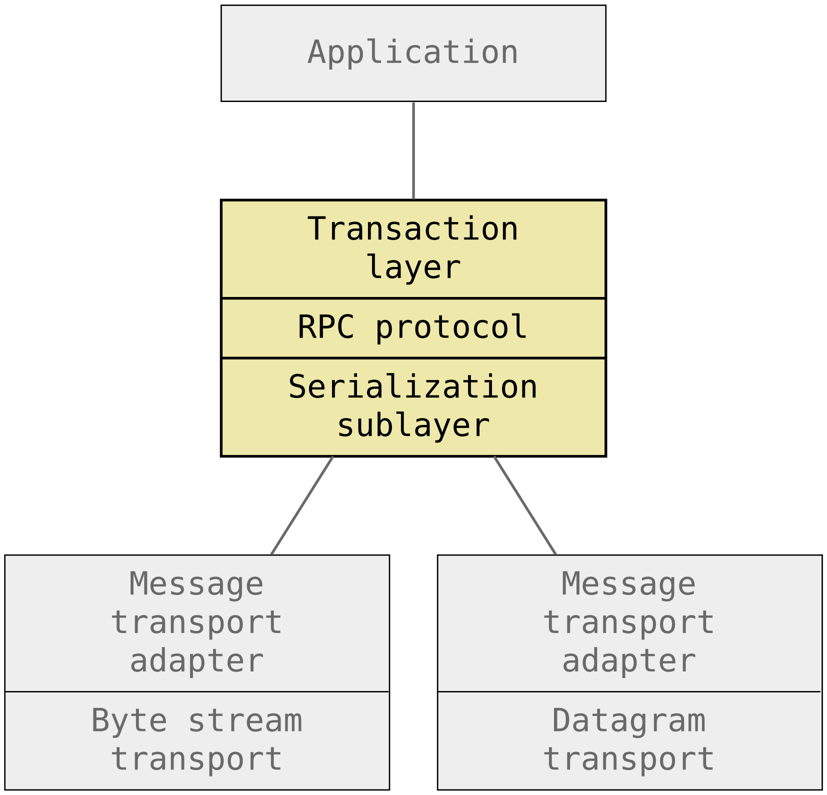
Lighweight Remote Procedure Calls

The solution can be split into three main functional levels:

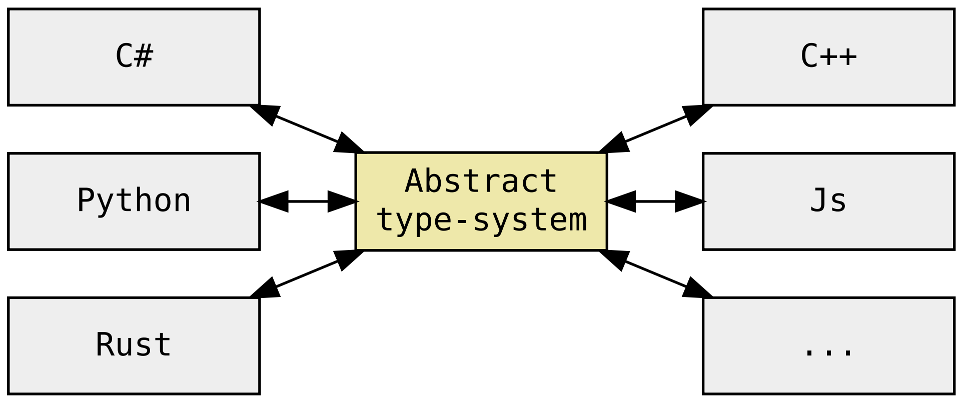
- A platform and language agnostic serialization format that enables transforming structured data to and from a byte sequence.
- An established protocol that uses these serialized messages to implement remote method invocation.
- An (optional) top-level transaction layer that standardizes some common session lifetime handling patterns.



Serialization

The part of the solution that is responsible for serialization utilizes a strongly typed data representation. It defines an abstract (source language independent) data type system where each message has an associated type that defines its logical structure and the corresponding serialization rules.

The structure of the data is represented at the endpoints in a source language specific way, that can be different on each end of a connection and an abstract data type may have multiple possible source language counterparts. This means that only the serialization type system needs to harmonized with the supported source languages not each language with all of the others.



Messages can only be (de)serialized knowing their type - in other words - the messages themselves are not self-describing. The purpose of this serialization format is to serve the needs of the RPC protocol, the messages are not meant to be processable out of context. It has obvious performance benefits to spare the extra resources that could be used to send meta-information that must already be known by the intended target (i.e. the contract).

Type system

All types in the abstract type system can be represented as a tree, whose nodes can be aggregates, collections, typed method handles or primitive types (at the leaves only).

Nodes

	Children	Textual representation
Integral	-	**i1**, **u1**, **i2**, **u2**, **i4**, ...
Aggregate	Members	{*T*, *U*, *V*, ...}
Collection	Elements	[*T*]
Method	Arguments	(*T*, *U*, *V*, ...)

Integral primitives

There are eight integral primitives, representing signed/unsigned integral values of 1, 2, 4 and 8 bytes.

Aggregates

An aggregate is a compund data record consisting of a list of values with predefined types and order between them. It serves the same purpose as (and can be mapped to) a C/C++/C# *struct* or similar language construct in other languages.

The aggregate type-node can have zero or more children.

Collection

A collection is a homogenous batch of data containing an arbitrary number of elements. Although the count of its elements is not known, the type of them must be defined in advance.

The collection type-node has exactly one child.

Method handle

A method handle is a type that has associated children type-nodes that represent the arguments of a function call. Contrary to the aggregate, the value it represents is not the values of the children themselves but a single handle that can be used to invoke a method that takes exactly those arguments.

The method type-node can have zero or more children.

Type signatures

For every tree of type-nodes exists a mutually unique string representation, called its type signature. The method of generating it from the type-tree is based on a depth-first traversal and per-node type specific operations.

Integral primitives

The string representation of an integral primitive is a literal of two characters:

- the first of which represents signedness: **u** for unsigned and **i** (as integer) for signed;
- the second is the size in the number of bytes used to store the value, it can be 1, 2, 4 or 8.

For example **i1** is the signature of a sigle byte signed integer (C/C++ *char*, C# *sbyte* or Java *byte*)

Aggregates

The signature of an aggregate is the type signature of its children (in order), separated by a comma **,** (without white space on either side) between curly brackets.

For example **{i4,u8}** the signature of is an aggregate that is made up of a four byte signed integer and an eight byte unsigned integer - in that order.

Collection

The type signature of a collection is that of its element type between square brackets.

For example **[i1]** is the signature of a collection of one byte signed integers - which could be interpreted for example as a character string by the endpoints.

Method handle

The signature of a method handle is the type signature of the arguments' types (in order), separated by a comma **,** (without whitespace on either side) between parentheses (round brackets).

For example **(u4, [i1])** is the signature of a handle for a method that takes a four byte unsigned integer and collection of signed single bytes - in that order.

Encoding

The serializiation and deserialization process of a value is generated by a depth-first traversal of its type tree. When encountering a node during the traversal the apropriate coding step generates/consumes raw data in a sequential manner.

Integral primitives

Basic integral values are serialized using full width, least-significant-byte-first (little-endian, LSB first) encoding, which is very close to the most natural in-memory representation of modern CPUs.

An additional requirement for efficeint CPU acces would be aligned base addresses for multi-byte values. But ensuring proper alignment could only be done by adding padding bytes in the general case, which is acceptable for in-memory usage but can easily be too wasteful for an over-the-wire format in certain bandwidth constrained usecases.

Aggregates

The aggregate nodes do not have explicit encoding. Aggregate values are serialized as a sequence of their constituent member values - in order, without no additional framing before, between or after the members.

Variable length encoding

Several data items are serialized using a variable length encoding, that assigns a shorter representation to smaller numbers. The serialization engine uses only 32-bit unsigned values encoded this way. These four byte values are encoded into 1-5 bytes based on the numerical value.

The encoding produces one byte at a time for 7 bit chunks of the original value. The least significant bits of the output byte are the inputs bits, the top bit signifies if there are more chunks following.

During encoding the least significant part is processed first, the last 7 bits are taken from the input:

- if the remaining value is zero, then there are no more parts required, so the output is the 7 input bits at the lower part and a zero at the topmost bit, the processing stops.
- if the remaining value is not zero, then there are more parts to come, so the output is the 7 input bits at the lower part and a one at the topmost bit. The processing continues the same way for the next 7 bits of the input.

Value range	Input bits (as 32-bit word)	Output bytes (in proper sequence)
0 <= x < 128	0000000000000000000000000aaaaaaa	0aaaaaaa
128 <= x < 128^2	000000000000000000aaaaaaabbbbbbb	1bbbbbbb 0aaaaaaa
128^2 <= x < 128^3	00000000000aaaaaaabbbbbbbccccccc	1ccccccc 1bbbbbbb 0ccccccc
128^3 <= x < 128^4	0000aaaaaaabbbbbbbcccccccddddddd	1ddddddd 1ccccccc 1bbbbbbb 0aaaaaaa
otherwise	aaaabbbbbbbcccccccdddddddeeeeeee	1eeeeeee 1ddddddd 1ccccccc 1bbbbbbb 0000aaaa

This encoding is sometimes called LEB128 which stands for little endian base 128, as the 7 bit chunks are the digits in the radix 128 numeral system.

Collections

Collections are encoded as sequence of their element values prepended by the number of contained elements using the variable length encoding specified above.

Method handles

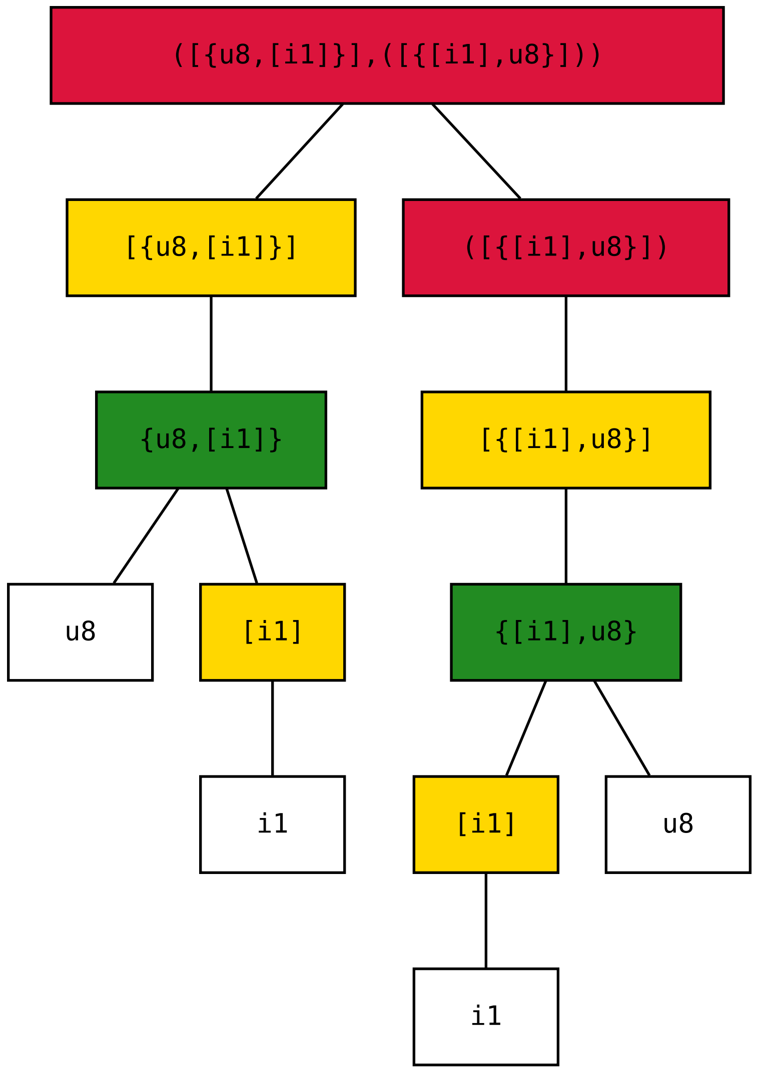
Method handles are unsigned 32-bit values used by the upper protocol layer as an identifier for the actual methods to be invoked. It is using the variable length encoding specified above.

Example

A method that takes a bunch of number-string pairs, and returns string-number pairs via a callback could be represented by this signature:

```
([{u8,[i1]}],([{[i1],u8}]))
```

Which is equivalent to this type tree:



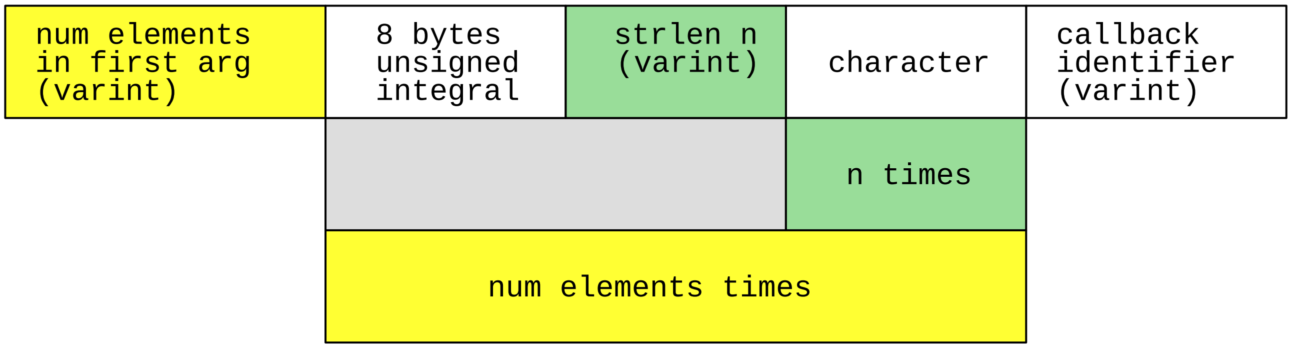
Type-nodes in the figure are color coded based on their kind:

- Red nodes are method handles,
- Green are aggregates,
- Yellow means collection,
- The rest are integral primitives.

A value of this type is a 32-bit unsigned integral which is encoded using the variable length encoding scheme if transfered.

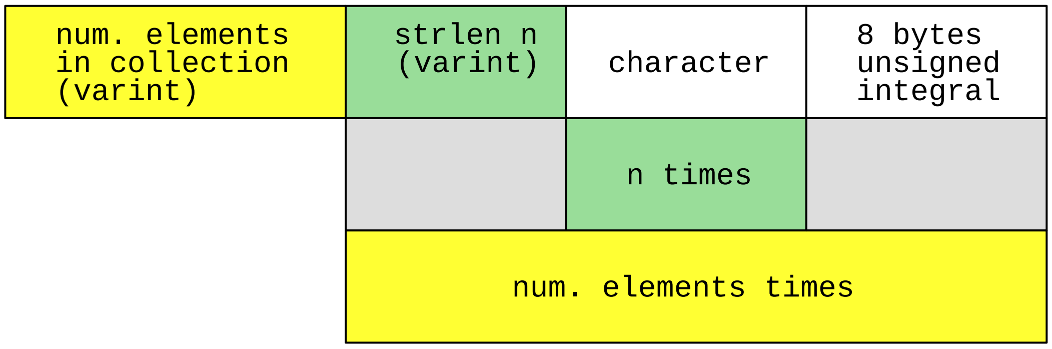
However if a method with the this signature is invoked its arguments are serialized as an aggregate of the arguments, like this:

```
{[{u8,[i1]}],([{[i1],u8}])}
```


num elements in first arg (varint)
8 bytes unsigned integral
strlen n (varint)
character
callback identifier (varint)
n times
num elements times

The data used in the invocation of the callback has the following byte sequence format:

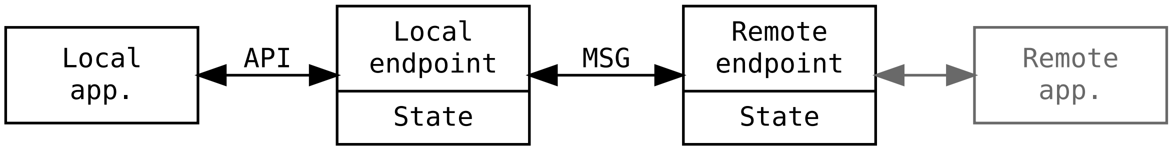
```
{[{[i1],u8}]}
```


num. elements in collection (varint)
strlen n (varint)
character
8 bytes unsigned integral
n times
num. elements times

Protocol

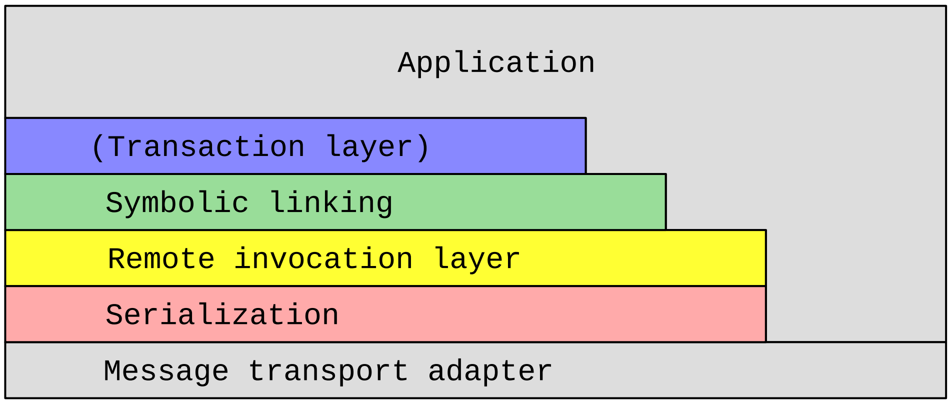
The RPC protocol can be defined in terms of endpoint state and interactions with the application and the remote endpoint.

The direction of connection establishment is irrelevant, the two ends of the connection function in exactly the same way.



The operation can be further divided in two logical layers:

- Basic remote procedure invocation,
- Signature based symbolic method lookup (or linking).



Remote procedure invocation layer

The lower protocol layer enables the remotely triggered execution of methods registered by the local application and the upper protocol layer.

Endpoint state

The endpoint stores internal state regarding registered methods and the associated identifiers required for remote invocation.

For each registered method there is a 32-bit unsigned numeric value that identifies the method uniquely on the endpoint. During assignment of an identifier the engine chooses the smallest possible value while also avoiding reuse as to circumvent confusion arising from different methods being registered at different times.

Protocol messages

Every message exchanged by the endpoints follows the same format and has the same effect as far as the invocation layer is concerned. Each message triggers the execution of a registered method at the receiving end. It contains the identifier for the method to be invoked at the receiver. The identifier is a key in the registry of of methods, so it either has to:

- identify a pre-arranged or well-known method or
- be retrieved earlier from the remote endpoint.

The identifier of the method is the first item in the message followed by the arguments to be used for the invocation. These values are serialized as if they were an aggregate of a method handle and all the arguments of the method, formally it has the type signature:

```
{(T...),T...}
```

Where **T** is the list of argument types for the target method, and *...* means list expansion. For example if a method with a string argument is to be invoked, it becomes:

```
{([i1]),[i1]]}
```

Upon receiving a message the endpoint deserializes method identifier at the beginning of the byte sequence and using that information it can look up the corresponding method. Using that knowledge it can deserialize the arguments and execute the target.

Application interface

The appliction is provided with the following operations regarding basic remote invocation functions:

- **install** a local method to be available for remote invocation,
- **uninstall** a previously registered method,
- **call** a remote method registered by the remote application at the remote RPC endpoint.

Symbolic method lookup

Cross-source-language type safety can be achieved by utilizing method signature based symbolic method lookup. The signature of a public method consists of a textual name and the type signature of a handle to that method.

For example a method named *foo* receiving a list of strings has a signature:

```
foo([[i1]])
```

In order for an application to be able to utilize some remotely provided functionality it must known the semantics of that service, including the relevant structure of the data to be sent during invocation of remote methods. Thus, it can be assumed that it is able to issue request using fully qualified method signatures as a basis for looking up remote methods. It is also valid a assumption the other way around: the public interface of service can only be specified in terms of well defined data structures.

To achieve type safety at the abstract level, it is enough for both ends to adhere to the proper data handling procedures waranted by the signature of interface methods.

Related endpoint state

The endpoint manages a registry of published methods available for lookup using method signature. Exported procedures must be available for remotely triggered execution as well, so they must be also registered at the invocation layer. Thus, all publicly available methods bear a valid identifier assigned to them as well.

Protocol messages

A public method can be looked up via a proper remote call, registered with a **well-known identifier 0**. This is the *lookup* method, although not needed to be registered as a public method. It has the theoretical signature:

```
lookup(u8,(u4))
```

The *lookup* procedure looks for a published method whose signature has a corresponding FNV-1a hash (64bit variant) value that matches its first argument and provides the result in the form of a callback issued to the method identified by its second argument. If the lookup was succesful it passes the identifier corresponding to the requested symbol as a normal unsigned 32-bit value to the callback as its first and only argument. In case of failure it return the maximal value of a 32-bit unsigned integer (0xffffffff or -1u).

Application interface

The appliction is provided with the following operations regarding signature based symbolic lookup:

- **provide** a local method as the definition of a symbol,
- **discard** the previously provided method for a specific symbol,
- **lookup** the handle for a symbol provided by the remote application at the remote RPC endpoint.

Transaction Layer

TBD

Message Transport Adapters

The serialized messages can be transported between the endpoints in any way considering that:

- The serialization layer does not implement any error detection or correction mechanisms.
- Depending on the implementation it may be beneficial or even required to buffer the whole message in advance before trying to process it.

- Also for a byte stream based transport it is beneficial to artificially (re)store message boundaries, without depending on the (de)serializer.
  Although concatenation of serialized messages is uniquely deserializable assuming that the endpoints only try to execute methods that are actually registered and the messages contain the arguments serialized in the way it needs to be done, handling the failure to meet these requirements gracefuly without known message boundaries is not possible.

It also worth noting that the RPC does not encrypt or authenticate messages by itself, this functionality can also be implemented in the transport adapter layer if required.

There are several properties of the interaction structure between the (de-)serializer and the trasport provider that may simplify implementation:

1. during serialization the length of the output byte sequence is known in advance relative to the generation of it (but only after the actual values to be written are known in general);
2. the deserialization algorithm does not require the length of the input byte sequence to be exact or even known in advance;
3. the processing of subsequent messages are independent at a low level. The application may impose arbirarily complex interdependencies though.

These properties allow for the use of simple message framing where the frame header can be constructed before writing the serialized payload, so messages can be generated in left-to-right, streaming fashion. The frame can also contain padding as required by some encryption algorithms. The frames can encode the length of - the possible padded - message to facilitate artificial boundary restoration. If message boundaries are known to the transport provider then, in case of a processing failure the next message can still be processed, although in a real life situation the application-level session state gets compromised at this point, but at the very least the connection can be closed gracefuly, which may provide invaluable diagnostic feedback.

Any subset of these options can be implemented without affecting the main functionality.

Interoperability-test byte stream adapter framing

There is a common framing scheme used to test the interoperability of implementations using byte stream channels. The adapter uses a framing that consists of a single-field header, prepended to the payload. The header contains the length of the payload, encoded on-wire using the variable length (LEB128) encoding used for several tasks by the serializer as well.

This framing can be used to transfer messages over a duplex or dual simplex (like TCP) byte stream channel without any additional out-of-band signaling.

Although the interop test uses this framing over a localhost TCP connection, it can be used for other purposes and over other types of byte stream transport namely:

- serial connection between physical devices,
- dual unix pipes between processes, for example as a machine interface via standard input and output redirection,
- two in-memory FIFO buffers in shared memory as an operational high performance interface between services.