Network Serialization and Routing in World of Warcraft

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What is JAM?

Joe's

Automated

Messages

The Problem

Game servers need to communicate with each other

Manual serialization is error-prone

```
void Serialize(stream &msg)
{
    vector<int> values;
    // ...Fill in some values...
    msg << values.size();
    for(int i = values.size(); --i;)
    {
        msg << values[i];
    }
}
```

```
void Deserialize(stream &msg)
{
    vector<int> values;
    int size;
    msg >> size;
    values.resize(size);
    for(int i = size; i--;)
    {
        msg >> values[i];
    }
}
```

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    vector<int> values;
    // ...Fill in some values...
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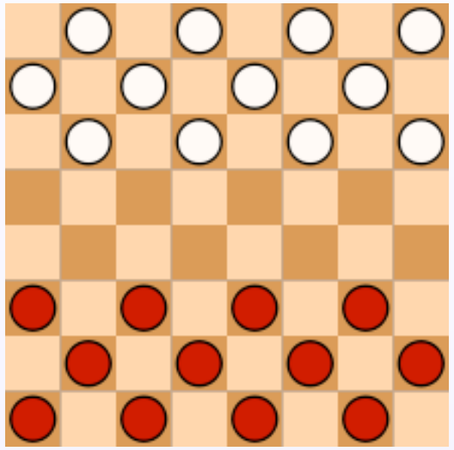
```

Manual serialization doesn't scale



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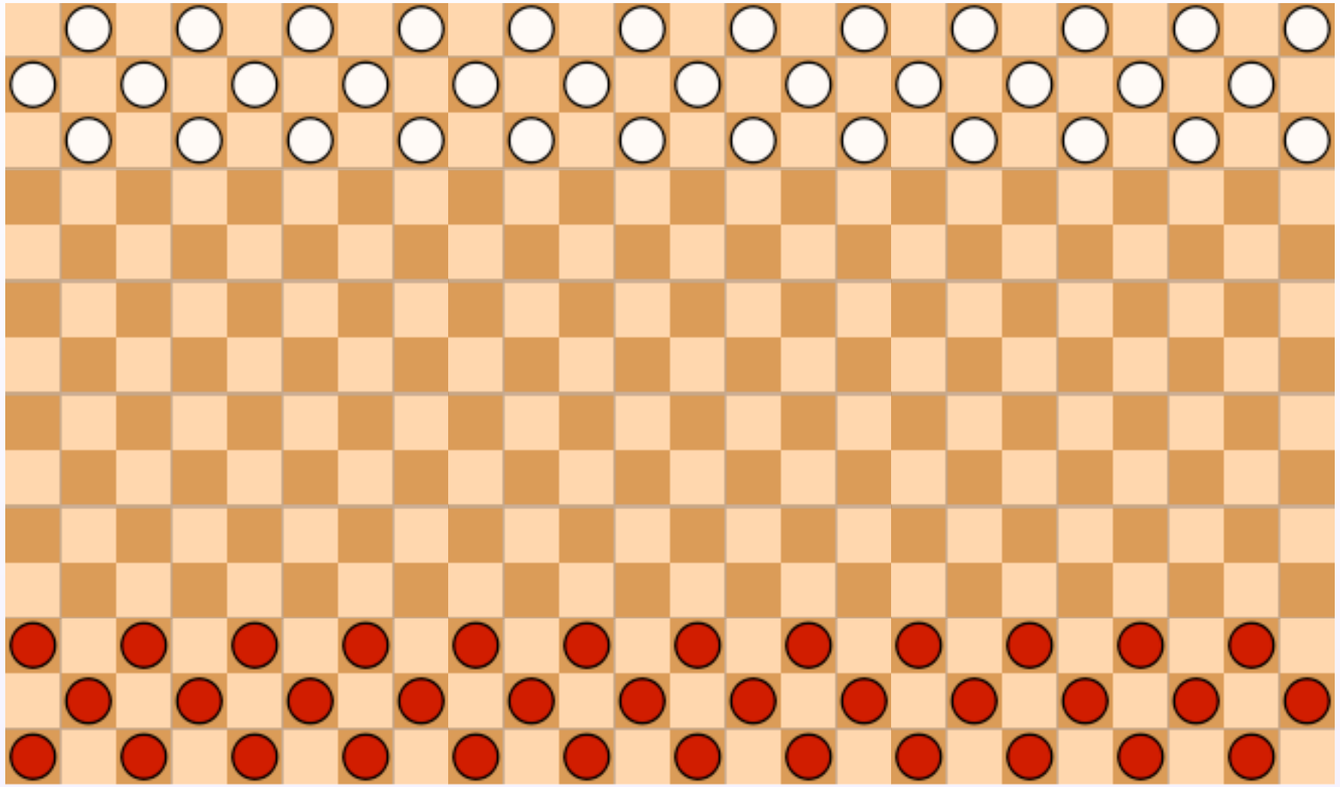
World Of Checkers



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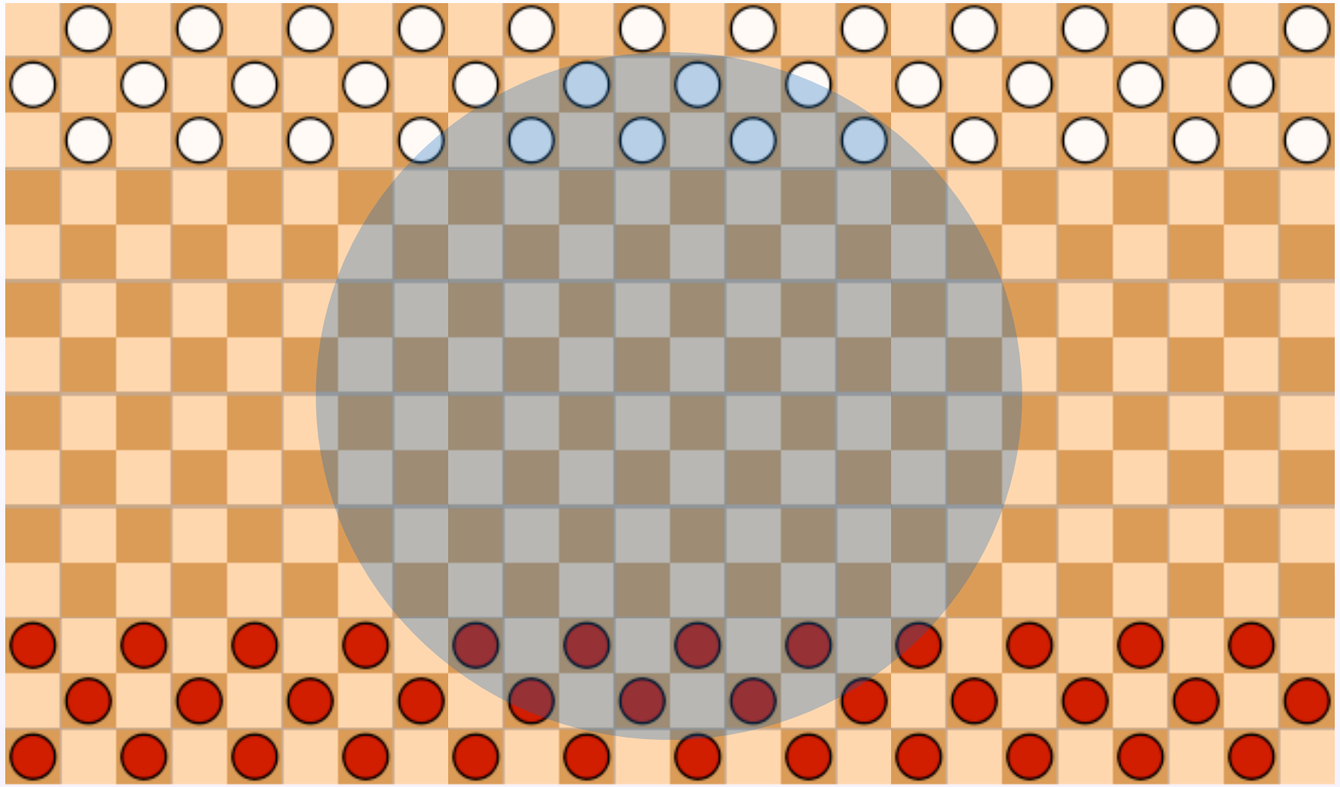

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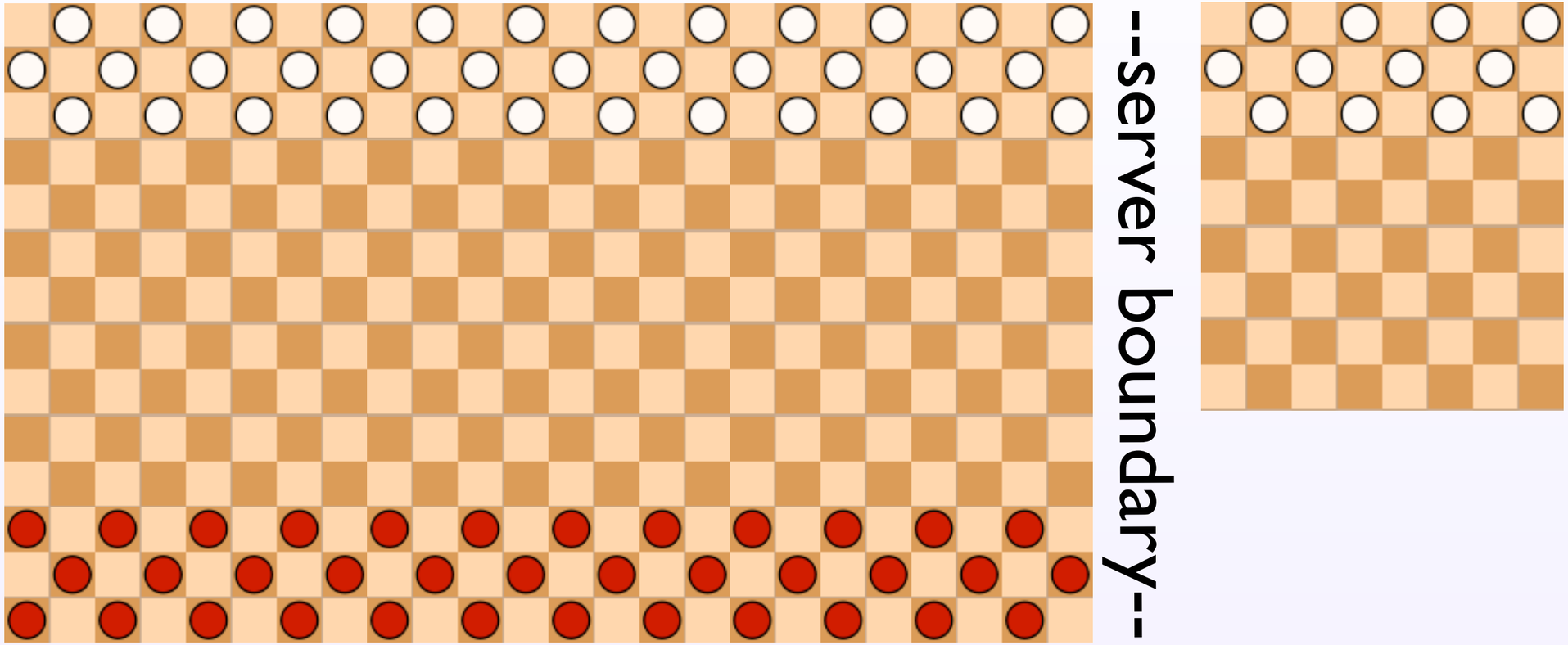

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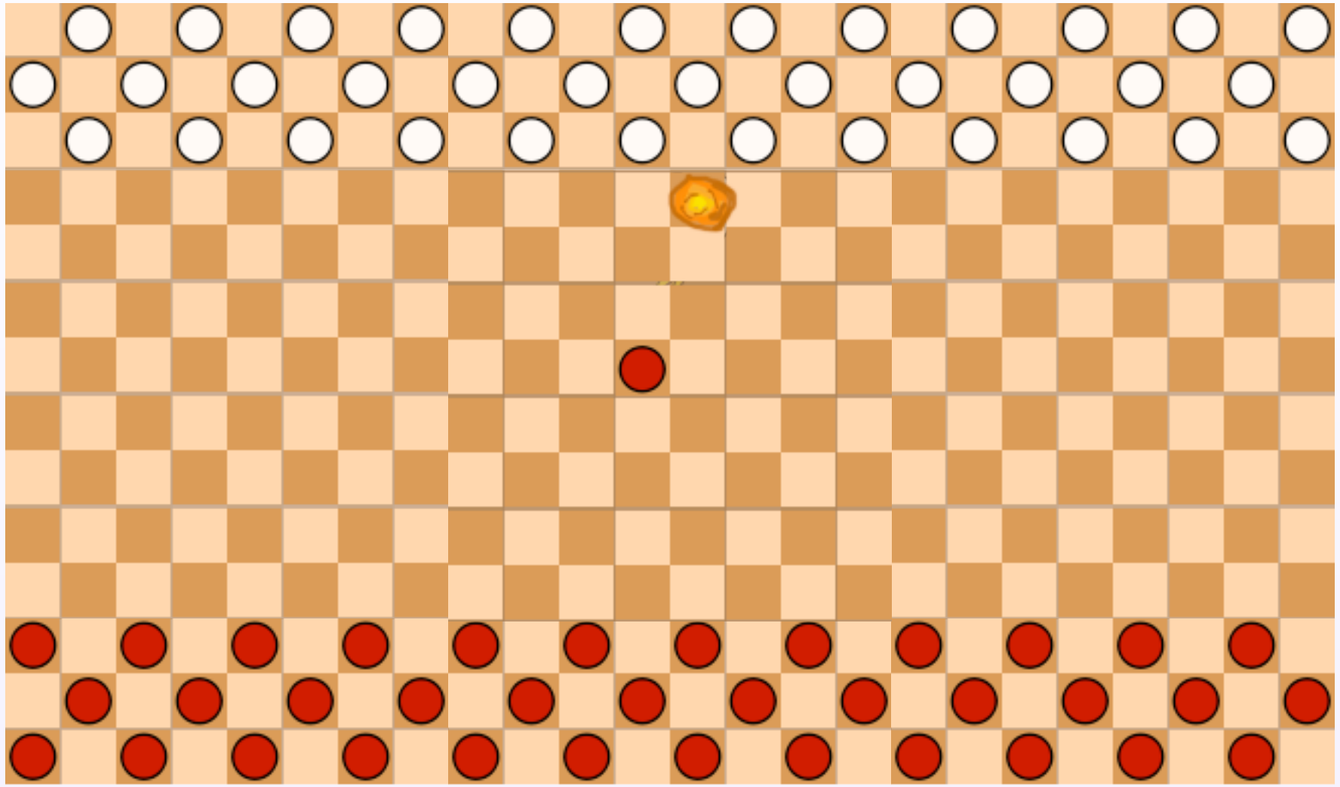

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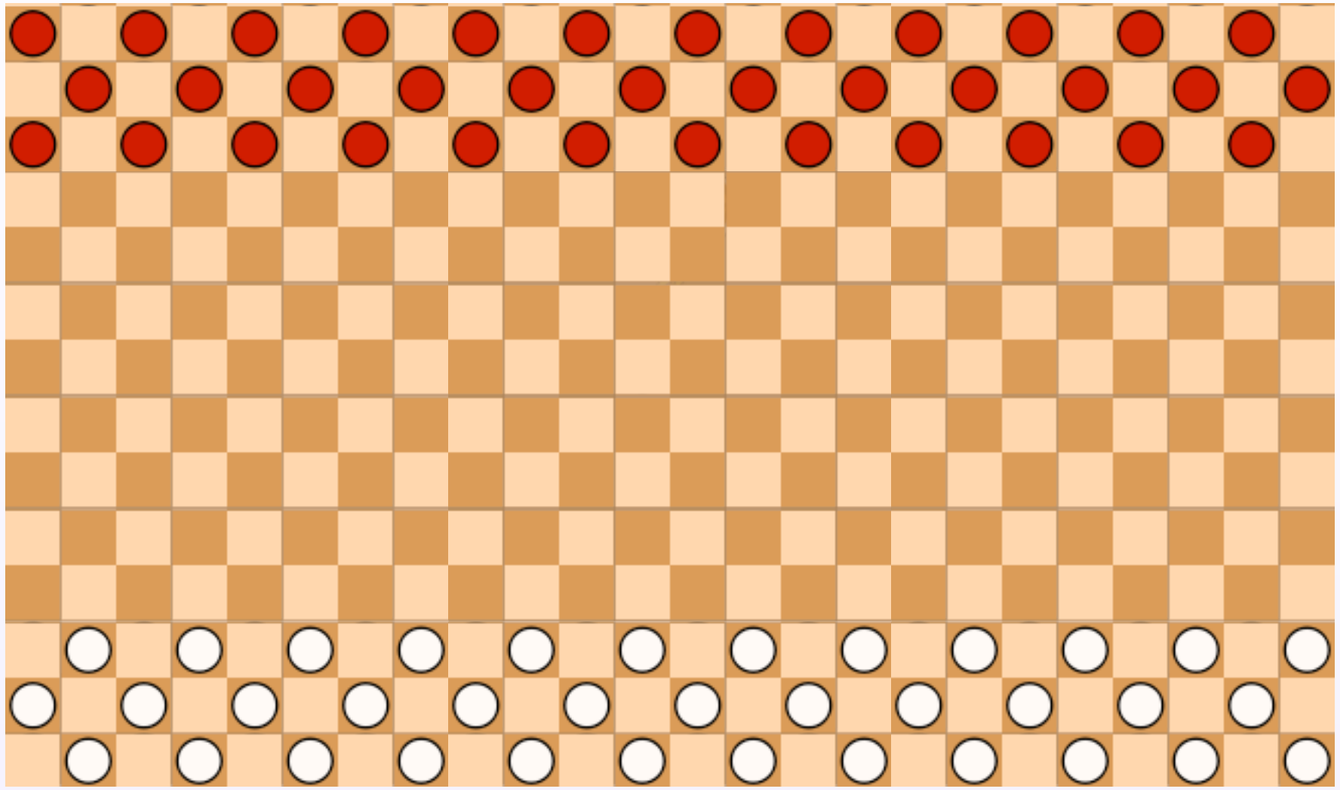

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- DRY - Don't Repeat Yourself
- Eliminate boilerplate to reduce bugs
- No more hand-coded serialize/deserialize
- Spend more time on the game, not the protocol
- Build a helpful robot that writes our code for us

Goal: Human readable code

```
struct CheckerCaptured {
    CheckerID id;
    CheckerID capturedBy;
    u8 jumpType;
};

void Capture(CheckerID id, CheckerID by, JUMP_TYPE jumpType)
{
    CheckerCaptured msg;
    msg.id = id;
    msg.capturedBy = by;
    msg.jumpType = jumpType;
    Send(&msg);
}
```

Goal: Human readable code

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Implementation Details

Development Cycle

- Describe the protocol
- Generate serialization and dispatch
- Send messages
- Receive messages
- Configure routing info

1-to-1 mapping of .jam messages to C++ classes

```
// From Checkers.jam
message CheckerCaptureCredit {
    CheckerID capturedCheckerID;
    CheckerID capturedBy;
    u8 jumpType;
};
```

1-to-1 mapping of .jam messages to C++ classes

```
// From Checkers.jam
message CheckerCaptureCredit {
    CheckerID capturedCheckerID;
    CheckerID capturedBy;
    u8 jumpType;
};
```

```
// 100% Generated code in JamCheckers.cpp
class CheckerCaptureCredit : public JamMessage {
public:
    // Message decoders
    BOOL Get(BinaryDecoder &decoder);
    BOOL Get(JSONDecoder &decoder);
    // Message encoders
    BOOL Put(BinaryEncoder &encoder) const;
    BOOL Put(JSONEncoder &encoder) const;
    /**** DATA START ****/
    CheckerID capturedCheckerID;
    CheckerID capturedBy;
    u8 jumpType;
    /**** DATA STOP  ****/
    // Lots more stuff...
};
```

Development Cycle

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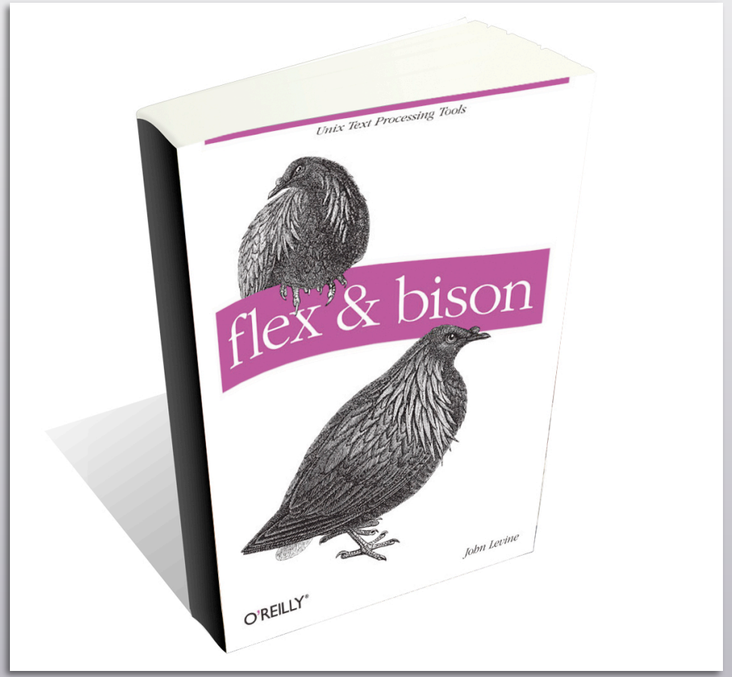
Auto-generated serialization code

```
//NOTICE: This is generated code.  DO NOT EDIT!
BOOL CheckerCaptureCredit::Put(BinaryEncoder &_encoder) const
{
    _encoder.BeginMessage(CODE, NAME);
    _encoder.Put("capturedCheckerID", capturedCheckerID);
    _encoder.Put("capturedBy", capturedBy);
    _encoder.Put("jumpType", jumpType);
    _encoder.EndMessage(CODE, NAME);
    return TRUE;
}
```

Flex and Bison make writing parsers easy



Flex & Bison - parser generators

Other tools

- ANTLR
- GOLD
- PLY (Python Lex & Yacc)
- Boost.Spirit

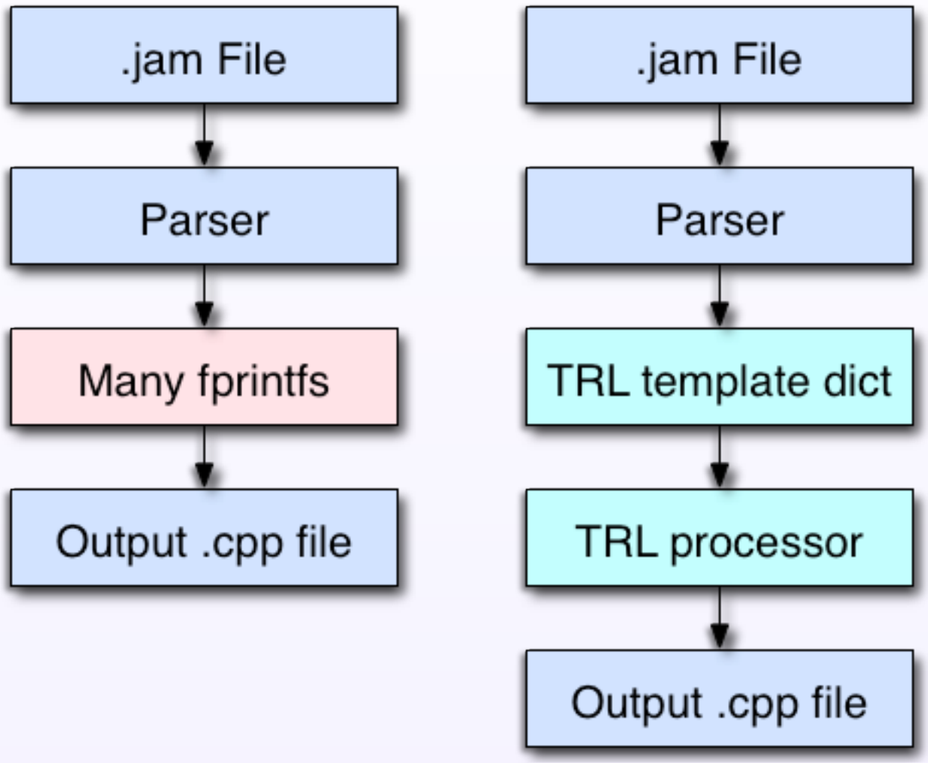
JAM File syntax is described to Bison

```
jamstructs      : jamstructs jamstruct
                | jamstruct
                ;

jamstruct       : structtype TIDENTIFIER messagename '{' { jam_start_s
                | structtype TIDENTIFIER messagename '{' '}' ';' { jam
                | jamcomment { /*printf("Comment\n");*/ }
                ;

structtype      : TMESSAGE { $$.type = GMESSAGE; $$.qualifiers = 0; }
                | TOBJECTMESSAGE { $$.type = GMESSAGE; $$.qualifiers =
                | TSTRUCT { $$.type = GSTRUCT; $$.qualifiers = 0;}
                ;
```

From .jam to .cpp



2004 2013

TRL Turns .jam into C++

```
{@ define OutputMessage(msg, encoders, decoders) @}
    //
    // NOTICE: This is generated code. DO NOT EDIT!
    //
    class {{ msg.structName }} : public JamMessage {
    public:
        static u32 CRC;
        static u16 CODE;
        static cchar *NAME;

        // No argument constructor:
        {{ msg.structName }}() {

            {@ foreach f in msg.fields @}
                {@ if f.hasDefault @}
                    {{ f.name }} = {{ f.defValue }};
                {@ end if @}
            {@ end foreach @}

        }
```

TRL to generate a message class definition

TRL Turns .jam into C++

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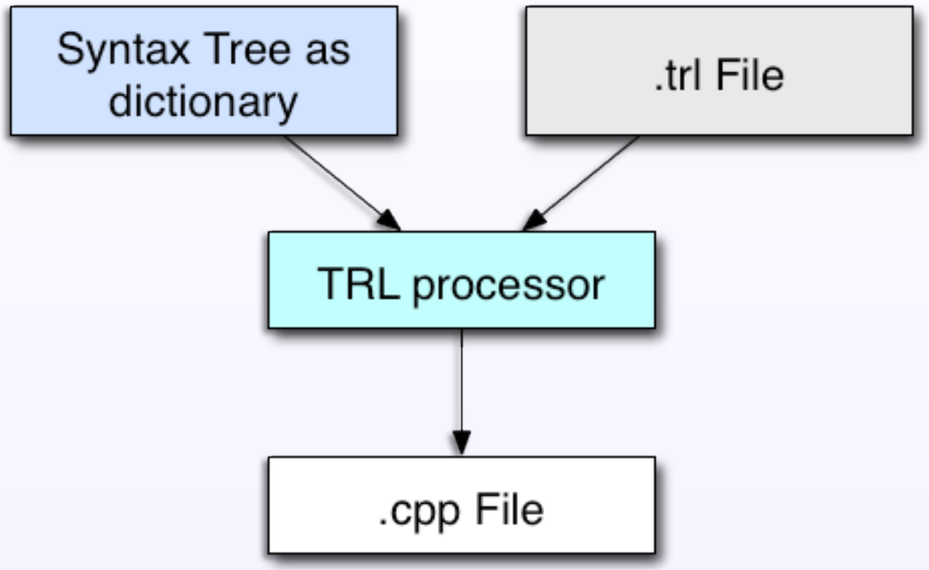
```

TRL to generate a message class definition

See Also

- CTemplate
- ngTemplate
- Django (HTML focused)
- Jinja (Python)

Fill out a dictionary and feed it to TRL



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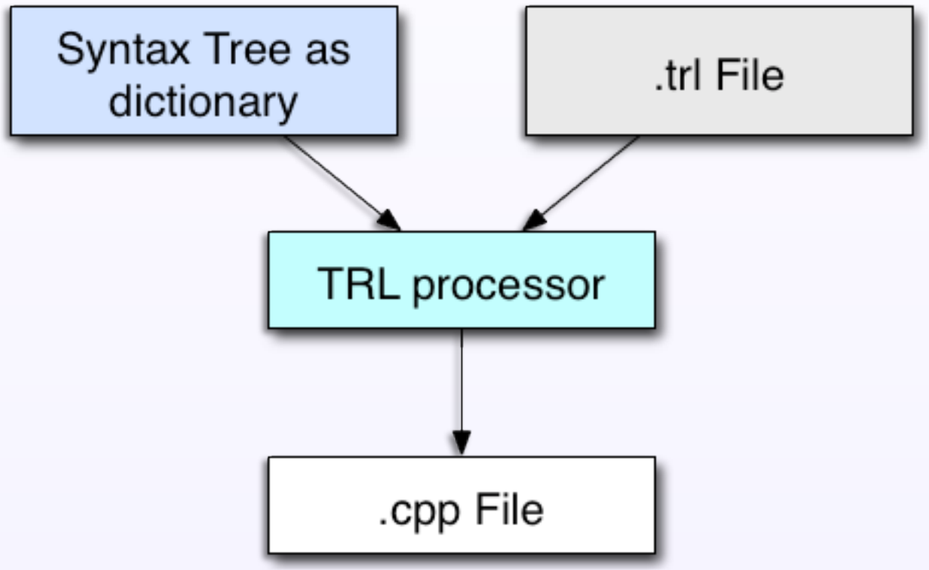


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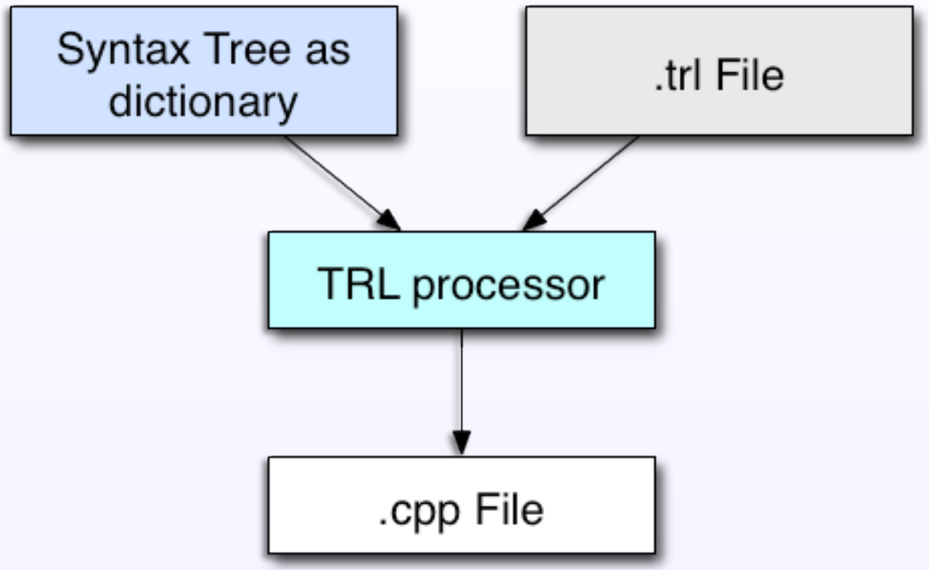


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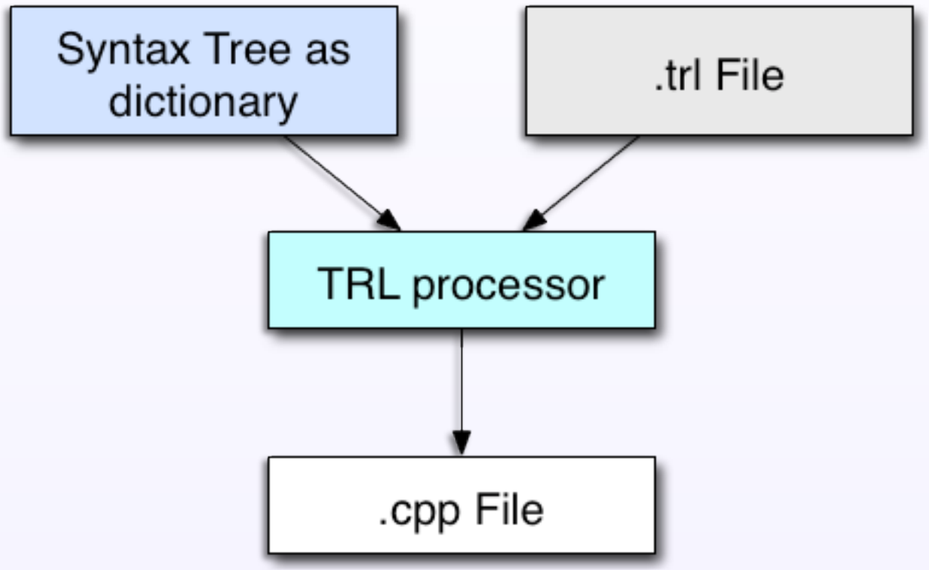


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{@ foreach f in msg.fields @}
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{@ end foreach @}
```

Global Feature addition using TRL

```
{@ end foreach @}
// Virtual encode/decode dispatchers
BOOL {{m.structName}}::Put(teDataChain *pPay
    switch(protocolType) {
        default:
            return FALSE;
        case JAM_PROTOCOL_BINARY_LITERAL:
        {
            teRawBinaryEncoder encoder(pPayl
            return Put(encoder);
        }
        case JAM_PROTOCOL_TEXT_JSON:
        {
            teJSONEncoder encoder(pPayload);
            return Put(encoder);
```

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177     // Virtual encode/decode dispatchers
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Create a message, fill in data, call send

```
void Checker::OnCaptured(CheckerID capturedBy, JUMP_TYPE how)
{
    CheckerCapturedCredit msg;
    msg.capturedCheckerID = GetID();
    msg.capturedBy = capturedBy;
    msg.jumpType = how;
    JamID destination = GetRouter()->GetCreditManagerID();
    GetRouter()->Send(destination, &msg);
}
```

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    GetRouter()->Send(destination, &msg);
}
```

Structs and arrays in messages

```
message GroupUpdate
{
    GroupID group;
    array<.CheckerID> checkers;
};
```

```
    /*** DATA START ***/
    GroupID group;
    vector<CheckerID> checkers;
    /*** DATA STOP ***/
```

```
void GroupService::SendUpdate(GroupID id)
{
    GroupUpdate msg;
    msg.group = id;
    msg.checkers.resize(MAX_GROUP_SIZE);
    // ...
}
```

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Definitions

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- Protocol - a collection of messages
- Service - a module of code that implements message handlers for one or more protocols
- Program - can be composed of multiple services

Message Destinations

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```
void MatchService::CreateBoard(u64 width, u64 height) {
    BoardID = GenerateBoard();
    // Send to a known, connected, service
    m_pServer->Send(m_boardServerID, &msg);
}
```

Message Destinations

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    BoardID = GenerateBoard();
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    m_pServer->Send(m_boardServerID, &msg);
}

void MatchService::GameOver(u32 gameID, u64 winnerID) {
    msg.gameID = gameID;
    msg.winner = winnerID();
    // Send to a service type, non-specified ID
    m_pServer->Send(JAM_SERVER_STATS_TRACKER, &msg);
}
```

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}

void MatchService::GameOver(u32 gameID, u64 winnerID) {
    msg.gameID = gameID;
    msg.winner = winnerID();
    // Send to a service type, non-specified ID
    m_pServer->Broadcast(JAM_SERVER_STATS_TRACKER, &msg);
}
```

Message Destinations

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    BoardID = GenerateBoard();
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}

void MatchService::GameOver(u32 gameID, u64 winnerID) {
    msg.gameID = gameID;
    msg.winner = winnerID();
    // Send to a service type, non-specified ID
    m_pServer->Broadcast(JAM_SERVER_STATS_TRACKER, &msg);
}

void Checker::HealChecker(CheckerID toHeal, u32 amount) {
    CheckerHeal msg;
    msg.healedBy = GetID();
    msg.amount = amount;
    // Send a message to a specific object
    m_pServer->Send(toHeal, &msg);
}
```

Message routing by type

```
MatchmakerAddPlayer addMsg;
addMsg.player = GetPlayerID();
addMsg.rank = GetRank();

// No JamID needed, send to any Matchmaker
// May be queued until a Matchmaker is available
m_pService->Send(JAM_SERVER_MATCHMAKER, &addMsg);
```

Send a message and expect a response

```
MatchmakerAddPlayer addMsg;
addMsg.player = GetPlayerID();
addMsg.level = GetLevel();

// Send to any Matchmaker, PlayerAddedHandler
// will be called with response when complete
m_pService->SendRegistered<PlayerAdded>(
    JAM_SERVER_MATCHMAKER, &addMsg
);
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Send a message and expect a response

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addMsg.player = GetPlayerID();
addMsg.level = GetLevel();

// Send to any Matchmaker, PlayerAddedHandler
// will be called with response when complete
m_pService->SendRegistered<PlayerAdded>(
    JAM_SERVER_MATCHMAKER, &addMsg
);
```

Send a message to an object

```
void CheckerGroup::ChangeBoards(u32 newBoard)
{
    CheckerChangeBoard msg;
    msg.boardID = newBoard;
    for(int i = 0; i < m_checkers.size(); i++) {
        m_pServer->Send(m_checkers[i]->GetID(), &msg);
    }
}
```

Each object is owned by one server

```
class Checker {
    //...
    CheckerID m_id;
    JamID m_serverID;

    JamID GetServer() {
        return m_serverID;
    }

    CheckerID GetID() {
        return m_id;
    }
    //...
};
```

Each object is owned by one server

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class Checker {
    //...
    CheckerID m_id;
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    JamID GetServer() {
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Each object is owned by one server

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    JamID GetServer() {
        return m_serverID;
    }

    CheckerID GetID() {
        return m_id;
    }
    //...
};
```

How messages get routed

```
void BoardServer::Send(Checker *pChecker, JamMessage *pMessage)
{
    m_pJamServer->Send(pChecker->GetServer(),
                       pChecker->GetID(),
                       pMessage);
}
```

Development Cycle

- Describe the protocol
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On receipt, look up and dispatch

```
// static callback registered with JAM by protocol ID
// called for each incoming message
void BoardServer::CheckerDispatch(JamLink &link, JamMessage *pMessage)
{
    CheckerID destID = pMessage->GetDestination();
    Checker *pChecker = GetCheckerObject(destID);
    pChecker->QueueMessage(pMessage);
    switch(pMessage->GetProtocolCRC()) {
        case JAMCheckerProtocol_CRC:
            JamCheckerProtocol::Dispatch<Checker>(pMessage, pChecker);
    }
}
```

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    pChecker->QueueMessage(pMessage);
    switch(pMessage->GetProtocolCRC()) {
        case JAMCheckerProtocol_CRC:
            JamCheckerProtocol::Dispatch<Checker>(pMessage, pChecker);
    }
}
```

On receipt, look up and dispatch

```
// static callback registered with JAM by protocol ID
// called for each incoming message
void BoardServer::CheckerDispatch(JamLink &link, JamMessage *pMessage)
{
    CheckerID destID = pMessage->GetDestination();
    Checker *pChecker = GetCheckerObject(destID);
    pChecker->QueueMessage(pMessage);
    switch(pMessage->GetProtocolCRC()) {
        case JAMCheckerProtocol_CRC:
            JamCheckerProtocol::Dispatch<Checker>(pMessage, pChecker);
    }
}
```

JamLink

```
void BoardServer::CheckerDispatch(JamLink &link,
                                  JamMessage *pMessage)
{
```

Generated Dispatch methods

```
//NOTICE: This is generated code.  DO NOT EDIT!
template<typename HANDLER_T>
static JAM_RESULT Dispatch(JamMessage *pMessage,
                           HANDLER_T *pHandler) {
    switch(pMessage->GetCode()) {
    case JAM_MSG_CheckerHeal:
        result = pHandler->CheckerHealHandler(link,
            (CheckerHeal *)pMessage);
        break;
    // cases for rest of protocol's messages...
```

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        break;
    // cases for rest of protocol's messages...
```

Generated message handler prototypes

```
// A message handler prototype is auto-generated for each message
// in the protocol.  #include these declarations in the middle
// of your hand constructed class.
JAM_RESULT CheckerHealHandler(JamLink &link, CheckerHeal *msg);
JAM_RESULT CheckerDamageHandler(JamLink &link, CheckerDamage *msg);
JAM_RESULT CheckerPowerupHandler(JamLink &link, CheckerPowerup *msg);
JAM_RESULT CheckerKingHandler(JamLink &link, CheckerKing *msg);
```

#include this in the middle of a class

Message handler methods

```
JAM_RESULT Checker::CheckerHealHandler(CheckerHeal *pMessage)
{
    m_health += pMessage->amount;
    LOG("Checker %d was healed for %d by checker %d",
        GetID(), pMessage->amount, pMessage->healedBy);
    return JAM_OK;
}
```

Send and Receive

```
void Checker::HealChecker(CheckerID toHeal, u32 amount) {
    CheckerHeal msg;
    msg.healedBy = GetID();
    msg.amount = amount;
    // Send a message to a specific object
    m_pServer->Send(toHeal, &msg);
}

JAM_RESULT Checker::CheckerHealHandler(CheckerHeal *pMessage)
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    return JAM_OK;
}
```

Development Cycle

- Describe the protocol
- Generate serialization and dispatch
- Send messages
- Receive messages
- Configure routing info

Define services

```
void Matchmaker::Configure(JamServer *pServer)
{
    JamRouteConfig &routeConfig = pServer->GetRouteConfig();
    routeConfig.ConfigureInbound<MatchmakerProtocol>(
        this, Matchmaker::DispatchMessage);
    routeConfig.ConfigureOutbound<MatchmakerResponseProtocol>();
}
```

Configure protocols the Matchmaker service sends and receives

Define services

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void Matchmaker::Configure(JamServer *pServer)
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    JamRouteConfig &routeConfig = pServer->GetRouteConfig();
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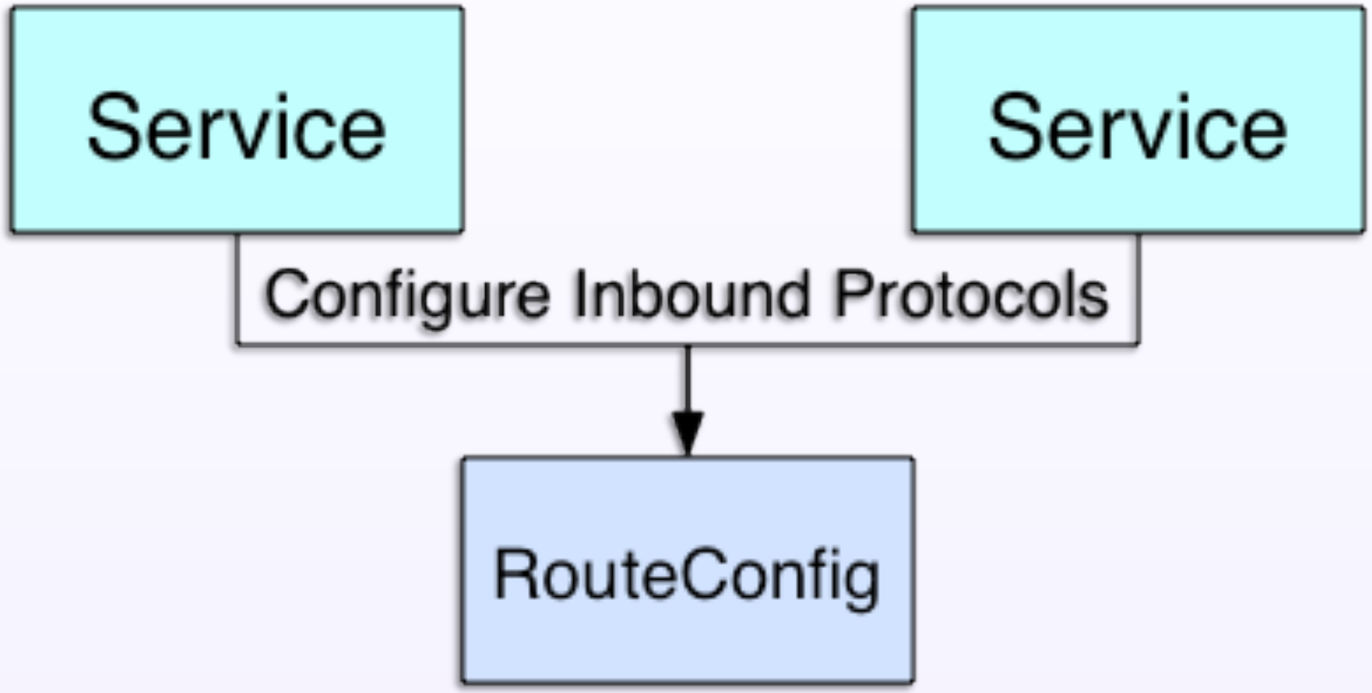
Configure protocols the Matchmaker service sends and receives

RouteConfig maintains a protocol to handler mapping



Handlers have access to sender and other metadata about received messages

```
JAM_RESULT BoardServer::AddPlayerHandler(JamLink &link,
                                         AddPlayer *msg)
{
    LOG("Adding player %s from server %s",
        IDSTR(msg->playerID),
        link.Describe().c_str());
    // Do stuff
    return JAM_OK;
}
```

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}
```

Coarse and fine-grained queueing and

Race Condition

Receiving via Message Queue

```
void Matchmaker::Configure()
{
    // Messages received at any time are placed into a queue
    routeConfig.ConfigureInbound<MatchmakerProtocol>(
                this, &m_messageQueue);
}

void Matchmaker::Idle()
{
    // Queue is processed in one thread at a known time
    pServer->ProcessQueue(&m_messageQueue, this);
}
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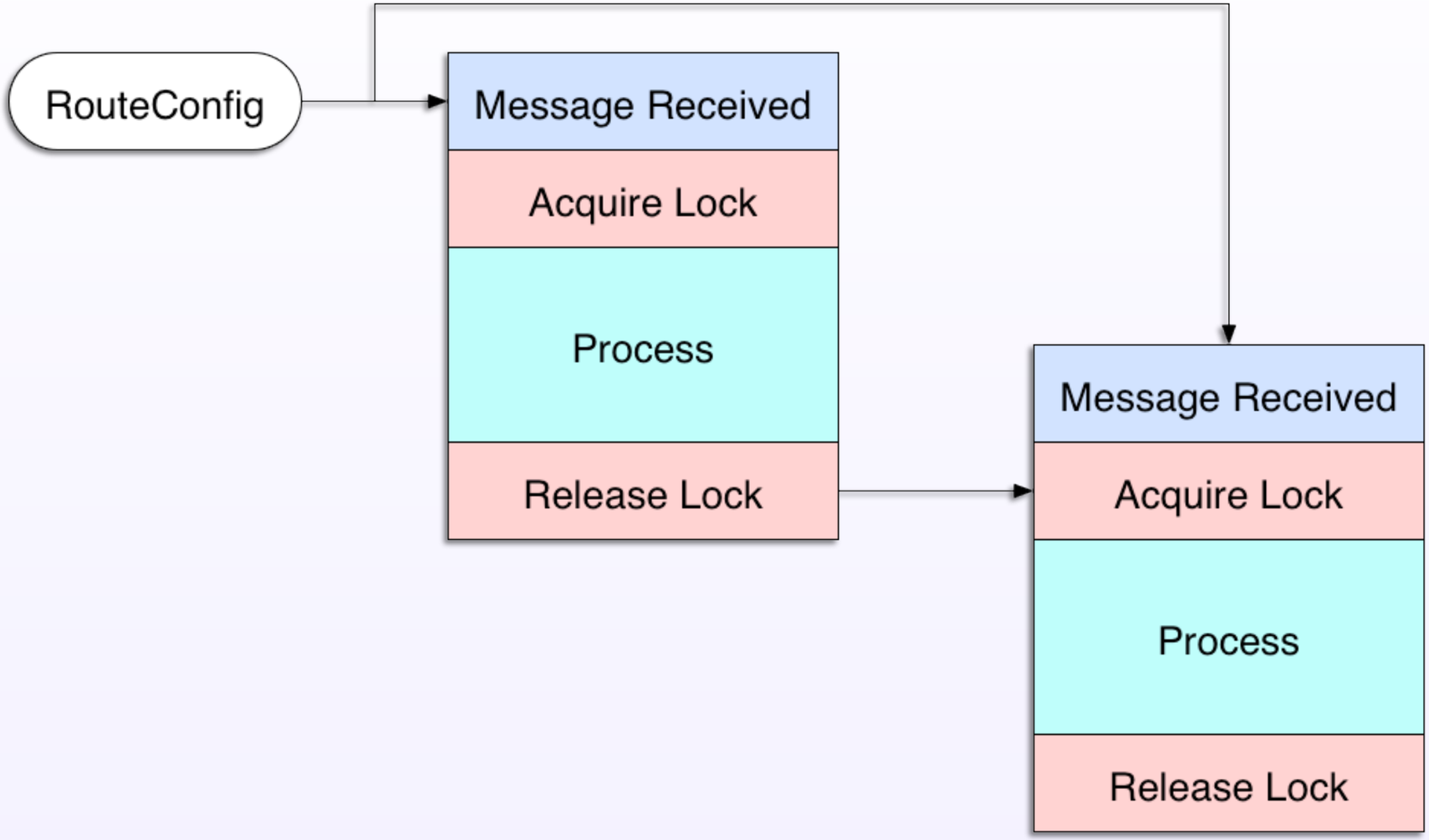
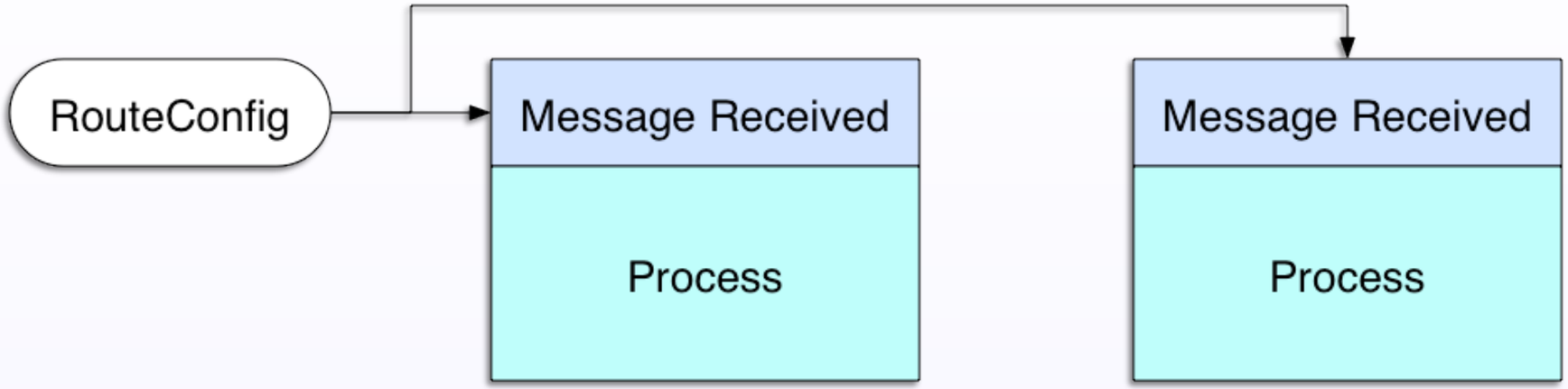
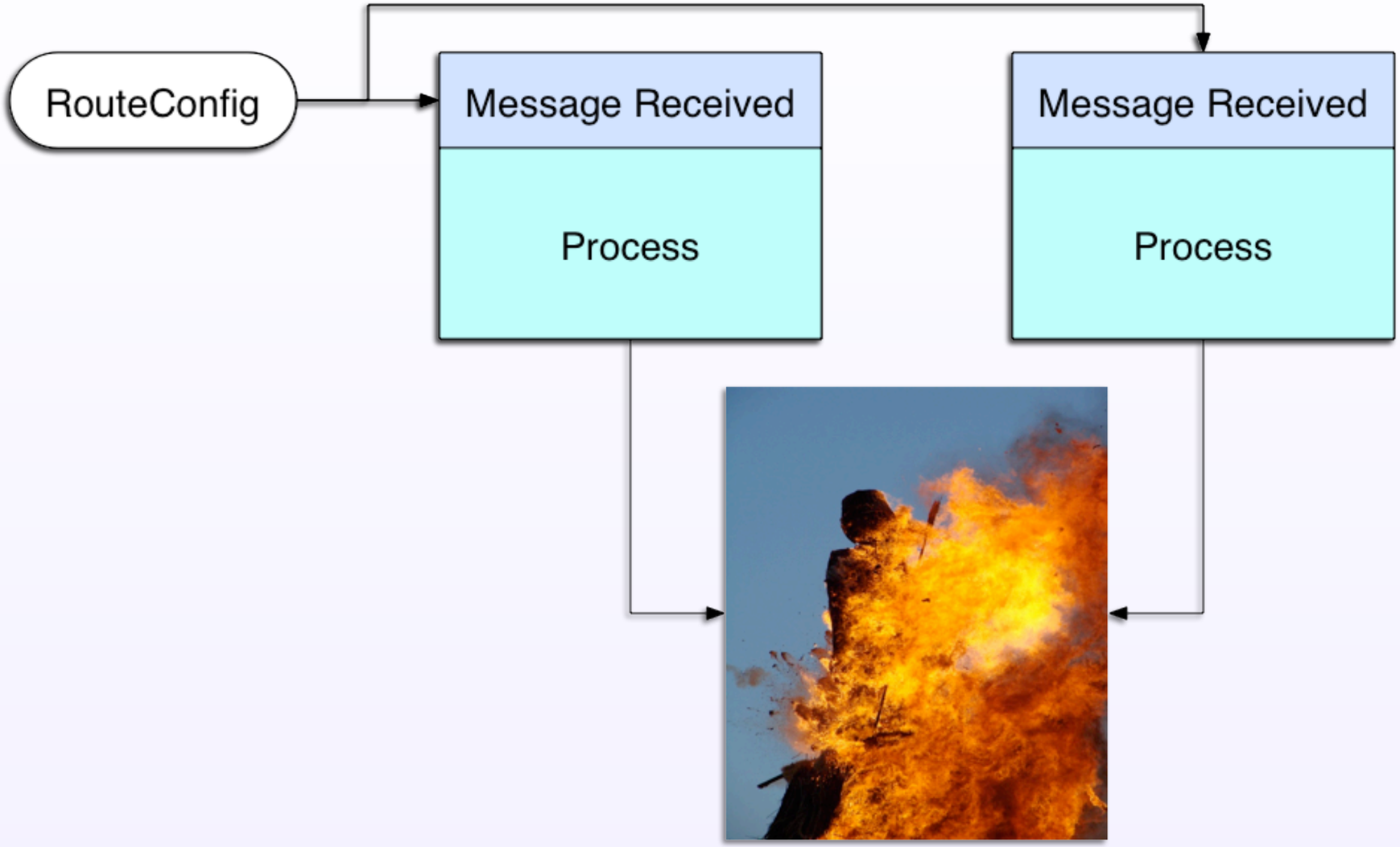
Global lock dispatching



Raw concurrent handlers



Raw concurrent handlers



Lock Policies

```
class MatchmakerLockPolicy
{
    Matchmaker *m_owner;
    void Lock(JamMessage *msg, JamMessageQueue **ppQueue)
    {
        // Adding a player requires a write lock
        if(msg->GetCode() == JAM_MSG_MatchmakerAddPlayer) {
            m_owner->AcquireWriteLock();
        } else {
            m_owner->AcquireReadLock();
        }
    }
    void Unlock(JamMessage *msg) { /* Same logic, release lock */ }
}
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- Messages contain no pointers to any other objects
- No circular references are possible

CPU And Bandwidth Efficiency

JAM is either efficient or backwards compatible

2004 - Assumed binary compatibility

Negotiation means dead-simple binary serialization most of the time

In some cases, can just memcpy it onto the wire

```
// This message could easily be memcpy'ed onto the wire
class CreateChecker : public JamMessage {
    /**** DATA START ****/
    u32 checkerType;
    u32 owner;
    /**** DATA STOP ****/
    // Code...
};
```

Generated code means easy optimizations

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```
_encoder.Put("capturedCheckerID", capturedCheckerID);
_encoder.Put("capturedBy", capturedBy);
_encoder.Put("jumpType", jumpType);
```

Fallback to JSON Serialization

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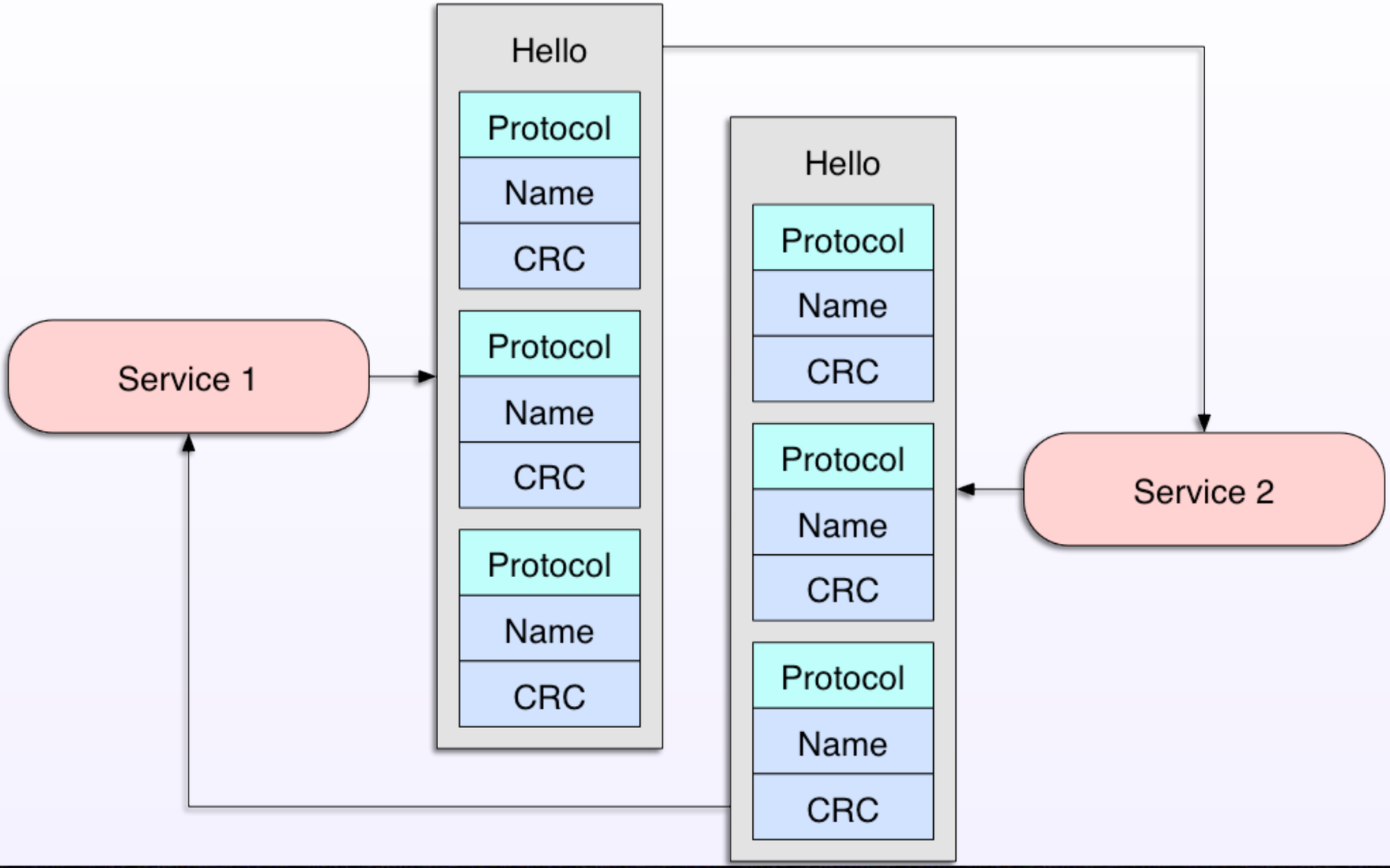
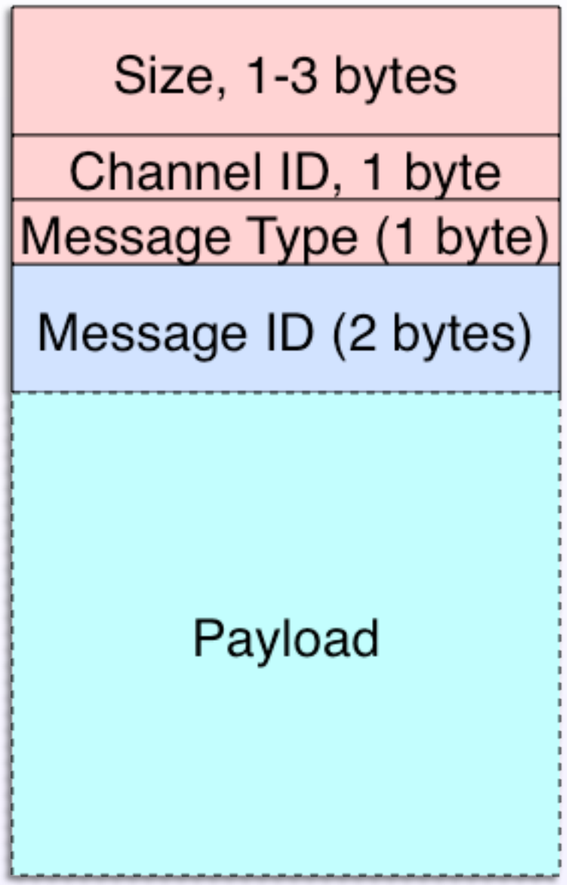
JSON


```
{
    "_msgID":10,
    "type":6,
    "error":0,
    "desc":{
        "m_id":"T2R00S40.00E14815726P10987H127.0.0.1:14001",
        "m_host":"127.0.0.1",
        "m_partitionID":0,
        "m_configID":0,
        "m_buildNum":0,
        "m_type":40,
        "m_subType":0
    }
}
```

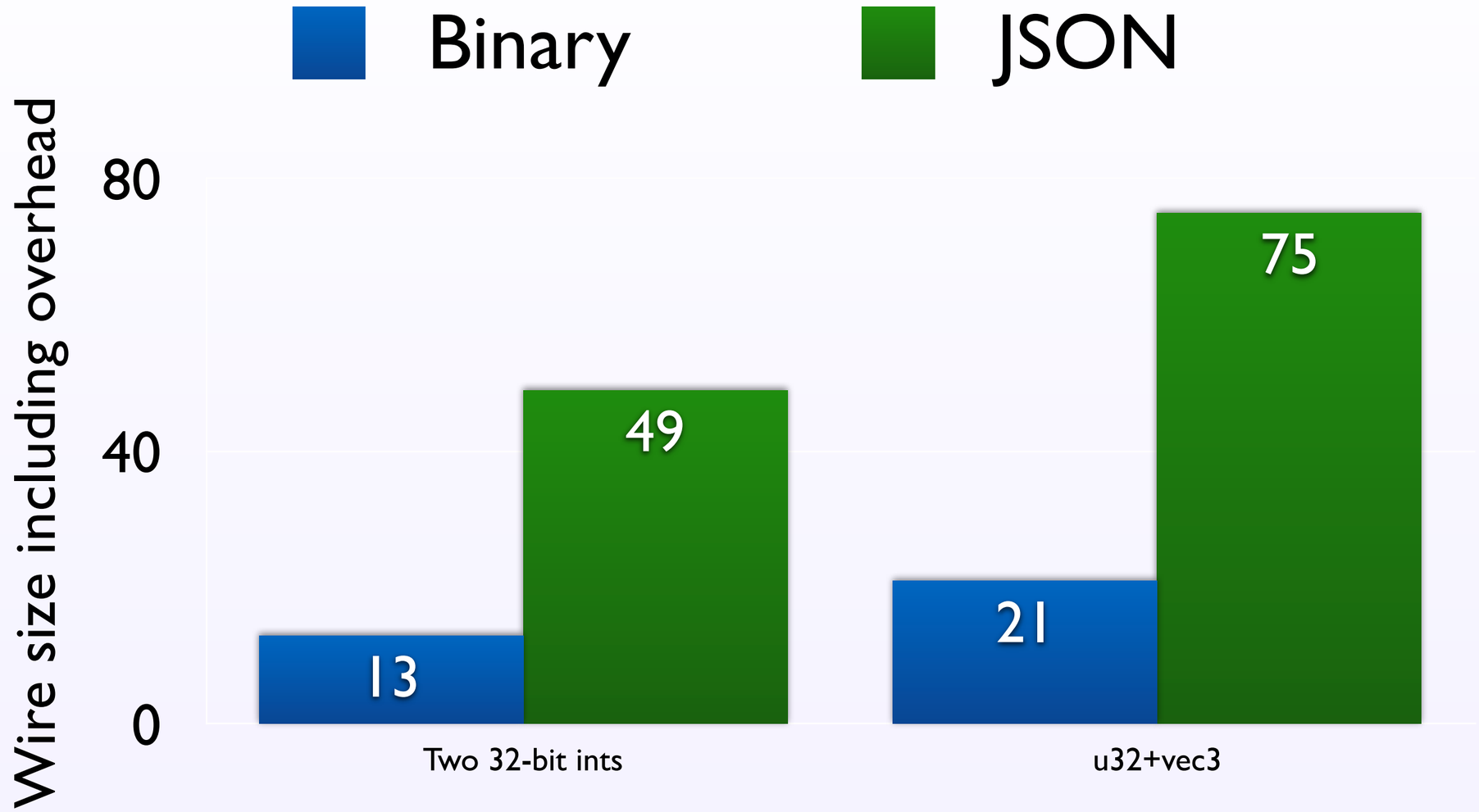
Protocol Negotiation



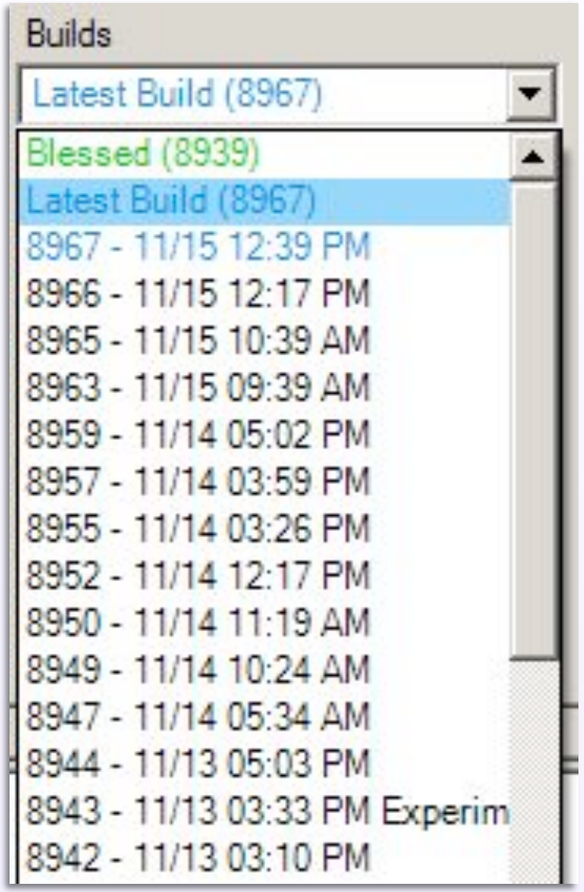
Message overhead



JSON vs. Binary performance



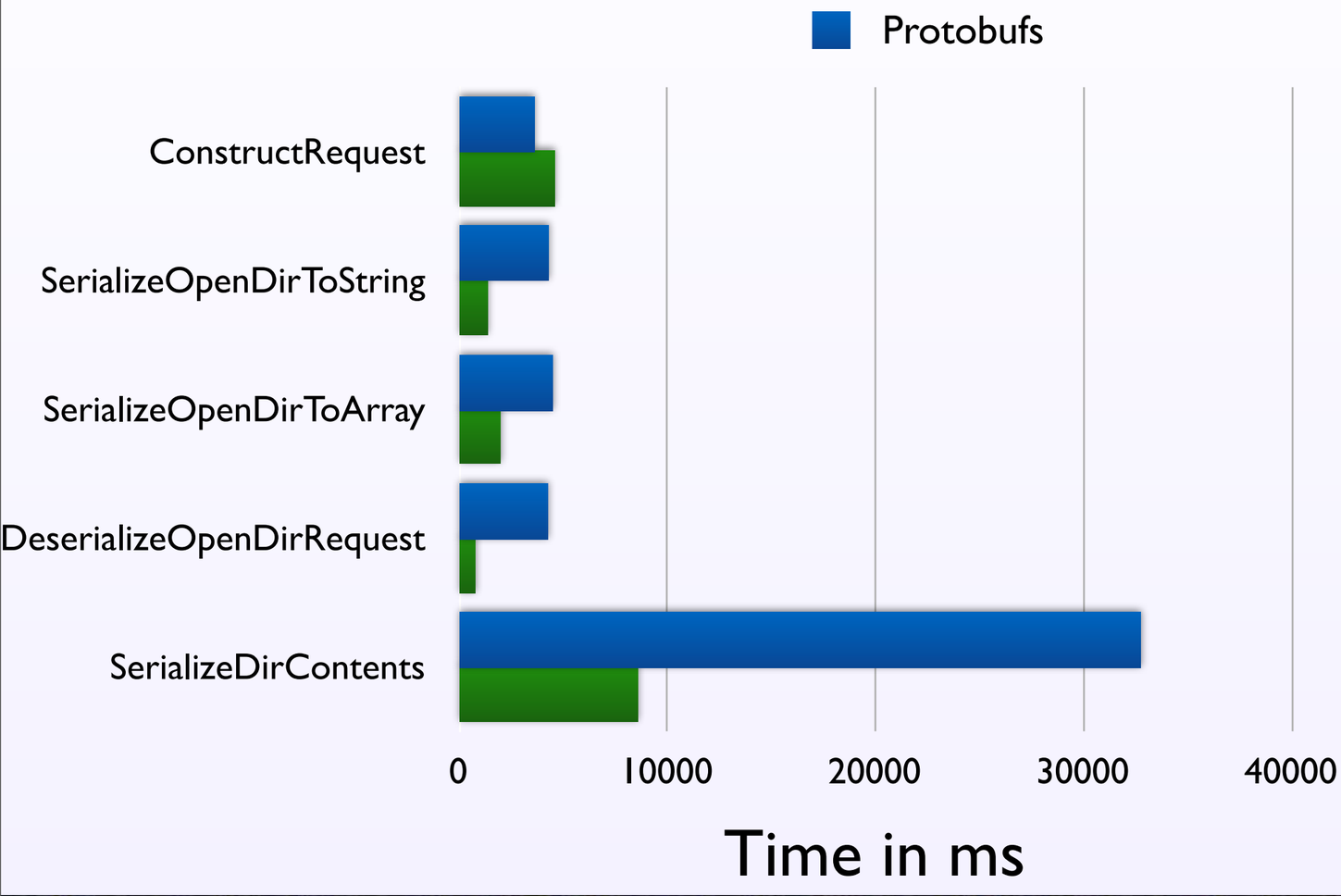
Still highly successful - some network tools run on old versions frequently

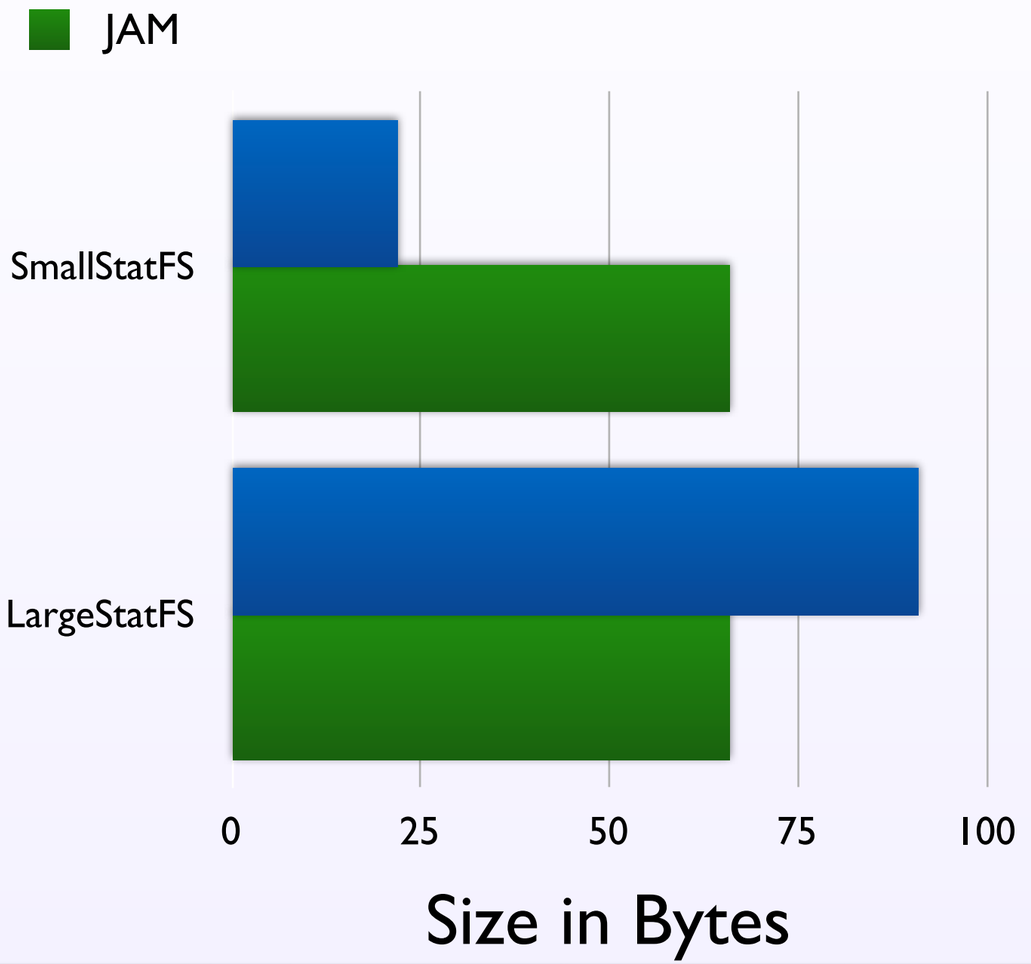


Google's Protocol Buffers and

For both speed AND inter-version compatibility, there are better choices

protobufs sometimes wins on bandwidth, but JAM is faster





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Writing our own gives us ultimate control over everything

- Automated serialization
- Easy yet flexible message dispatching
- High performance
- Inter-version compatibility
- Less tedium = more awesome

Thanks! Questions?

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Disclaimer: Blizzard is not really making World of Checkers