NOSTALRIUS
VANILLA LEGACY SERVER

POST MORTEM

2015 - 2016

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1 Introduction

12 years ago, the biggest MMORPG in the history of gaming was released. No one, not even Blizzard could have expected this astonishing success. Today, previous expansions of the game are no longer available, orphaning hundreds of thousands of players.

While some other MMORPGs chose to provide their community with previously available content, this is not the case for World of Warcraft, even if it is asked by hundreds of thousands of players from around the world.

We - the Nostalrius team - committed ourselves to recreate the Vanilla experience by setting up and handling the largest unofficial server of its kind. After several years, we are more than ever convinced of the importance of this game, and are thus willing to share all of our experience and data in the hope that it may help Blizzard Entertainment in making the best decision for everyone involved.

The goal of this document is to describe how the Nostalrius project was managed, providing multiple kinds of analysis such as quality, cost, schedule, process, customer and product. All aspects of Nostalrius were analyzed, including the key points to our success and failures.

A secondary goal of this document is to propose, as an example, a successful organization for large volunteer projects along with a complete analysis of the challenges we faced.

All of these lessons learned are the result of more than 5 years of experience managing a volunteer WoW private server team. This document is published in the hope that it can be useful for anyone willing to start a similar project. Some technical and specific parts will however remain restricted, such as the anticheat techniques; as we believe that the whole WoW community could suffer from this information being publicised.

This document is dedicated to all of the people who helped us to do what we achieved. Former or current volunteer staff members, players, guilds, gaming figures and legacy server supporters: without a strong team, and without supporters, this movement would not have gone so far.

Kind regards,
Nostalrius Team.

Some people dream of success while others wake up and work hard at it.
Napoleon Hill.

List of volunteers since the opening of this international project in 2015:

Daemon, Viper, Déus, Clank, Poluxgama, Hoover, Joan, Chakor, Geist, Raazi, Sredna, Hammer, Helios, Mute, Igen, Witcher, Dreadzi, Krusher, Lecat, Digitalz, Launcher, Elessar, Life, Cantrip, Kraos, Wyzel, Morran, String, Makumba, Fenrir, Cthulhu, Paraskoi, Cursive, Korval, Aerbax, Metzu, Theldras, Etiakor, Pottu, Tyrael, Same, Testy, Velsdra, Eurie, Faith, Neo, Rizah, Shatterbird, Nano, Leamas, Voltog, Eragon, Radius, Tigru, Ithlien, Syrah, Seshinryu, Abathur, Xendly, SanAntonio, Ninniel, Nathrizyr, Benevael, Eldoth, Arthad, Naealath, Leythia, Shahkar, Adarlas, Coff, Nalorius, Fafner, Stryg, Theloras, Hawk, Roffeal, Akasso, Quietist, Cabotage, Eragon, Carbuncle, Schluepper, Vaelanor, Bulmonk, Cygore.

2 Executive summary

This post-mortem of the Nostalrius project presents our analysis of why Nostalrius was such a successful legacy server, through 2 analytic levels.

Firstly, explanation through this document on how the project came upon leading a successful WoW emulated server:

- How the initial realm launch was advertised.
- The bug-processing workflow through GMs, IsVV and Dev teams to ensure gameplay quality.
- How software was designed to handle over 13,500 online players in a single realm.
- How threats faced were mitigated.
- How and aggregated a strong community was built through regular communication and regular content releases.

Secondly, the human resources challenge faced: how to make such a large project with high responsibility work for a volunteer based virtual team. This document shows how Nostalrius handled these challenges:

- Designing hierarchical levels gives volunteers a goal to achieve and helps maintain a level of motivation.
- Designing different team-specific information access levels and checking applicants backgrounds deeply would greatly reduces the risk of an information leak, which is critical in the private server market.
- Mature and clear internal procedures, documentation and training processes allowed Nostalrius to quickly train new recruits, being able to face the high turnover due to both stressful and volunteer activities for our staff members.
- Internal mobility between teams provided team members with exciting entirely new areas to explore, new knowledge and experience to acquire. Team managers would also gain new members already familiar with the Nostalrius organization and who were known to be trustworthy.

In the appendix, information gathered regarding the Vanilla WoW community is also provided. The statistics show that Vanilla WoW attracts both former and new players, beyond the simple nostalgia.

3   Context

3.1   Nostalrius

World of Warcraft was released in 2004. After 2 years, the content and mechanisms changed dramatically, however, the zones and lore of existing Vanilla content weren't modified significantly. When the Cataclysm expansion landed at the end of 2010, the Vanilla zones and lore changed so much that it was no longer possible to interact with the original part of the game.

3.1.1   Private servers

Everything began with the GotWoW platform created in 2003 during the World of Warcraft Alpha version. This platform made of around 2,000 active members was used to develop tools and servers around 3 years before World of Warcraft was released. The platform got shutdown in 2004 creating a lot of disorganization among server developers, working on project like WoWD, WoW Daemon or OpenWoW.

All these project disappeared few months later, and MAnGOS was then created, mainly based on one of the most advanced private server project at that time named WoW Daemon.

During this period, private servers were first seen as a personal challenge for a very small part of the community, trying to express their skills by developing and re-engineering existing content. But once significant content was removed from Blizzard's realms, another kind of server appeared, driven by a different objective: legacy servers.

Vanilla, Burning Crusade and Wrath of the Lich King legacy servers in particular became the most popular. We believe it is because veteran players don't recognize the old version of World of Warcraft that they fell in love with, especially regarding game mechanics. More details are given in the market analysis below.

3.1.2   Nostalrius Begins and previous Vanilla private servers

Private servers already existed prior to Nostalrius' release, but most of them provided paid services, and an average quality in terms of content and services which wasn't always seen as professional.
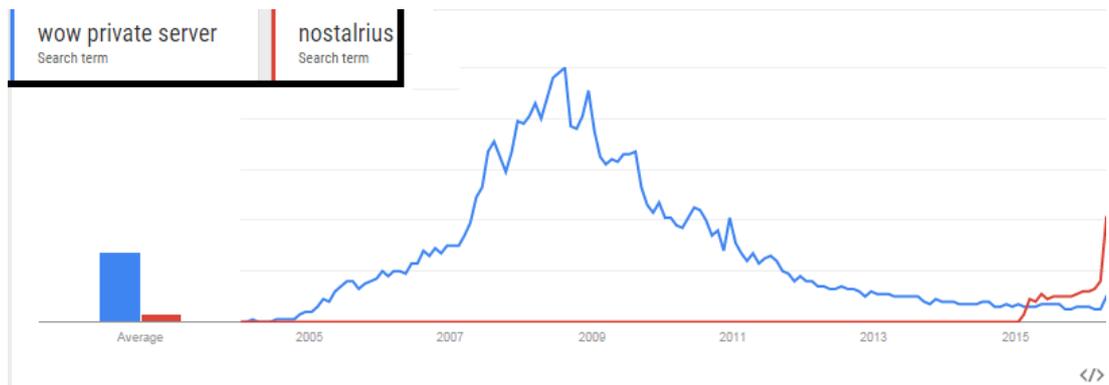
FIGURE 1. Google trends of "Wow private server" and Nostalrius.

Nostalrius tried to break this situation as a non profit organization, and actually succeeded in some ways. With this new quality, our communication and volunteer spirit, our project gathered around 90% of the Vanilla population on our realms. Most of the previously existing profit-based Vanilla servers disappeared, and only a few were launched during the period when Nostalrius was available.

Our servers' shutdown left 220,000 players (monthly statistics) without a home, and created a huge demand for Vanilla WoW. In this context, dozens of servers appeared in a few weeks, most of them implementing in game micro-transactions.

3.2   Market analysis

During the 6 years spent working in the emulation scene, administrators gained a better understanding of the World of Warcraft community by trying multiple kind of servers: arena realm, cross faction realm, realm with faster leveling, custom re-specialization cost, meeting stones allowing teleportation, custom features, etc.

The conclusion we've reached today is that a huge number of players want a genuine retail experience without any custom features. Other attempts failed because they did not match the needs of the largest part of the community which often remained silent. Tuning difficulty, altering leveling rates, economy or any others features making things easier would cause people to feel less engaged with their character and they would tend to change realms quite frequently. Keeping the game as it was before make things way more difficult, creates challenge through which true communities and friendships emerge, making all players a band of brothers in a difficult adventure, building strong shared memories.

This choice does not come without a cost: some suggestions for custom features may get a lot of support, but we made the decision not to accept them, otherwise we would be categorised as a "fun legacy server".

Customer service also needs to be as fast as possible for general cases. As a consequence, and under a worldwide server context, the game master team needs to be spread all around

the world, covering as many time zones as possible. Having game masters - GMs in North America, Europe and Asia covered this need best.

FIGURE 2. Geolocation of the GM team members all over the world.

GMs are located in the USA (east and west coast), Canada, England, France, Switzerland, Germany, Romania, Sweden, Norway, Finland, China, Singapore and Australia. One of the benefits for the GMs was that they could easily be active 24/7 without members having to be up through their own night. This coverage needs a lot of organization which is described later in the document.

FIGURE 3. Geolocation of the GM team members in Europe.

3.3 How Nostalrius differs from the original legacy experience

There were multiple custom aspects that made Nostalrius unique which derived from the following choices we made such as no population cap and being an international server.

The decision not to enforce a population limit was quite an undertaking for us which involved adding dynamic creatures, ore and herb re-spawns, zone phasing and clustering technology was also under development. The players loved these features as it made the entire server feel more alive. It was beneficial for the GMs to have most of the player base being on one server as it kept everything in one place.

Nostalrius also decided to fix exploits available during retail in order to protect the overall server economy (monitored by a live control overall dashboard) as much as possible, or keep the Alterac Valley Battleground in its pre-nerf version, leading to battle lasting around 24h without interruption.

Opening the servers internationally fostered some hate and blaming towards certain nationalities, also creating language barriers, but mainly broadened our player base, allowing players to discover others cultures, and explore the game, not matter the international frontiers.

3.4 Working in a virtual team

A virtual team is a group of individuals who work across time, space and organizational boundaries. Virtual teams have become a fact of business life, with more than 2.9 million full-time virtual workers in the U.S (+61% in 10 years), and approximately 11% of the EU population.

In order to synchronize virtually, the whole team would meet on a Teamspeak server, where official meetings were organized. This solution was used for the first 5 years Nostalrius ran as a french server, but no longer satisfied the team's needs as it became an international server.

FIGURE 4. Working in a virtual team.

When the team members started spanning across time zones from all around the world, new issues arose:

- The need to keep coherence in our actions: when something new happens and a new policy is applied, the whole team needs to be informed about it. Otherwise, for example, a GM who logs in 4 hours later may not been informed about the recent actions, and may make a different decision in a similar case.

- The need for managers to be reachable as soon as possible in case of emergency.

Both of these problems have been solved by the following solutions:

- Moving from Teamspeak to Discord - an instant messaging and flexible application supporting voice. Teamspeak did not provide chat history, nor a free mobile application. Discord was used for instant communication or short-term synchronization.

- Mid-term synchronization inside teams was ensured through Google Documents, where information requiring reviews, tickets escalation, etc. would be gathered.

- The forums was still used for internal long-term synchronization: major news, policy changes or strategic directions were listed there for archival purposes.

- Another technique used by the GM team specifically was the use of internally posting leaderboards that would reset weekly for a variety of GM activities such as tickets closed, number of posts on the forums, accounts sanctioned, etc. This would cause a sense of competition for the most active members and helped management in identifying areas for improvement regarding less active members. All player complaints regarding GM actions were verified and logs were reviewed by the GM manager only to verify that all GMs were following proper policies and procedures and were remaining professional, honest and impartial at all times.

Working in this kind of team is a challenge in itself since meeting colleagues face-to-face is not possible, and neither are social interactions that build relationships and rapport. In addition, cultural differences can sometimes lead to misinterpretation.

Establishing trustful relationships is thus made more difficult, especially in the context of the highly competitive legacy server market, where information/code leak can have huge consequences. Mistrust can also undermine everything that the virtual team is trying to achieve. This is described more in detail later.

| 4 | **Project analysis** |

4.1   **Organization**

4.1.1   Organization breakdown structure - OBS

The Organization Breakdown Structure presents the responsibilities of each member for each project's tasks. OBS evolved during the project lifecycle. Initially, it was a 2 layer organization which was best suited for a small team (less than 20 members). Each staff member was assigned to a dedicated task, under the direct supervision of the administrators. No communication team was necessary as it was directly handled at the administrators level. This organisation was used for 5 months after official international release.
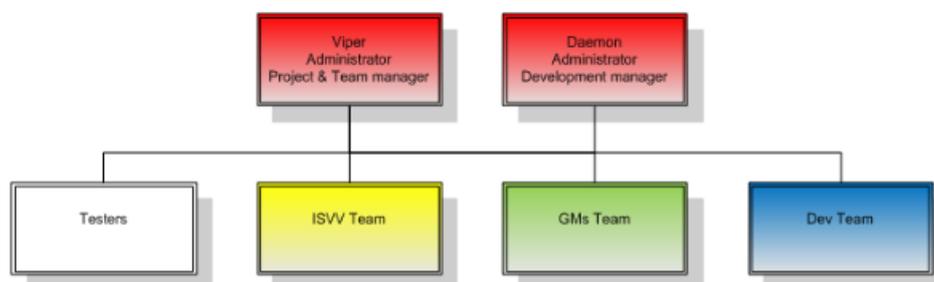
FIGURE 5. Two layer organization.

Issues appear once the size of the staff grows above 20 members: administrators then have to take a lot more time managing all of the staff, plus all of the other activities only they could do leading to delays regarding decisions impacting the whole project. As a consequence, an additional layer was created in the OBS, offering new opportunities inside the staff and delegating much more work. This new core team needs a core meeting to synchronize each week in order to be in line with the latest project information. This new organizational structure makes it possible to deal with a much bigger team.
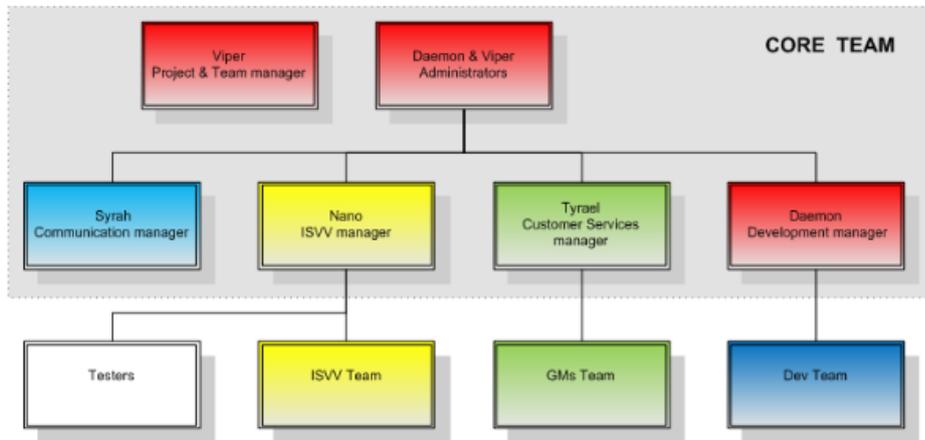
FIGURE 6. Three layers organization.

The IsVV and customer service teams became larger over the following months. Adding the fact that further tasks were being delegated to the corresponding managers, a new opportunity was created in order for them to delegate common work, as such a transverse manager support position was opened. The picture presents the final state of our OBS. Few weeks after the success regarding the creation of this opportunity, manager support was included inside the core team.
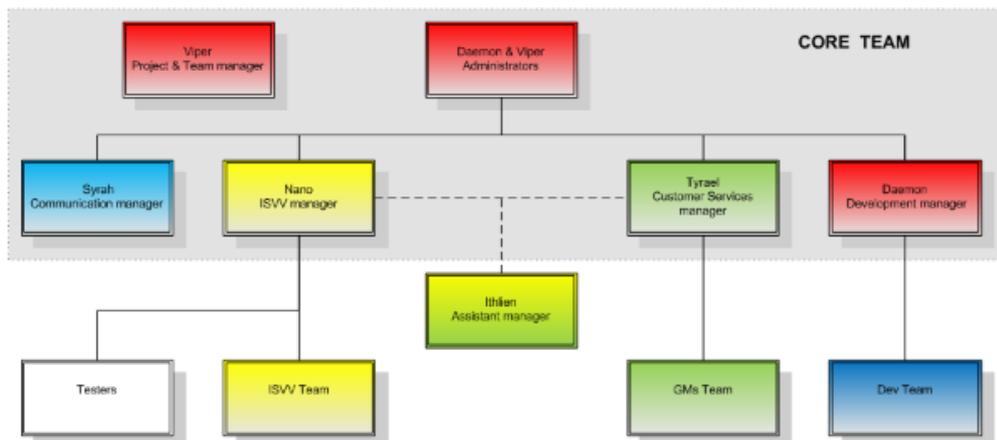
FIGURE 7. Three layers organization with transverse assistant.

Beginning of April, the staff size was around 40 people and 1000 active bug reporters, including:

- 6 members in the development team.
- 24 members in the GM team.
- 7 members in the IsVV team.
- 1 member in the communication team.

4.1.1.1 Core team

The Core team consists of the administrators and team managers. It is dedicated to the project's strategic and tactical management. It makes decisions that affect several different teams, such as the roadmap or content changes, delays, tasks and recruitment.

During the weekly Core team meeting, administrators provide information regarding the short and long-term objectives, past and future goals while all managers provide overall information about their respective team.

4.1.1.2 Communication team

The Communication team is in charge of the external communication: social media, marketing and advertising for Nostalrius. This team also provide thorough analysis of the community's needs, issues, and act as a liaison for the administrators.

Note that the communication team was still under consolidation at the end of Nostalrius' journey.

4.1.1.3 Development team

The development team is in charge of the design, implementation, and maintenance of the various technical systems that Nostalrius deploys. It includes the emulator, the scripts, the database, the website, monitoring tools, etc.

This team is also in charge of hardware and networks issues that may affect the player's experience.

4.1.1.4 Customer service (Game master) team

The game master team provides in-game and forum support and enforces the rules through sanctions on both platforms. It gathers volunteers from around the world; in order to ensure quick response times during the 24 hours of a day. GMs are known for their professionalism, impartiality and integrity.

4.1.1.5 Independent Software Verification and Validation - IsVV team

The IsVV team is responsible for the bug tracker. This team deals everyday with reported bugs, by researching the correct behavior, documenting a step by step way to reproduce the issues and forward them with a level of priority to the development team. Having an dedicated IsVV team significantly decreases the workload of the development team.

This team is also in charge of the Player Test Realm - PTR, assisting players when new content is added and monitoring raid tests as they are conducted.

4.1.1.6 Transverse management support

With the constant population increase came a workload increase for both the ISVV and GM team managers. To maintain the reactivity and level of quality, a transverse opportunity has been created to support the IsVV and customer service support teams.

The goal for the transverse management support is to decrease common tasks handled by both managers in order for them to focus on critical tasks.

Bug reporters aren't part of the staff but hold a key role in the project's success. The amount of content available could not be properly tested without these hundreds of people helping the official teams.

Content cannot be released prior to proper players testing on the PTR.

4.1.2 Work breakdown structure (WBS)

The Work Breakdown Structure is a hierarchical decomposition, based on tasks and activities that the project's teams need to execute in order to meet milestones and the project's goals.
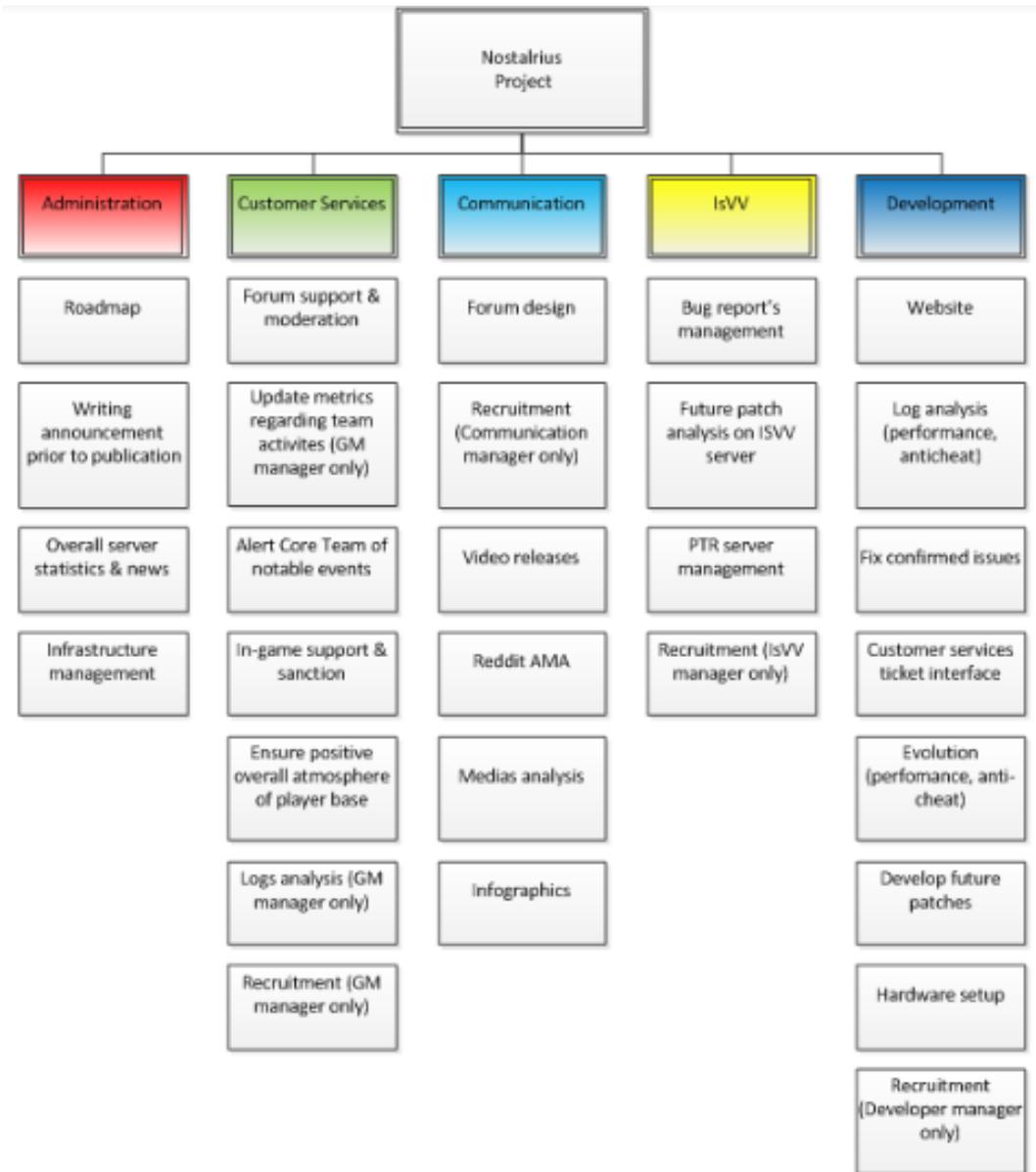
FIGURE 8. Work breakdown structure.

Each team manager was in charge of their own recruitment process which is then validated by an administrator. Recruitment was based on skills, motivation and in-game behaviour if the candidate was playing on the server.

Each announcement was provided to staff members prior to any official publication. The

goal was to validate the document and to involve staff members in common tasks while getting access to sensitive information.

Each week, the customer service manager had to update metrics regarding his team: number of tickets handled, number of posts on the forums and future vacations scheduled, plus a check on all his team member's activities. A complete report was then provided to the administrator for weekly review. Once abnormal activity was detected, the corresponding member was more actively monitored to avoid any possible issues.

Focusing on internal work in order for the project to be a success can drive away the core members from their community. A Reddit AMA - Ask Me Anything had been organized to maintain the communication with our community: anyone can ask any question for 2 hours, while the team answers as many questions as possible during the 2 following hours. The goal was to do an AMA every 6 months along with constant announcements on the forums and our other media to preserve this link between the team and the players.

Prior to a new patch being applied on the live servers, corresponding modifications would be added to an IsVV internal server. This would allow the IsVV team to validate the fixes applied during the development process and give our team one more pass through the content to uncover any potential issues. This process helped reduce the number of new bugs introduced when a new patch was launched.

Nostalrius generates more than 10GB of logs every week. Content of these logs are processed by automated systems in real time but can also be reviewed by development and customer service managers for deeper investigation.

4.1.3 Human resources management

4.1.3.1 Staff members background

Recruitment of staff members on a volunteer basis is a very difficult task. The turnover was also significant, with an average loss of 2 members per month. The turnover started to decline during Q3 2015 thanks to reorganization and internal mobility that will be described later.

	March 2015	April 2015	May 2015	June 2015	July 2015	Aug. 2015	Sept. 2015	Oct. 2015	Nov. 2015	Dec. 2015	Jan. 2016	Feb. 2016	March 2016
Real FTE	21	29	32	29	25	25	25	26	26	28	35	35	38
Estimated FTE	20	20	20	23	24	29	29	30	31	32	32	35	37
In	14	14	11	2	3	1	2	1	1	6	7	2	6
Out	-5	-6	-8	-5	-7	-1	-2	0	-1	-4	0	-2	-3
Delta	9	8	3	-3	-4	0	0	1	0	2	7	0	3
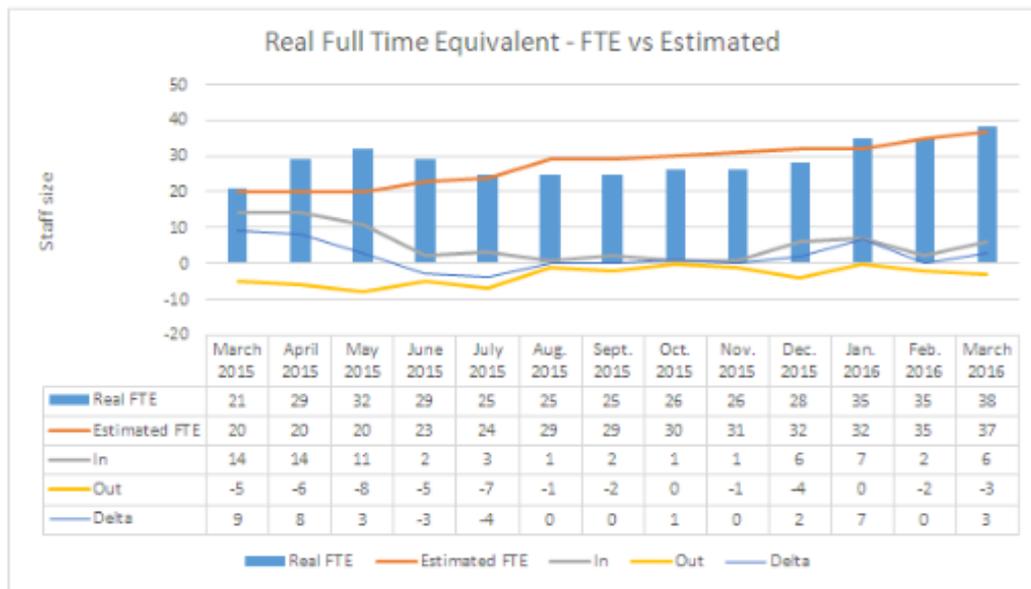
FIGURE 9. Human resources evolution during the project.

At the beginning of the project, the staff wasn't fit for more than 20 people. Everything was directly managed at administrator's level. As a consequence, a lot of members left between May and July. It resulted in a lot of stress starting July since we had more work than resources available.

The forced reorganization, mobility, additional tools and the opening of more volunteer positions allowed us to manage many more people, ending with nearly twice the number of volunteers than at the release date, and was still growing.

As described above, staff members are located all over the world, and their current professional activities span over a large number of sectors. Find below as an example, a list of some main jobs of our staff members:

- Truck driver.
- Farmhand.
- Emergency ambulance crew.
- Director of marketing and sales.
- Software trainees, developers and manager.
- Librarian.
- Lead financial analyst.
- Lawyer.
- Company director.

4.1.3.2   Trusting unknown staff members

The Nostalrius team was essentially virtual. Staff members would work mostly with people they never met, coming from around the world, and with different cultural backgrounds. At the same time, Nostalrius held sensitive information such as data, code, etc. whose leak could irreversibly harm the whole project.

Thus, applicants had to first pass a "background check", where game logs regarding their characters were examined. It includes a deeper search for potential rule violations. The in-game played time was also a major factor in the final decision: the more implicated the player is, is the more we can trust them to be an honest and dedicated staff member.

Staff members were always assigned to a specific team, either GM, IsVV Comm or Dev, and would not have access to unnecessary internal information outside of their team. Each team had different information access levels.

The GM team had different permission ranks, associated with different information access. Most of the developers did not have access to complete source code, which had the drawback of making development even more difficult. To give an idea of the impact of this constraint, this was one of the main reasons why our next project became open source (Nostalrius TBC).

However, having staff members feeling involved in the project was something crucial to keeping them motivated for their volunteer job, and to keep the whole team united behind the project. To achieve this, we had to provide regular information regarding strategic changes we were making, but only shared information to be publicly released soon.

4.1.3.3   GM specific training

Recruitment on a volunteer basis can be challenging, so the team utilized multiple technics in order to keep team members engaged, one example was a GM ranking system. This meant that after a scrupulous interview process we would start off the new GMs as a training rank and with hard work and effort they could move up. This allowed the GM staff to build trust with each other, it allowed newer GMs to become familiar with the commands, procedures and policies, and it also played a huge role in keeping volunteers around as they had a goal to work for. Once a GM became familiar and put in enough effort they would be ranked up, given new commands, given more access to private documents and information, and given more trust from the GM manager and assistant manager. There were a total of 5 ranks, the 5th being dedicated for the GM manager.

4.1.3.4   IsVV specific training

Each new IsVV member underwent a 4 week trial period. During the first week, a list of 5-10 bug reports were provided to the potential IsVV member asking them to validate or invalidate the issues while explaining their answer with concrete evidence. The list was then verified by the IsVV manager based on his own work and made corrections as necessary. They would then be explained how player questions should be answered, and given some best practices to use while working on the bug tracker.

During the second week, potential IsVV members would receive access to the internal

IsVV realm and would walk through all of the commands needed to reproduce and confirm issues as quickly as possible.

During the 3rd and 4th week, potential IsVV members had to report to the IsVV manager each bug report they had worked on for him to validate their work. Assuming everything had gone well through this process, potential IsVV members would then be given all of the tools necessary to do a proper job after 4 weeks.

4.1.3.5 Promoting internal mobility

Working with volunteers is different than working in a standard company. If staff members don't like the organization or don't like what they are doing, they will leave right away. As a consequence, a lot of effort was put into internal organization, in order for everyone to have a clear vision of what they were in charge of, and the criticality of their tasks.

The second step was to create internal mobility inside of the staff. Once a staff member became trustful through an extensive process, losing them would have been seen as a failure because of all the time spent on training, and the fact that finding another staff member will be difficult and a time consuming task. As a consequence, Nostalrius offered team members the option to switch to another team if they weren't satisfied with their current tasks anymore, once again reducing turnover in the staff. The usual patterns were to see GMs switching to IsVV, and IsVV switching to Dev.

FIGURE 10. Promoting internal mobility.

GMs often had a summarized view of the critical issues because of the time they spent going through players tickets. They would thus be able to quickly help with testing, once given basic IsVV training.

4.2 Project communication and community management

The communication of Nostalrius has been designed to answer the following objectives:

■ Provide competitive intelligence and community feedback.

■ Maintain a link with previous players through social media.

■ Develop and maintain a good brand image.

An extra objective was to build the initial excitement around the project to ensure a successful launch.

4.2.1 Pre-launch communication

The success of Nostalrius relied on the successful launch of the PvP realm. Before being internationally launched in 2015, Nostalrius was a french server which had progressively turned into an international realm.

However, despite having an already similar level of quality, players were not willing to join a MMORPG with 100 online players, for several reasons:

■ Most of the players already built an established community which was quite difficult for newer players to join.

■ A realm having a low population for a few years is considered a "dead realm" and is unattractive for a part of the community.

Once it was realized that these factors would prevent us from having a more populated realm, we decided with the community to shutdown the previous gaming realm to prepare a fresh, new and international launch for Nostalrius.

Lot of research were done, involving participation in multiple convention mainly in Paris related to company creation and handling, creating a successful marketing campaign and brand, plus personal research on social medias, how it needs to be used, for which kind of population, and depending on which countries, culture from different countries, etc. Based on all these strategic intelligence, a marketing plan was built few weeks after.

The pre-release promotion was mainly targeting former private server players and more specifically the Vanilla community. The pre-launch marketing campaign was conducted in several steps.

4.2.1.1 Creation of a newsletter registration page and a basic website.

This registration was used as a benchmark for our marketing strategies. We would also send exclusive information to the newsletter recipients that included special access to the public testing realm prior to release.

4.2.1.2 Communication through our Facebook page and release of feature and content videos.

The goal was to gain feedback regarding the type of video the community was expecting, and to become more familiar with Facebook as a promotion media outlet. At the same time, a minimal team of English speaking moderators had to be recruited for the upcoming forums.

4.2.1.3 Release of the forums

The goal was to have a place for the community to start planning their stay on the server: guild registration or advertising, questions about Vanilla WoW, etc.

Regarding human resources, moderators had been trained to handle a growing community at this time. They would then become the initial GM team of the upcoming realm.

4.2.1.4 Several specific testing sessions had been conducted

These tests were necessary for the Dev team to gather feedback, but they were also a true showcase of our scripts and quality. At the same time, streamers joined the adventure helping a lot Nostalrius advertising on streaming platforms, especially Twitch.

The testing sessions were short and focused on specific content to concentrate the population at the same place at the same time. This was also a way for a lot of players to experience the "Vanilla experience" for the first time.

These testing sessions truly gave the project the credibility required to validate the release process.

4.2.1.5 Server trailer and release

Due to the highly competitive nature of the legacy realms market, it was decided to release the realm shortly after the release trailer. 2 weeks were necessary for the players and guilds to organize themselves.

During this process, we made sure to publish at least one video and newsletter per week. This way we created and maintained a level of hype throughout the whole pre-release process.

The launch went beyond expectations: we expected about 1,000 players online, but over 3,000 were connected concurrently during the first day, and more than 4,000 the second one.

After the server release and the initial excitement, the population decreased during the first 2 months by about 15%, before increasing consistently again after. It may be related to the leveling difficulty in the over-crowded context of a server launch. This is something that has been also noticed after the PvE realm launch.

Online Players
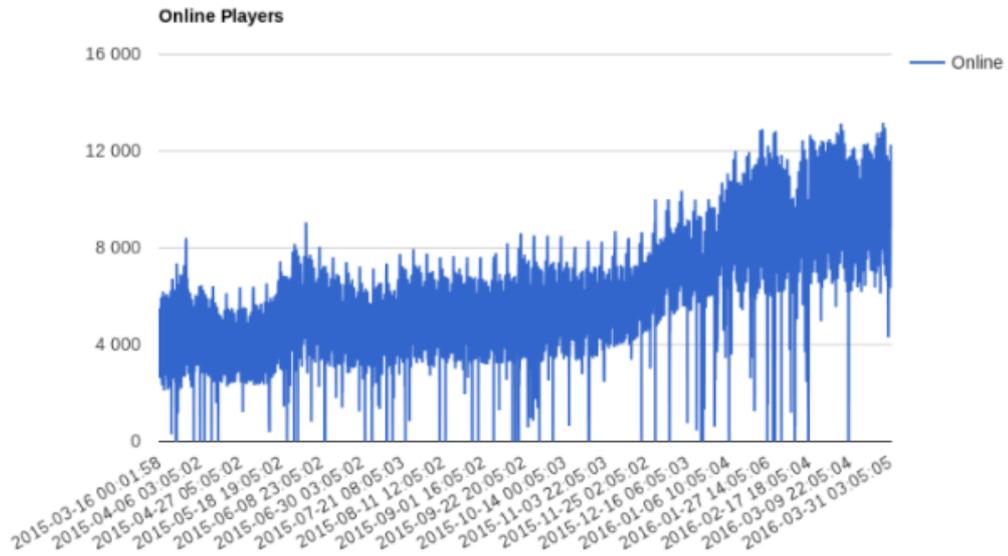
FIGURE 11. Nostalrius PVP server population over time.

Online Players
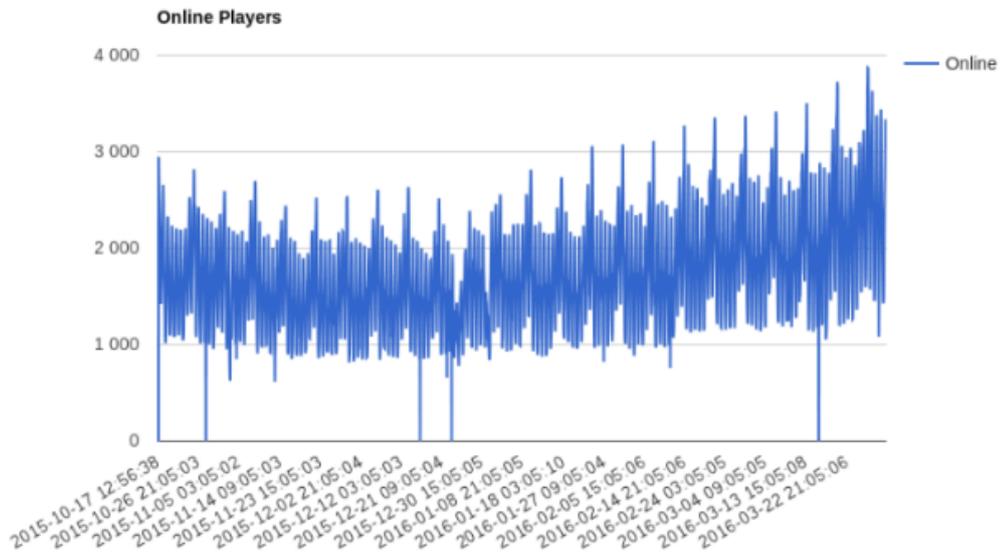
FIGURE 12. Nostalrius PVE server population over time.

4.2.2 Communication scheduling and characteristic times

In order to keep the player base active and involved in the project we needed to update our community regularly with news, updates and content.

The goal was to publish new content every 2-3 months such as new patches for example, and regular announcements in order to keep our community updated on a weekly basis. These included:

- A list of fixed bugs: every month on average.

- 2 announcements per content release: one to announce the player testing session, and a second one to announce the release date.

- Policy changes.

- Major server events or milestones.

- Hardware upgrades.

- Recruitment announcements.

- Upcoming development or improvements.

- Website updates.

- etc.

In order to maintain this rate of one announcement per week, we had to keep a schedule one month ahead of planned announcements. Sometimes, we would prefer splitting a patch release or an announcement, or delaying another to maintain our release or communication rates.

Depending on the media, we would also provide more frequent updates. These were mostly images that were posted on Facebook and Twitter between forum announcements. The following statistics provide an inside first look on how our different official media outlets had been used. All of this data had been gathered before the final shutdown announcement.

	Forums	Twitter	Facebook	Youtube
Community	200 online users*	8k followers	16k likes	8k subscribers
Announcements per week**	80k registered users 1-3 announcements	20 tweets/RT	3-6 publications	Content release trailers
People reached per announcement	15k views	30k views	20k views	30k views

TABLE 1. Media statistics.

* Forum accounts active within the last 5 last minutes.
** Official forum announcements, tweets, and Facebook posts.

4.2.3   News publication workflow

As described above, Nostalrius would typically publish an announcement every week. All of these announcements however had to follow a strict validation process, in order to make sure that they were error-free and would not contain grammatical mistakes. The process would usually stick to the following timeline:

D-0	News public release
D-1	News review by staff members
D-1 to D-7	News validation by Core team
D-1 to D-7	News writing
D-30	News scheduling

TABLE 2. News publication workflow.

Involving the whole team allowed for a deeper review of the news, regarding both words used and the content itself. This is also a major point for unifying the team around the project, since everyone is getting involved in the process.

4.2.4   Schedule Analysis

Starting in September 2014, a complete schedule had been created with a release goal for the server of February 11th, 2015. The existing team worked extremely hard but the project was released with a 2 week delay for a 6 month planned ahead roadmap. The delay was a result of the item progression through patches (little more than a week) and of the anti cheat system upgrade. Both of these tasks weren't part of September roadmap but appeared to be mandatory prior to the server release.

During February, a new roadmap was provided covering more than a year and a half (until Naxxramas release). Compared to what was initially planned, the team fell into a delay of about 5 months. The following paragraph will provide complete details about what kind of unexpected events we had to deal with taking critical team member resources which had not been scheduled at the server opening.

Nostalrius was expected to host around 1,000 connected players during peak hours at the server release, with a target goal of 2,000 for the following months. The fact that more than 13,500 players were connected during peak hours on one server before Nostalrius shutdown was unexpected. To face this challenge, server performance had to be enhanced, new hardware had to be bought, teams had to be reorganized, a new PVE realm was released, and specific developments were needed which costed us an extra 62 days of work, representing 46% of the overall delay.

Another unexpected challenge was the tremendous will to bypass our terms of service through hacking, gold selling, botting, and sometimes these hacks were made by companies with the help of skilled professionals. Resources were mobilized to ensure a technological watch for potential future threads and update our protection systems accordingly. They also responded to threats Nostalrius was facing, such as gold selling, advertising, and DDoS attacks. These tasks were done at the cost of a schedule delay totaling 46 days, 34% of the

overall delay.

Transverse work like requests from the community to deliver a public bug tracker and improving the website took a total of 17 days, representing around 12% of the overall delay.

The Burning Crusade project overall organization including the complete open source approach, agile/scrum management and all of the related tools took a total of 10 additional days, representing 8% of the overall delay.

Even with the experience that the team had managing projects and development for years, the unexpected amount of population and the resulting fight against people willing to earn money from the project summed up to 80% of the overall delay and was something completely new to the team. Nostalrius succeeded to address these challenges at the strong cost of a content release delay.

ID	Date	Unscheduled task	Delay (days)
1	2015/03	Server performance enhancement	5
2	2015/03	New public bugtracker	7
3	2015/03	New hardware	3
4	2015/04	Hacking upgrade over time	10
5	2015/04	Gold seller tracking + analysis over time	15
6	2015/05	Bot detection system + analysis over time	15
7	2015/06	Server performance enhancement	5
8	2015/07	DDOS attack	3
9	2015/08	Team re-organization	3
10	2015/08	PVE test server opening + log analysis	4
11	2015/08	GM tool to handle 2 realms at the same time	7
12	2015/09	Server performance enhancement	5
13	2015/10	PVE realm announcement event "Kryll" (promotion + development)	4
14	2015/10	New website	10
15	2015/10	PVE realm release	3
16	2015/12	Dynamic respawn for herbs and ore	3
17	2016/02	Clustering development phase 1/3	10
18	2016/02	Burning Crusade project	10
19	2016/03	Security enhancement (VPN, countries & website)	3
20	2016/04	Clustering development phase 2/3	10

TABLE 3. Schedule analysis delay after 1 year.

5 Quality analysis

5.1 Development team

5.1.1 Automated Tests

Automated Tests - AT were first implemented at the beginning of 2015 and were presented through a video delivered on our Youtube channel February 3rd, 2015 available here:

www.youtube.com/watch?v=JozAj-wrBWw&feature=youtu.be&list=PLPgrywi0V6Q0h5HFZyHzia4W7nHkbrEp8

AT are part of the best-practices in software development and have become a standard in every industrial project. They help to increase the release quality and decrease regressions. Furthermore, properly done automated tests can also be reused on other projects (Nostalrius Vanilla and Nostalrius TBC for example).

What can be automated?

- Any repetitive task.
- Any test which takes a lot of time to manually run.
- Any task which is not tolerant to human mistakes.
- Any task where human added value has low interest.

FIGURE 13. Automated tests being run on Nostalrius.

Usually tests are defined during the early specification process, along with the frequency that they are meant to be executed (every commit, every content release, etc.). The AT strategy is used for some of the testing requirements.

In our case, AT were developed once the project was nearly ready for official release. It was a mistake to develop AT directly in C++, resulting in a limited Return On Investment - ROI.

Developers with direct source code access are already a critical and limited resource for future content releases and bug fixing. AT should optimally be written by non developers, or developers without source access.

As the IsVV team grew in maturity, we rewrote our testing framework and ported it to LUA, a scripting language, cross-platform and easy to use. This language is widely used in video game industry.

It now allowed nearly anyone, even outside of our team to create their own scripts and tests through a simple API. That's the choice we made for our Burning Crusade project. A dedicated website was being developed in order to propose, test and validate AT. Once validated, AT scripts could be regularly run on a dedicated test server.

The IsVV team would be in charge of AT validation, while AT would have been created by the community itself. This is the highest ROI possible from our point of view. It would eventually have created a sandbox for prospective TBC developers where we would be able to recruit the most talented developers for the official team.

5.1.2   Peer reviews

The development team consisted of up to a dozen members, and some of them were quite new to World of Warcraft emulation environment, or to programming in general, for example in case of internal migrations. We thus had to conduct peer reviews in some cases.

This ensured a strict respect of the coding quality standards imposed by ourselves in order to prevent software regressions or errors. Furthermore, it was an essential part of the training of our new recruits, allowing them to collect feedback and best-practices from senior developers.

A peer review could be sometimes requested by a developer for a specific change, and was systematic for code modifications in critical systems. The Dev manager would at least always review the modifications made to the emulator "Core" repository.

5.2   Customer service statistics

The variety and number of tickets remained stable on average with temporary spikes in daily tickets shortly after patches and content releases for service related issues. Ticket numbers increased linearly with the population and a lot of attention was put into efficiently reducing the number of incoming tickets (see: Efficiency strategy). On average, the GM team would receive 1,200 tickets per week since launch.

Described below are how many tickets were open at a time, how many game masters were online, and all around percentage of categories reported to the GM team.
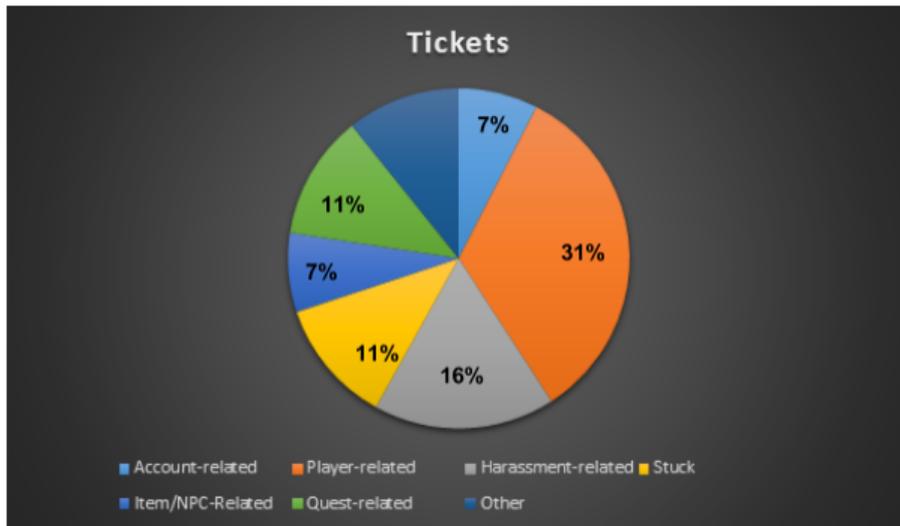
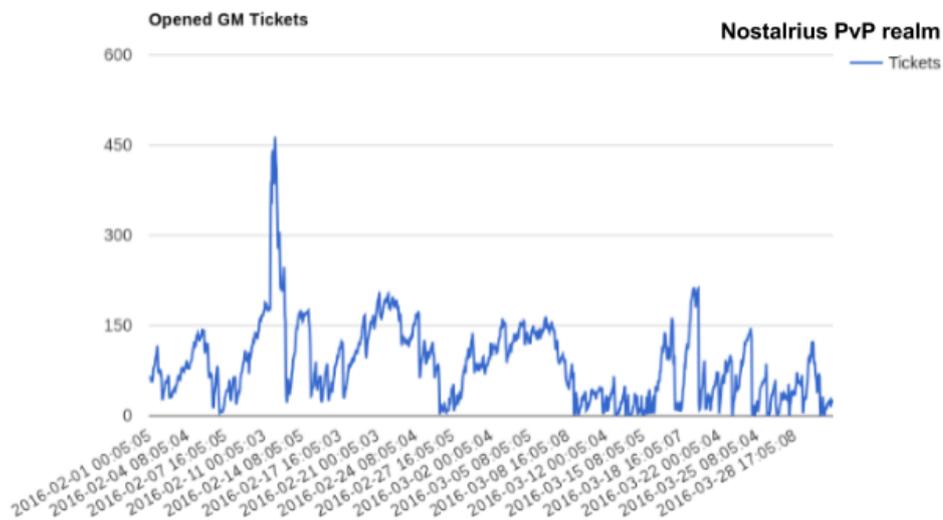FIGURE 14. For how long would you play on Blizzard legacy realms ?

FIGURE 15. Tickets activities on PvP realm starting 2016.
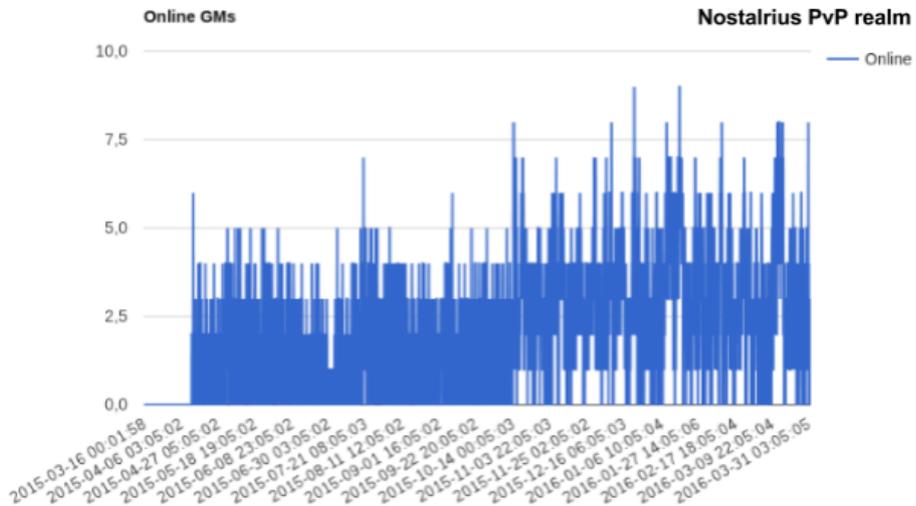
FIGURE 16. GMs activities first month after official international launch.

The graphic above is an extract of the GM activities at the PvP server release. The graphic below is nearly one year after the PvP realm release. Thanks to GM team's complete reorganization, there was a significant increase in coverage.

FIGURE 17. GMs activities last month prior to project shutdown.

5.3 Efficiency strategy

All teams were limited in resources, even though the GM team was the largest in the staff (more than 60%), they were still not an exception. The following are examples of methods that were used to reduce the impact on the team and allow to them to work more efficiently:

5.3.1 Define specific policies to reduce GM intervention

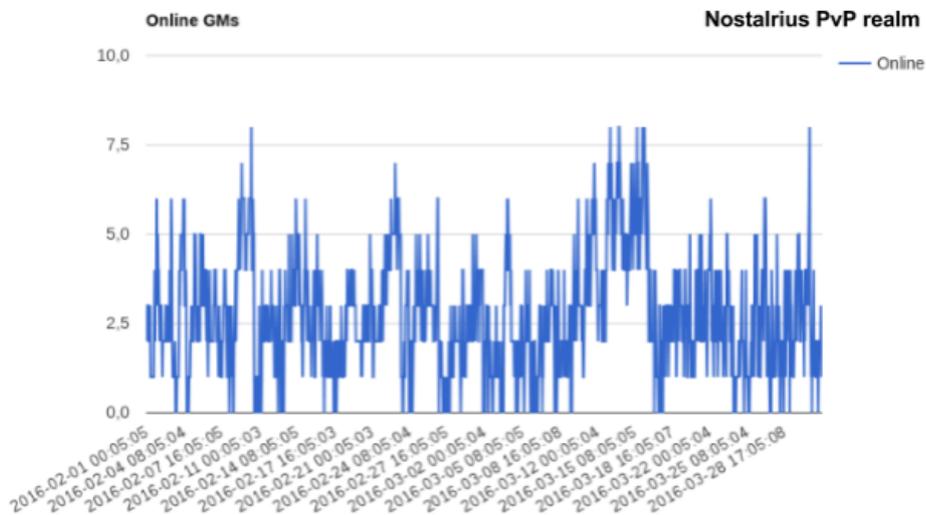Corpse and spawn camping was allowed. There was no limit on time that it could go on for. It was not reasonable for GMs to monitor the activities of a suspected offender and would cause too many conflicts trying to police players in this way. If the policy was to be changed then the detection and sanctioning would have to be automated.

Most harassment and chat violation reports were eliminated by the requirement for players to utilize the /ignore function prior to reporting for these types of offenses. If a player bypassed this function by using alts or public channels then the reporter would have to provide a screenshot proving the offense and only then would a GM intervene if the offense was confirmed. Requiring a screenshot would also have the added benefit for GMs not to require access to chat logs unless screenshot was edited.

There were strict rules on the restoration of items. This would eliminate the need for GMs to have the capability to spawn items for security reasons and would again remove them from the need to have to handle such tasks. The only time an item would be restored was if it was a raid epic that was lost during a rollback (when server restart). This would also occur rarely as Nostalrius was becoming more and more stable so the server would likely only be restarted once per week for updates and all raid epics were saved the moment they were looted. This would cause nearly all item restoration requests to be negated.

FIGURE 18. Strict rules on the restoration of items.

Whenever reasonably possible, most bugs that required GM intervention would not be handled in-game. Players would instead be directed to the bug tracker.

5.3.2 Forum support

Most technical support issues were handled on the support forums which were open for other players to respond and provide their own support along with official answers by GMs. This had the added benefit of identifying helpful and knowledgeable players within the community that may be suitable to join the GM team. There were also multiple stickied threads being maintained on the forums containing frequently asked questions and resolutions for common issues.

5.3.3 Other

Whenever possible, repetitive tasks would be automated and recurring bugs would be prioritized.

GM tools and commands were actively being developed and iterated on for further efficiency.

5.4 In-game ticket enhancement

When a ticket was filed it was assigned a unique number and displayed to all GMs which showed the ticket number and the name of the player that opened the ticket. GMs would then have the option to either assign it to themselves or assign it to another GM with the in-game interface. Once a ticket is assigned or closed it's also then displayed to all GMs showing that a ticket has been assigned or closed showing the ticket number, the player's name and either the GM that it was assigned to or displaying the fact that it was closed. To see the list of tickets in-game, a GM would either use a specific command which would display either the open tickets of players that are online or the tickets of all players. If a ticket is assigned to a GM it would then also display which GM the ticket is assigned to. GMs normally assigned tickets to others either for organization, training or escalation purposes.

5.5 Mobile player support - MPS

The web-based ticketing system was a graphical layout with a better view of information, easy to use buttons, and had a list of commands with tabbed chat for different channels and whispers. It was still under development and quickly became a powerful tool to help GMs in becoming more efficient without needed the game to be launched. As a consequence, the GMs could use the MPS with their smartphones. It allowed GMs to work on the PvP and PvE realms.

5.6 Public bug tracker

Vanilla World of Warcraft has more than 9,000 different creatures with different behaviors and scripts, 4,000 different quests with all of the possible interactions, and around 22,000 different spells. These elements have to interact with each other at some point.

It's clearly not possible to handle a project of this scale completely internally and without any contribution from the community. The project required a lot of testers to alert the staff about incorrect behaviour.

Having a public bug tracker is a win-win solution as the community can be actively involved in helping the Dev and IsVV team while utilizing a shared platform. The whole team felt that they supported the project by seeing each report as a contribution to make the in-game experience even better.

5.6.1 State of the art and needs

A bug tracking system or defect tracking system is a software application that keeps track of reported software bugs in software development projects. It may be regarded as a type of issue tracking system.

Prior to official international release, the bug tracker used was Bugzilla, a very basic and easy to use tracking system used by developers and IsVV only. After the server release, the community asked for a public bug tracking system, which was not possible with Bugzilla because of access and organization limitations. A bug tracker is an important link with the community that is willing to help by providing information on game mechanics. Active members can also be good candidates for IsVV recruitment.

As a consequence, we searched for a bug tracker which could answer to the following needs:

- Free.
- Integrated into a project management system.
- Administration regarding rights management.
- Able to hide specific fields based on group management.
- Able to handle metric graphics.

After some research, the decision was made to use Tuleap, an Project Lifecycle Management - PLM platform.

5.6.2 Tuleap and PLM

Tuleap is a Product Lifecycle Management (governance, development, and maintenance) for application software. It encompasses requirements management, software architecture, computer programming, software testing, software maintenance, change management, continuous integration, project management, and release management.
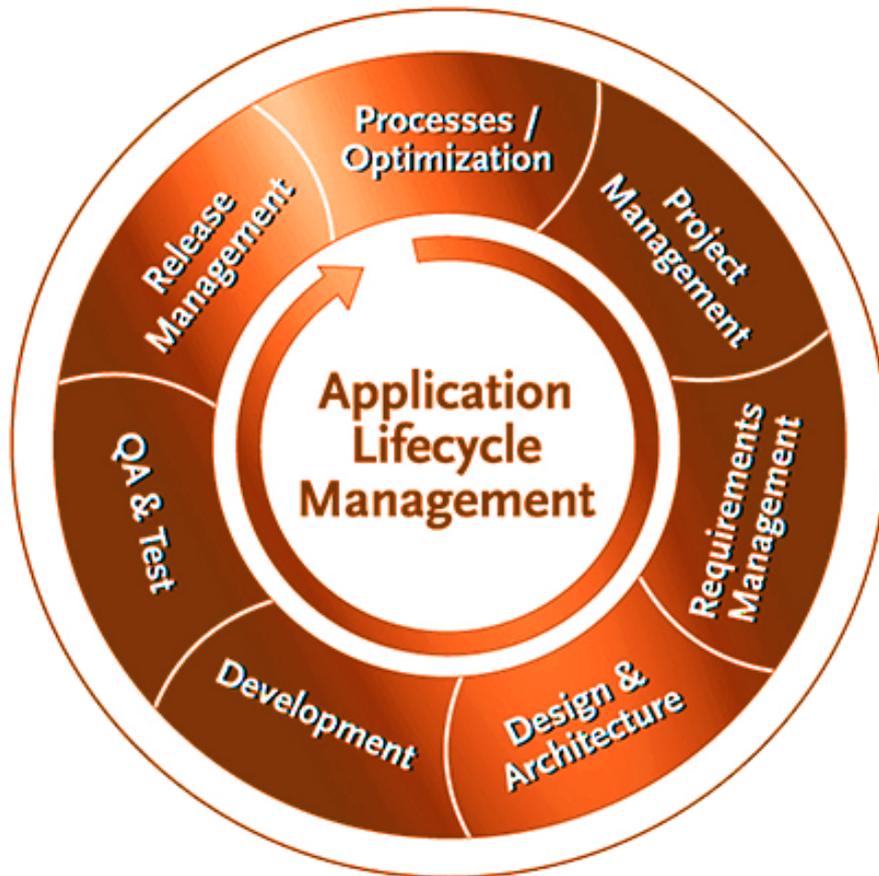

FIGURE 19. Application lifecycle management.

The PLM used by Nostalrius Begins, Tuleap, contains a lot of functionalities used to cover the scope described above. One of them, the bug tracker system, is public for everyone. The players can create and modify issues once registered on this system. It also help us to generate reports for each patch automatically.

When someone reports a new artifact; Summary, Description and Category are mandatory fields. It's also possible to update existing artifacts with comments or attach relevant documents to them.

Shortly after the bug tracker became online, around 1,000 active users were interacting with it. This amount of users never decreased.

6 Product analysis

6.1 Emulator presentation

The Nostalrius emulator had not been build from scratch by our development team. It stood on the shoulders of all the work that had been done before by the World of Warcraft emulation community, since 2003. Formally, Nostalrius was based on a 2009 MaNGOS version, which was forked from a late 2005 version of WoW Daemon, which used technical elements that were reverse engineered from the original client by previous teams. Nostalrius Burning Crusade project is based on a Q3/Q4 2015 version of this same emulator under a GPL v2 license.

From 2009 to 2016, Nostalrius developers worked to improve the game server, and from 2011, all of the changes were exclusively written by our team, except a few commits cherry-picked from open source emulators.

The Nostalrius game server was made of several main parts:

- The Emulator "Core" written in C++. It is the main server binary, and contains all of the generic handling systems.
- The scripting library (C++). This library is independent from the Core, and is loaded as a third party library at runtime. It contains scripting for specific units, objects, instances and spells.
- The Character dynamic database (MySQL, about 28GB for the most populated realm), storing all of the player related data (characters, spells, pets, guilds, etc.).
- The Log database (MySQL, about 3GB per week), storing all transactions, chat, character actions (login, logout, delete, etc.), and various data used for machine learning training (see: Anti cheat protection part).
- The static data.

The static data could be divided into 5 parts:

- The static World database (MySQL, about 100MB). This database contains among other things, the world object spawn information, some data related to specific spells, texts, items, some Event-based basic scripts, etc.
- Raw DBC files extracted from 1.12.1 client MPQs, containing for example spell definitions, area information, etc.
- "map" files extracted from 1.12.1 client ADT files, used to compute terrain height.
- "vmaps" files computed from 1.12.1 client ADT files, containing all visible spawns (M2/WMO files triangles), organized in a Kd-Tree, and used for ray tracing (line of sight, water/area detection, height computations, etc.)
- "mmaps" files containing tiled navigation meshes computed from both "vmaps" and "map" files, and used for path finding.
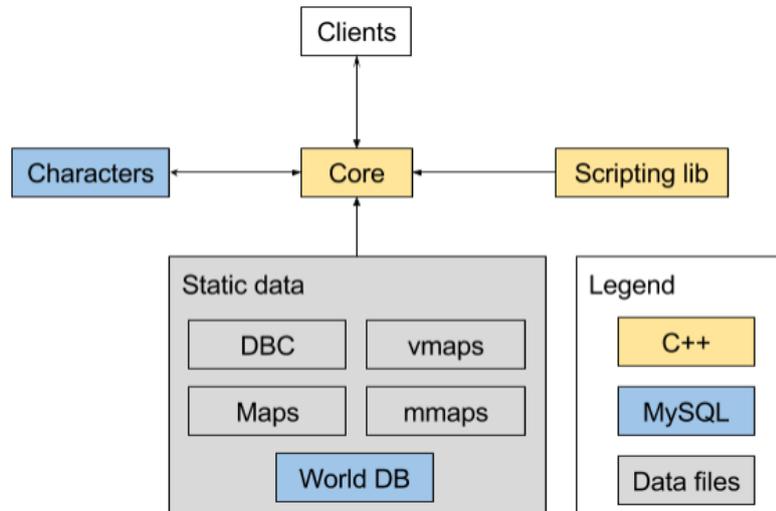
FIGURE 20. Game server architecture.

6.2 Hardware and hosting

Our game server did not implement any kind of clustering or distributed computing systems. Thus we had to use a single powerful physical server as hardware, and heavily relied on multi-threading for economical constraints.

The database also had to be entirely cached in the RAM, or to be stored in SSD drives for efficiency reasons.

	MG128 (PvP realm)	SP64 (PvE realm)	VPS1	VPS2
Maximum population	13,500	4,300	N/A	N/A
CPU	2xIntel E5-2650v2	Intel E5-1620v2	3 vCore	2 vCore
Storage	2x2TB HDD	2x180GB SSD	50GB HDD	50GB SSD
RAM	128GB	64GB	4GB	8GB
Network (max upload and download reached)	300/50 Mbps	80/20 Mbps	No data	No data
Supported population without quality tradeoff	10,000	4,000	N/A	N/A

TABLE 4. Hardware details.

Our multiple services were spanned over several physical servers. For network reasons, the databases were hosted on the same machine as the corresponding service whenever it was possible. Database systems did not use a lot of CPU, and there was no significant gain in splitting the database to a different machine.

3 servers would also be used to fully backup other servers' data (sources, databases, etc.) on

a daily basis, and to ensure that there would only be minimal data loss in case of hardware failure.
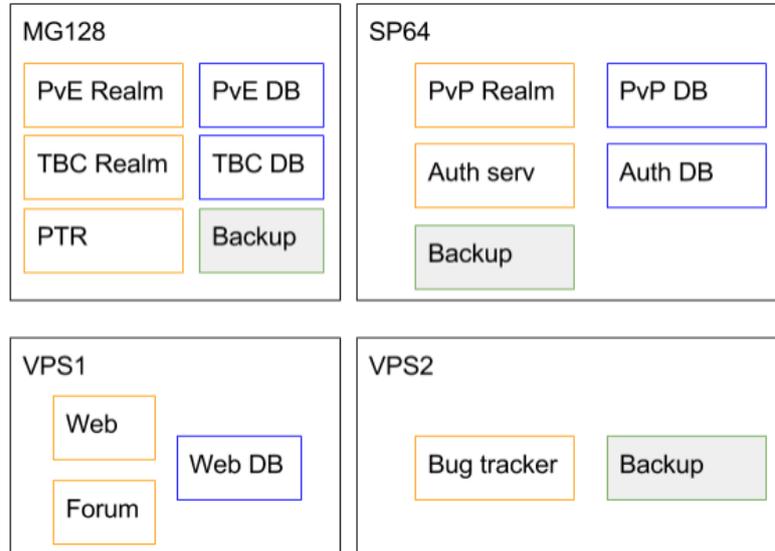

FIGURE 21. Hardware and service distribution.

Nostalrius servers were hosted by OVH. This hosting company provided us with:

- Good network peering - except for specific west-coast ISPs during some evenings. From around the world, the "ping" was excellent.
- Strong DDoS mitigation. We did not experience any prolonged outages, despite the attacks we regularly received (1-2 per week).
- Both powerful and reasonably priced servers.

We did not experience any significant issues attributed to OVH.

6.3 Produced code statistics

The table below describes the Vanilla project's source code statistics.

Source code modification over years

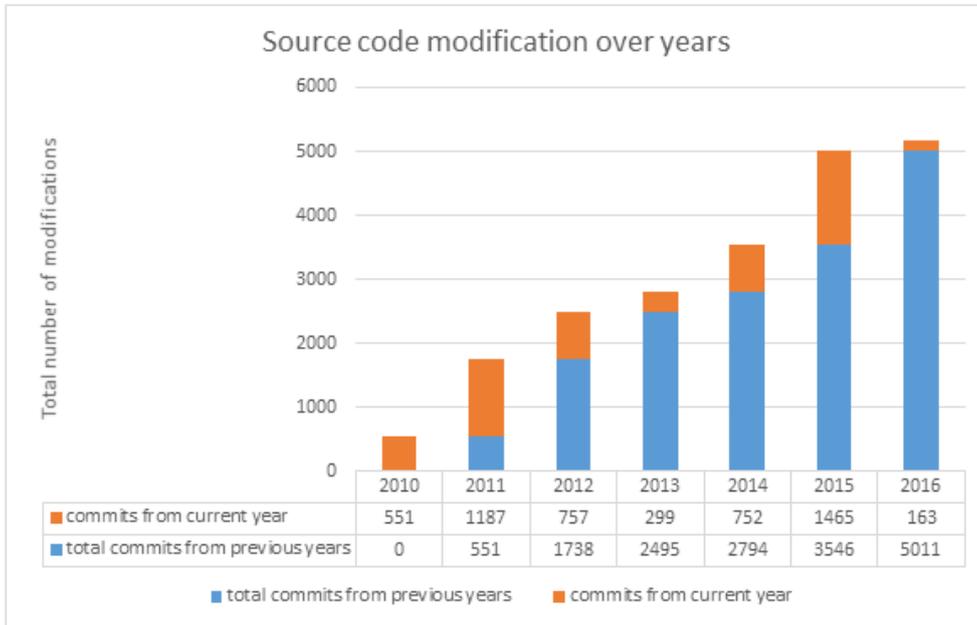|	2010	2011	2012	2013	2014	2015	2016
commits from current year	551	1187	757	299	752	1465	163
total commits from previous years	0	551	1738	2495	2794	3546	5011

FIGURE 22. Source code statistics.

Developers from the Nostalrius project did around 5,200 modifications on the source code since our project was created. Year 2011 and 2015 were the most active in terms of development with nearly between 1,200 and 1,500 modifications. The project now has a total number of 330,000 Line Of Codes - KLOCS. As said earlier, this source code is the same used for PVE and PVP realm.

6.4 Configuration management

Nostalrius Vanilla consisted of two online realms (PvP and PvE), and maintained several other realms for testing purposes (PTR, IsVV team dedicated realm, developer realms, etc.). They all shared the same source code, and the same world database, with slight modifications (patch progressions for items, instances opened, etc.).

Every update went through the following steps:

- A server compilation from a main source repository.
- An Import of the latest world database.
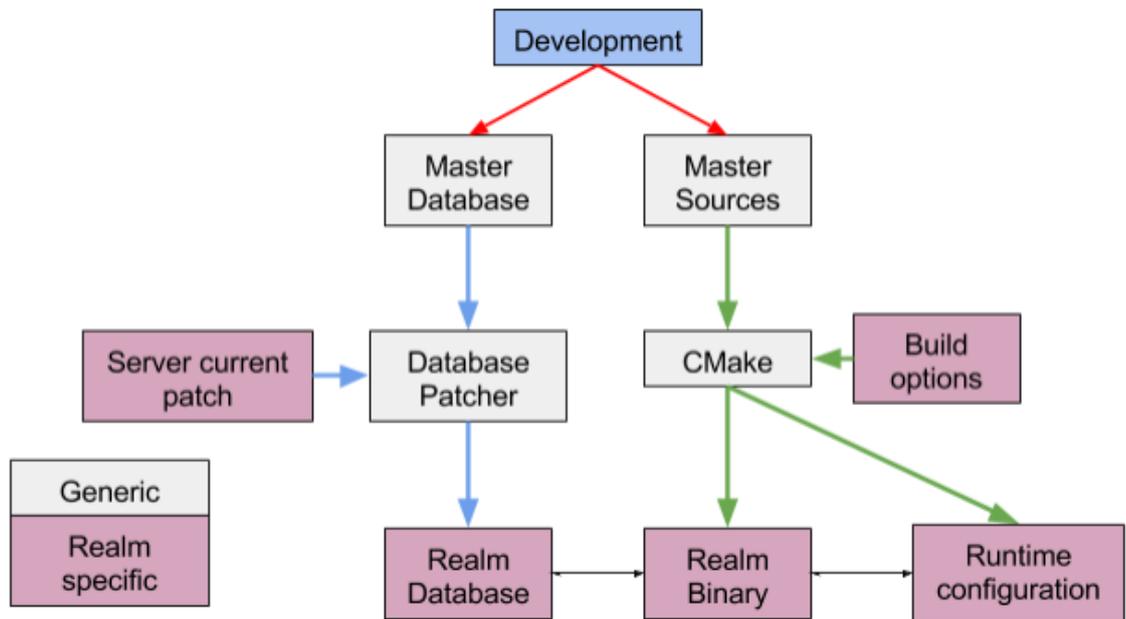- Application of specific database patches.

FIGURE 23. Configuration management.

Upon preparing a binary for a specific realm, we could provide some basic compilation options. The following were the most significant:

- Build mode: Optimization enabled or not ("-march=native -O3 -lto ...").
- Sanitizer: The clang/GCC sanitizer were enabled for testing realms (IsVV / PTR). We could track memory leaks and errors that way, to identify "random crashes" as soon as possible.
- Enable or disable building of scripting library: disabling it reduces the compilation time by 50% in some situations. This optional library is not needed when developing generic mechanisms.
- Profiling Guided Optimization: this option allowed the compiler to gather performance information at run time (on a PTR realm usually) to choose the best optimizations for the live realms.

The runtime configuration of a realm would typically include:

- Hardware specific performance tweaks.

- Gameplay specifics - realm type for example (PvE or PvP).

This configuration management procedure/system allowed us to have several realms sharing the same improvements/fixes running at the same time, with completely different database patches:

- The PvP realm with a 1.8 patch database.

- The PvE realm with a 1.5 database plus Alterac Valley.

- A development realm with a 1.12 database.

- An IsVV/PTR realm running to test the next upcoming patch (1.9).

We followed the same workflow for the under development TBC realm, except that the master database and sources were publicly available on Github.

7 Conclusion

7.1 Development strategies

The Nostalrius PvP and PvE realms were without a doubt a huge success as a legacy server, and in a way it aggregated the Vanilla community together. The next big project was the Burning Crusade realm which was to be released Q1 2017.

A lot of resources were invested into the TBC project, and used all of the feedback from the Vanilla experience to make it the best possible in our minds. As the project would be started from scratch, it was an occasion to improve things that could no longer be changed for the Vanilla project.

The project would have been way more community driven. The goal was to reduce the staff time needed to a minimum, and to increase the productivity and efficiency of all of the processes. It was designed around the following criteria:

- Open source emulator development with pluggable modules, namely an anti cheat module being closed source.
- Putting automated tests as an interface between bug reports and developers. The testing framework developed allowed tests to be written in the LUA language and safely executed by the server. The goal was to automatically check for regressions when a change is proposed.
- A platform to allow anyone to create, develop and test LUA scripts directly in the Nostalrius TBC testing realm.

The TBC development would create an open source development platform that could be used to train developers, even without programming knowledge, mainly because LUA is an easier language to learn. Anyone could contribute to the project, even without providing a minimum number of hours per week.

This would provide fixes, and unite a developer community around the project, which could be used to evaluate Dev applicants.

The official team developers and testers would only provide a schedule, priorities, and validate proposed fixes.

7.2 Others projects

Nostalrius was also working on 2 additional projects:

- A dedicated part of the forum related to pen and paper RPG, with a focus on the World of Warcraft book based on AD&D 3.5 system published by Werewolf. Forum would have been dedicated to provide guidelines, organization and all the tools necessary to make a successful RPG virtual team, providing campaign related to the subject. Goal was to provide this feature to the community June 2016.

- Another project was to create a legacy server platform including all the existing projects willing to share their experience, news and advices, including volunteers developers "marketplace", creating strong bond between this community, always bigger and stronger. Goal was to provide a dedicated platform starting September 2016.

8 APPENDIX

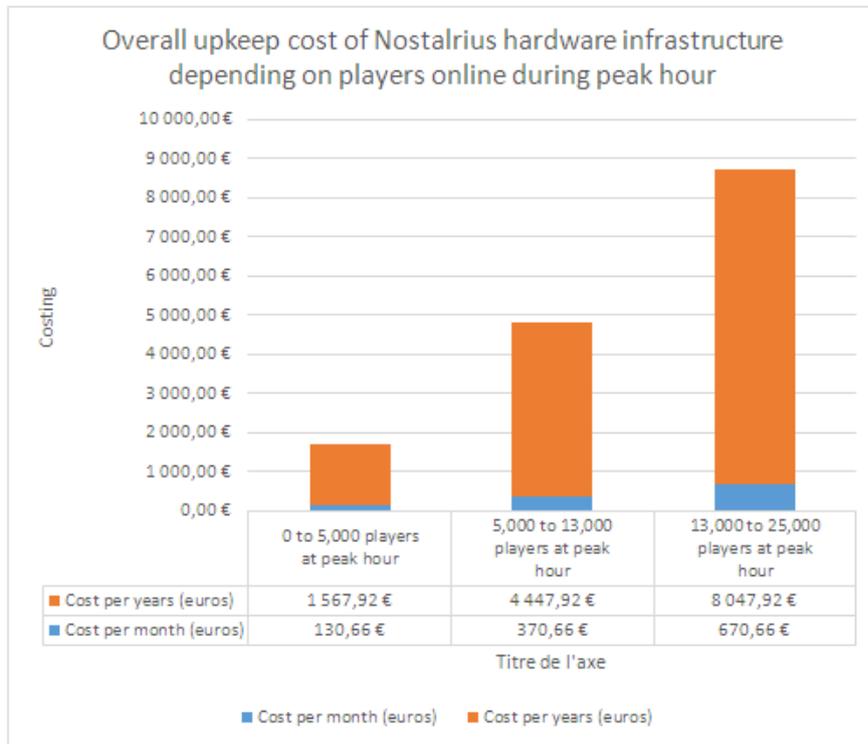### 8.1 Costs analysis

8.1.1 Initial expenses

FIGURE 24. Overall upkeep cost of Nostalrius hardware infrastructure.

Since the beginning of the project back in 2009, Nostalrius never asked the community for anything. The cost had been handled by the team itself for all of these years.

The first hardware infrastructure was composed of:

- OVH-SP64 (with SSD option) for about 1,200€ per year.
- Domain Name for 14.38€ per year.
- Kimsufi (for data Storage) for about 250€ per year.
- OVH-VPS (for forums and website) for 115.15€ per year.

For a total cost of 1,567.92€ per year.

8.1.2 Hardware upgrade and PvE realm

Nostalrius had several times more than the number of expected players at launch, and it increased over time to reach the hardware limitations server had at the moment. Upgrad-

ing the hardware was mandatory but would also multiply the global cost by more than 2. Renting an OVH-MG128 server would have raised costs by 4,447.92€ per year.

At this level, it was no longer possible for the team alone to support the hardware costs alone. A shop would most likely cover the hardware costs and possibly way more, but it was something deeply against our vision of the game. Being a non-profit organization was part of our DNA, and so it was our will to create a pure Vanilla experience without any game bonuses that would break the immersion and feeling.

To solve this issue, we offered the community a way to donate money helping with the server upkeep. Without any special advertising of this possibility, Nostalrius got enough support to cover the increasing costs of total the server hardware (8,047.92€ per year).

After some months, we had received enough money for a few more months, so we removed this donation link and direct links to support our hardware provider were published, for complete transparency. The population kept rising, but developers were still able to manage the server workload with software solutions, see *Performance improvements chapter* for more details.
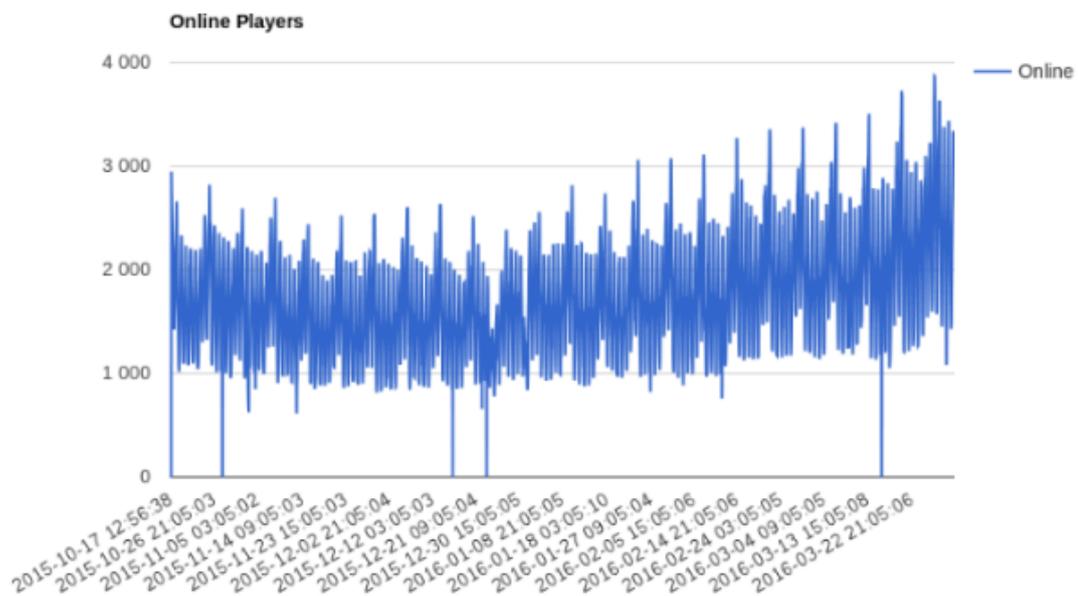

FIGURE 25. Population of the PVE server since launch .

The former hardware was then used to set up a PVE Vanilla legacy server, after we confirmed the community demand for it. This new server was opened in October 2015, becoming the biggest PVE legacy server in the world with approximately 4,000 players online.

8.1.3 Planned hardware upgrade

At the end of January 2016, the PvP server was hitting more than 12,000 players online at peak times every day. Once again, developers worked hard on a software solution. The Dev team proposed to split the workload inside a hardware cluster. This solution would allow flexibility and scalability on a larger scale but would require new hardware. The hardware considered was a OVH-MG256.
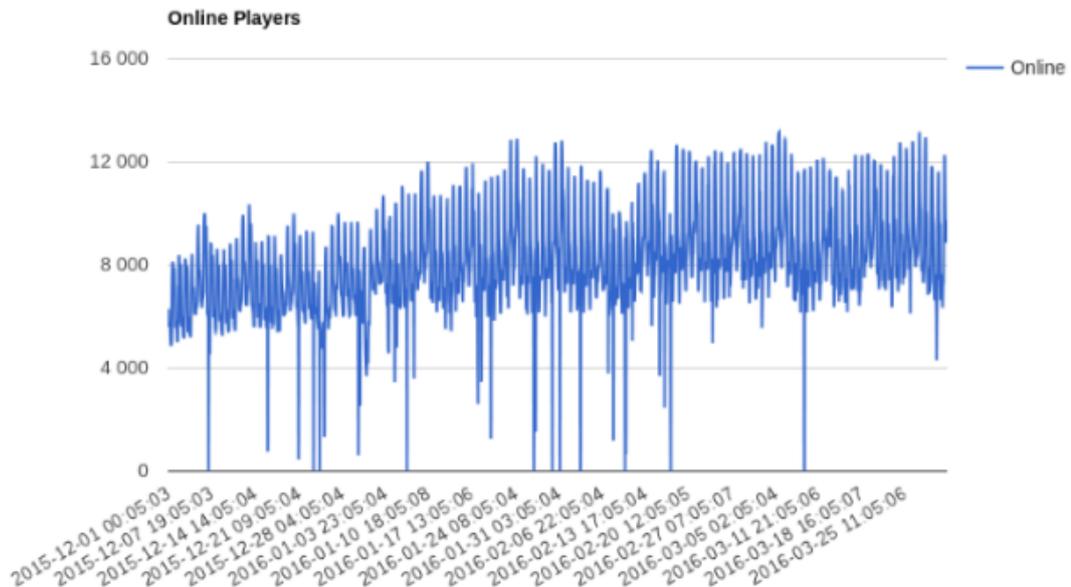

FIGURE 26. PVP server reaching more than 12K players everyday starting 2016.

An official announcement had been made on our forums. A chinese VPN company based in Germany proposed to pay directly to our provider for one full year of hardware renting, including the one needed for clustering system without anything in return from Nostalrius. An announcement was ready when the letter of formal notice from US and French lawyers had been received.

8.1.4 Transparency: community based server funding

Providing a direct link to pay the hosting company for hardware is something that had never been done before in the WoW private server community.

It took nearly one month to get this process organized and managed to always have three months paid ahead for all of our hardware infrastructure. That is the only option found to be fully transparent with the way funding was provided, as the Nostalrius team would no longer hold any money.

Talking about upkeep and money of a private server is a taboo in which we were the first to completely break. It's always difficult to estimate what a server needs in order to be operational, but Nostalrius could communicate on that topic since nothing was hidden. The

community was then aware of the total cost of a WoW server with different population values. Nostalrius never had less than 5,000 players during peak hours since its international release. The players should definitively keep in mind that for smaller servers, the cost should be even less than 150€ per month for example.

8.2 Performance improvements

There are several ways to deal with more than 13,500 online players on a single realm. The overall architecture should ideally be initially built with performance constraints in mind, to allow for example, flexible clustering in the cloud (increasing the computational capacity on demand), or a safe highly multi-threaded environment.

It was easier for us to focus on multi-threading with powerful hardware, rather than a complex clustering solution that could bring many issues.

We also analyzed what can be done to reduce server delays when reaching performance limits: what are the key parameters to tweak to provide our players with the smoothest game experience.

Finally, analyzis was done on some specific cases that require dedicated performance improvements.

8.2.1 Threading architecture

8.2.1.1 Parallelized maps

The first multi-threading possibility is to parallelize map processing. This can be done quite easily, and provides a significant capacity improvement. This change is even already proposed by default in some open source emulators.
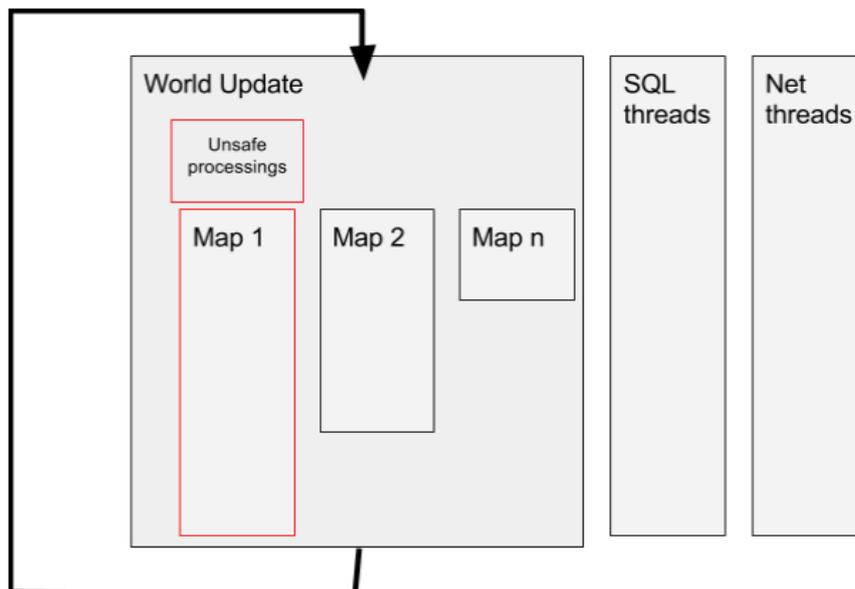

FIGURE 27. Parallelizing map processing.

Problem with this solution is that the CPU still spends a lot of time "waiting" for the slowest thread:

- Some computations are not safe and cannot be parallelized.

■ The delay felt by any player is the delay of the slowest map.

The following improvements have been applied to deal with a consistently growing population:

■ Update a map several times within a single world update. For example, battlegrounds with 20 players can be updated several times while a continent with thousands of players gets updated once.

■ Make code more thread "safe" and handle at the map level, reducing the overall blocking time spent on unsafe code.

■ Move some processing into their own threads. For example, auction house read-only searches, or /who requests.

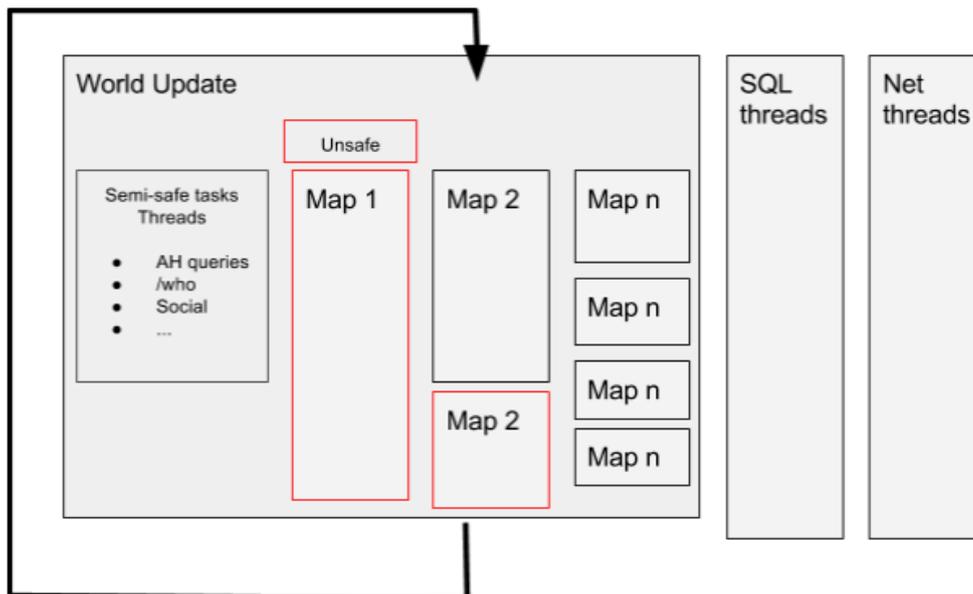Improvements can be summed up on the following schema:

FIGURE 28. First improvement form map processing.

8.2.1.2 Inside a map: instantiated continents

However, the biggest issue remains the update time for main continents (Eastern Kingdoms and Kalimdor). With more than 13,500 online players at peak times, we often had way more than 4,000 players per continent. How this challenge was adressed?

Single continent is split into several maps depending on the player position on the continent. Attention is paid to make sure our borders go through unpopulated areas (neither NPCs nor Gameobjects).
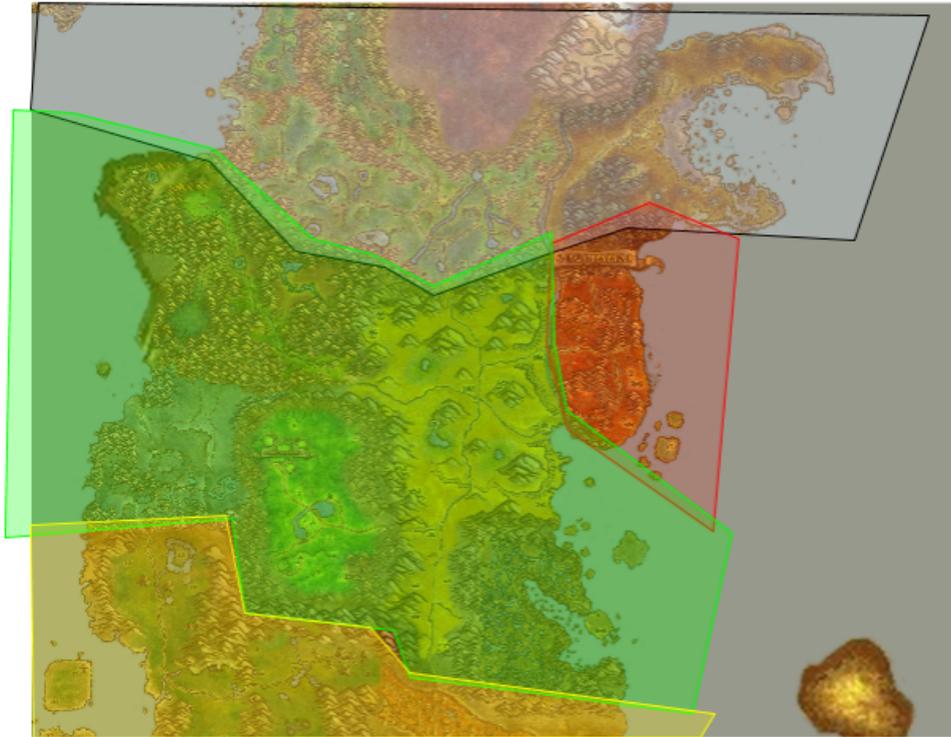
FIGURE 29. Instantiated map.

The consequence of this was a dramatic decrease regarding the map update time, and as a consequence the world update time.

Before:

Map	Average update time (= delay for players)
Map 1	T
Map 2	T/2
Map 3	T/4

Maps Update

Map 1.1	Map 2.1	Map 3
Map 1.2	Map 2.2	Map 3
Map 1.3	Map 2.1	Map 3
Map 1.4	Map 2.2	Map 3

FIGURE 30. Original map update system.

After:

FIGURE 31. Nostalrius map update system.

All players have a delay reduced by 75% compared to the delay experienced by some users in the previous case.

This is the most significant changes we made that affected performance. It is worth mentioning that the compiler flags used also have an impact (profiling guided optimizer in GCC/Clang for example), as well as the tweaking of the number of CPU cores assigned to specific tasks - the previous ideas assume that the number of CPU threads is not limited.

8.2.2 Acceptable trade-offs

As soon as the number of online players goes beyond the hardware capacity (which used to happen for us with more than 10,000 online players), several tradeoffs can be implemented to improve the game's reactivity while reducing the number of computations the server has to do.

Mentioned below are the choices made, and what is acceptable for the players.

8.2.2.1 Priority between players

On Nostalrius, all of the players and all of the maps were not updated with the same priority. The battleground and then raid maps were on the top priority causing players to not experience any significant delay there. Inside a single map, actions of fighting players were handled on a priority over actions from non-fighting players, or even idle players.

8.2.2.2 Priority between actions

A priority has also been established between player actions, in the following order:

- Top priority: Movements and spells.
- Map related actions (pet command, loot, etc.).
- Mail, auction house, etc.

This was achieved by handling packets a different number of times depending on their category.
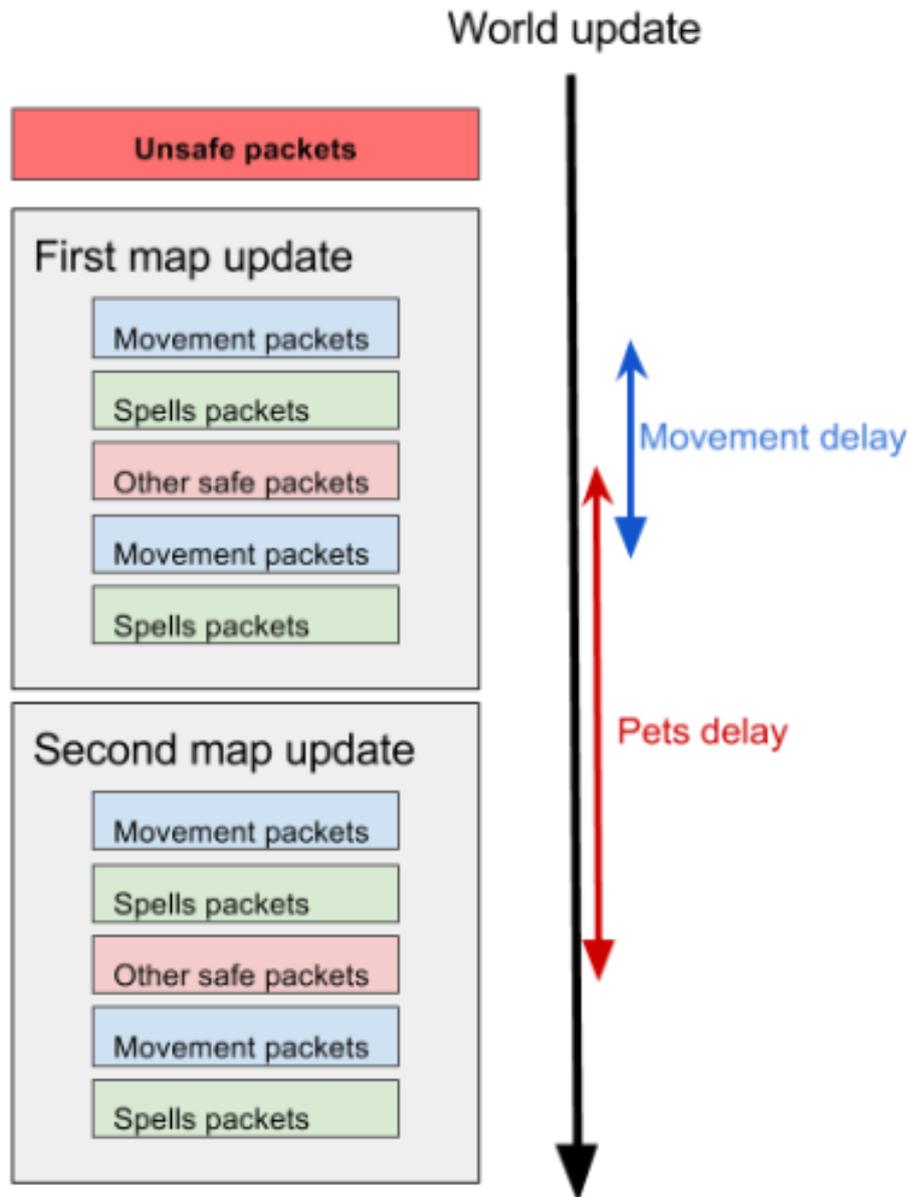
World update

FIGURE 32. Priority between actions.

Visibility distance reduction

The last option to increase performance was ultimately to reduce the visibility distance. This is something that has a really high impact on the gameplay, and should be avoided if possible.

The visibility distance reduction for NPCs, game objects and players was reduced on Nostalrius when a single map update would take more than 400ms (meaning more than 200ms of delay for spells, as they are updated twice per map update).

In practice, this would only happen on continents with a really high number of online play-

ers. With the continent instantiation system, only specific overcrowded continent areas would be affected by this reduction.

However, Nostalrius limited the visibility distance reduction to 60 yards, as the game would no longer be playable at all below this limit.

8.2.3 Players in the same area

"... or how to handle Ahn'Qiraj gates opening event on a realm with 15k online players"

In some very special situations, the previous optimizations are no longer sufficient to reduce the delay. For example, when thousands of players meet in the same area.

FIGURE 33. Ahn'Qiraj gates opening event.

"It might not have been the right idea to have everyone on our realms at the exact same place at the same time." Rob Pardo on Blizzcon 2013 [https://youtu.be/SLfELz-rzJs?t=12m47s]

In these situations, every single player's public action (movement, mana / health modification, spell casted, etc.) has to be broadcasted to every other player in the area. For 100 players in the same area, it means 10,000 packets per second if every player is doing one action per second in average.

As this situation was anticipated for either capital raids, or special world events (world bosses release), a benchmark was created to figure out how our emulator could handle these situations.

FIGURE 34. Bot-simulated gnome invasion on Orgrimmar. Benchmark for server performance.

When we saw the results, we decided to work to allow these very special Vanilla events to happen on our realm without crashing the server. We identified the main bottlenecks in these situations:

- SMSG_(COMPRESSED_)OBJECT_UPDATE: This packet is prepared and sent (compressed) for every player in the area individually, whenever one value of a player changes (health/mana regeneration for example).
- When a player moves, the server has to send them all of the objects now visible from his new position.

The map update workflow was also changed to parallelize these computations whenever a specific area is overloaded, using a "Map-Reduce" paradigm. With this novel algorithm, Nostalrius is able to use all of the computational power available to deal with insanely populated areas.
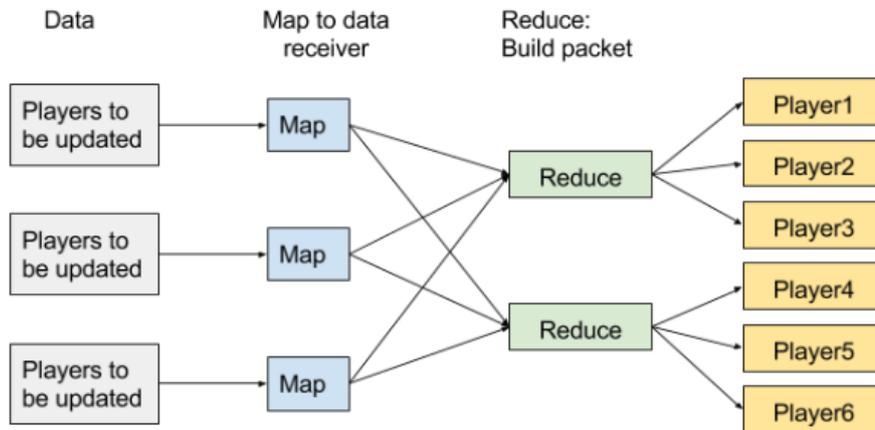
FIGURE 35. Map-Reduce paradigm.

The final benchmark happened during the server shutdown. The PvP realm had "only" 4,000 online players, but they were all concentrated in a few areas (Orgrimmar and Ironforge). The performance parameters were specially tweaked, and did not reduce the visibility distance (set to 100 yards).

FIGURE 36. Orgrimmar during the server shutdown.

FIGURE 37. Ironforge during server shutdown.

During the final minutes, we had thousands of players in the same 100 yard radius (way more than during retail Ahn Qiraj gate event). One player here had about 1,200 players visible in his client. One can see the impact on the network usage, and the hardware overall performance screen proves that all CPU cores were used.
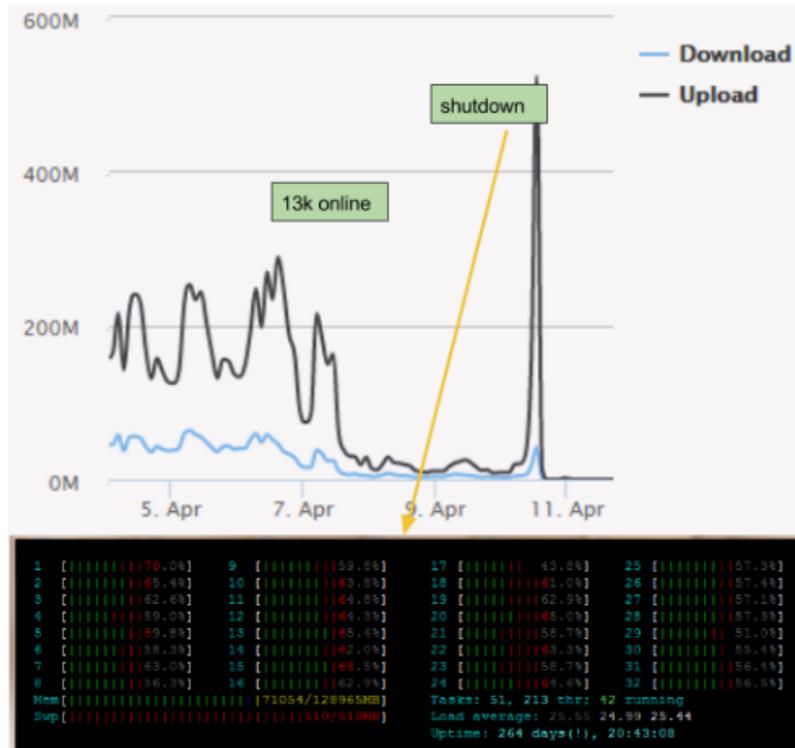
FIGURE 38. Workload during server shutdown.

8.3   Data recovery: the example of the items progression

A key and unique feature of Nostalrius is the items statistics updates with content releases. Along with patches introducing new bosses, raids or dungeons, items, quests and objects would also be changed the same way they were during Vanilla.

Recovering reliable data about items was a very difficult and time-consuming task, and to our knowledge Nostalrius was the only private realm to provide it.

8.3.1   Analysis and general method

Gathering data in order to re-create the Vanilla experience is a very long process, because of the poor quality of videos and online databases made more than 10 years ago, and because most of the content has been removed or modified with Cataclysm. Recovering a whole static database for WoW manually is a job that would have taken several years. Doing it for every one of the 12 patches to 1.12 is even more challenging!

The item progression through patches had thus to be done automatically. The assumption made was that all the data for all the versions of items could be recovered in archived versions of no-longer existing databases: Thottbot and Allakhazam (Wayback machine). These websites were the most famous World of Warcraft databases before the Burning Crusade expansion collecting retail server information automatically.

These websites were using an addon similar to the one currently used by Wowhead to retrieve precise data from the original game servers for items, objects, quests, loot tables (deduced from numerous loots), complete creatures characteristics, position, patrol, etc. Only a few things cannot be retrieved such as creature spell cooldowns and armor values. For the few objects with missing data they can be manually redone using videos to find the right position angle, etc. Armor and attack power values are reproduced from damage seen on videos, after taking into account different buffs and equipment levels.

8.3.2   Process

The whole process started by downloading from the Internet Archive all of the snapshots from the Thottbot and Allakhazam websites before the date of the TBC release. This was done by recursively crawling and downloading all of the archived pages.

It took around 5 days 24 hours a day for the system to retrieve and store 40GB of raw HTML: the database needed in order to start our specific data processing. The second part was the data extraction to get properly structured items data from HTML raw code.

8.3.3   Data extraction

Now that 40GB of raw HTML is stored, it needs to be converted into multiple databases usable by the emulator (1 per patch).

The parsing of these pages was more difficult because it had to be done over pages from 2004 to 2006, and the formatting of items changed several times in these 2 database websites. Besides, the data gathered by these websites was not 100% reliable as it came from

players and was collected through a specific addon on official World of Warcraft realms (hopefully!).

Every item occurrence was reported to a single table, along with the dates when it had been seen on the Internet Archive. Then, different databases could be generated for different game versions.

This automated process took around 3 days, running 24 hours a day, and gave pretty accurate results. However, in case of conflicts, IsVV members would manually review the item, assisted by the extractor which also provided a list of possibilities.

Maintaining multiple databases isn't something we could handle easily. The Nostalrius Dev team would instead work on a 1.12.1 based static database, and item patches would be applied to "downgrade" items, quests and content to previous patches when applied to the live realm.

8.4 Community analysis

Nostalrius as a legacy server gathered a broad community, with 220,000 active accounts on March 2016 (monthly statistics), the month before the shutdown announcement. These players came from around the world and had different motivations for playing Vanilla WoW.

After the shutdown announcement, Nostalrius focused on uniting an even larger community: the current and former players wanting to experience the original World of Warcraft again. Through an internet survey, 50,000 answers have been collected and analyzed.

This section is dedicated to the analysis of the data collected from the Nostalrius server and our survey results.

8.4.1 A note on the survey data processing

The raw data collected from our survey has been processed to eliminate incoherent responses such as:

- Respondents who say they have played a certain expansion on retail but also that they have never played on a retail server.
- respondents who say they have played a certain expansion on a private server but also state they have never played on a private server.
- Respondents who say they have played the game longer than is physically possible.

After this filtering, 30,000 responses remain from the original 50,000. The results below are based on the remaining 30,000 responses.

Which WoW expansion did you play on official Blizzard servers?

☐ Vanilla (Classic)

☐ The Burning Crusade

☐ Wrath of the Lich King

☐ Cataclysm

☐ Mists of Pandaria

☐ Warlords of Draenor

FIGURE 39. Which WoW expansion did you play on official Blizzard servers.

8.4.2   Nostalrius: a worldwide community

Based on the IP localization, here is a list of countries with Nostalrius players. This community was spread worldwide. Note: Many players from China would connect to the server through a VPN based in another country to bypass the Great Firewall.

FIGURE 40. Players geolocalization per countries.

The daily population graph can give a better insight on the nationality of Nostalrius players. Even though the daily population peak matches the asian prime time, the gaming

realm would always have at least 6,000 online players at any give time, switching between a majority of Asian, European and US players around the clock.
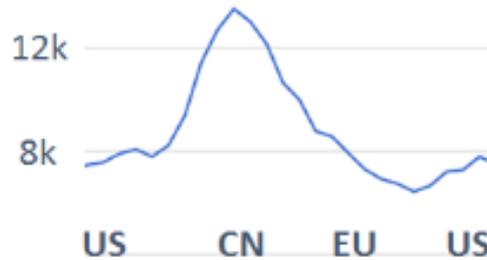
FIGURE 41. Daily population on Nostalrius.

8.4.3 Survey general demographic analysis

The first interesting thing to notice is the age distribution. A large part of the respondents did not play Vanilla WoW on retail 10 years ago. This is confirmed by the expansion players played on retail WoW.

A second point is that 99% of the respondents did actually play on Blizzard official servers at some point in the past. This is not something surprising: more than 100 million official WoW accounts have been created since 2004 and every player potentially interested already had time to try the game, especially the players requesting a previous version of the game.

Most of the players are veterans of the game, and actually played for more than 8 years on Blizzard official realms.

FIGURE 42. Ages distribution.

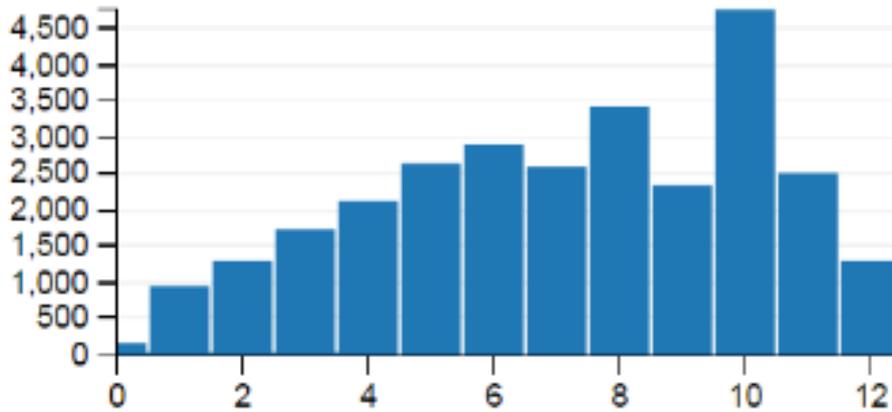## For how long on official (years)
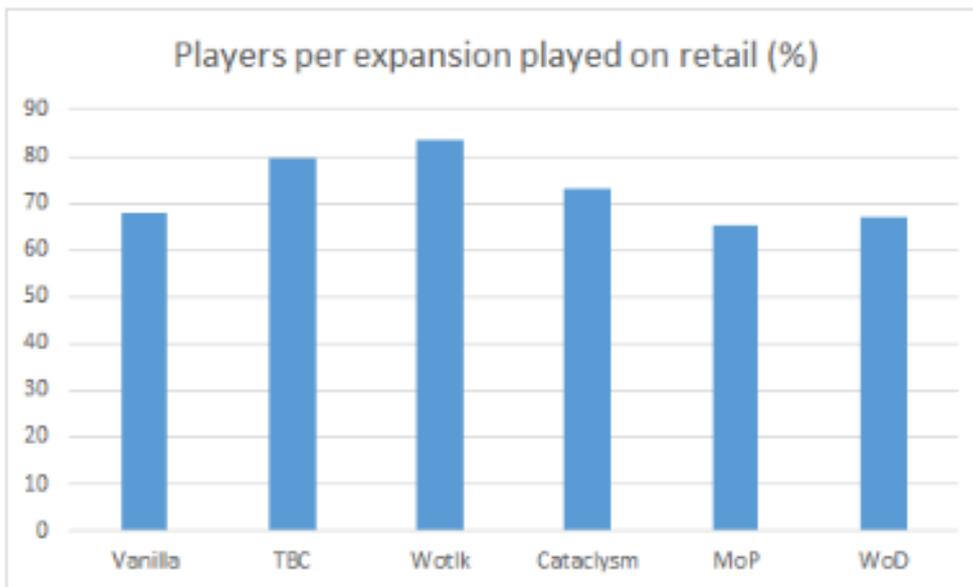

FIGURE 43. For how long did you play on retail.

FIGURE 44. Players per expansion played on retail (%).

8.4.4 No longer official WoW subscribers

Most of the respondents are no longer playing on official World of Warcraft realms. Through the questions asked, it is possible to gain a better understanding of this phenomenon. Several non-exclusive explanations were proposed. Without surprise, most of them left because of changes brought to the game, and the lack of time or money represents a minority of players.

The following data has been collected on all the respondents who played on retail, but are no longer playing (27,819 responses).
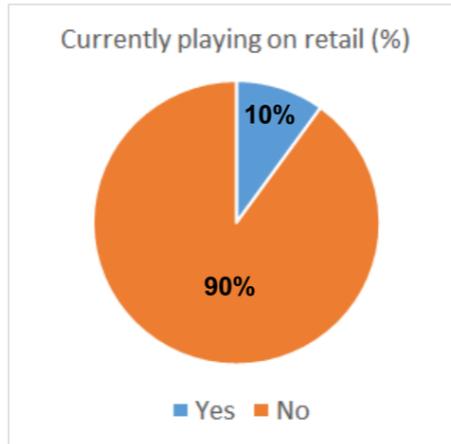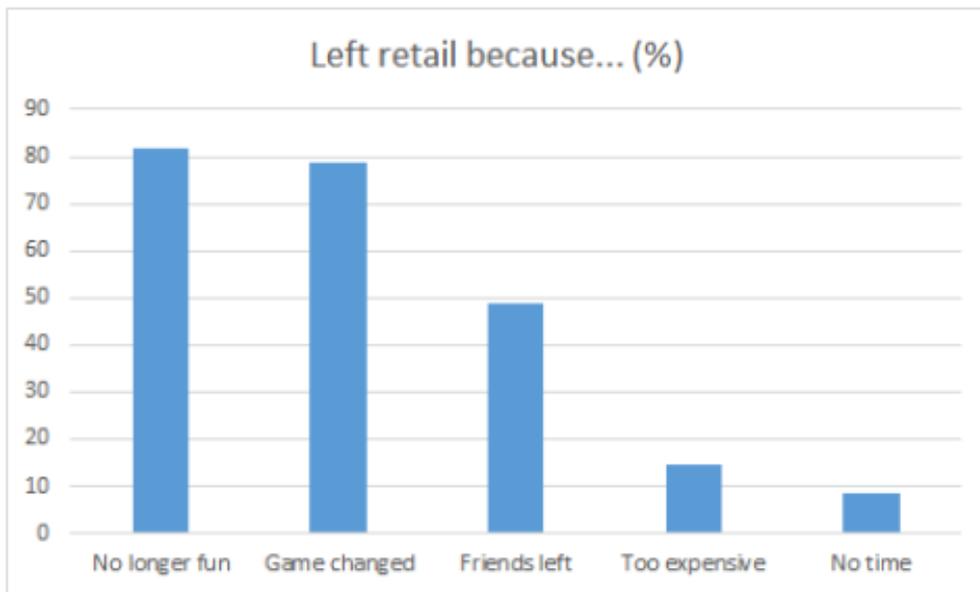

FIGURE 45. Currently playing on retail.

FIGURE 46. Left retail because.

8.4.5   What is a legacy realm?

Legacy is a broad term, that could potentially also apply to Warlord of Draenor realms once Legion is released as well. Through the community survey, players were asked to rate several WoW expansions to find which were the most attractive expansions, and where the highest demand for legacy realms is.

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0 is the lowest rating, while 10 is the highest.

The results are unambiguous. The most attractive expansions are the ones before Cataclysm, that brought a lot of irremediable changes to original areas and content.

This is confirmed by the expansions played on private servers. Note however that as the survey has been mostly answered by people willing to play legacy WoW, and is as such biased towards the first expansions. This data is based on the 27,498 responders who already played on a private server. Note that at least 30% of the respondents played on Nostalrius, which is a bias towards playing vanilla on legacy servers.
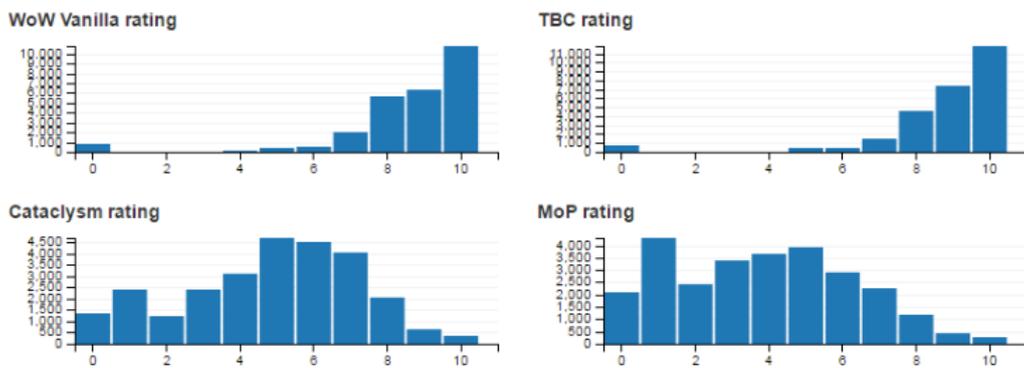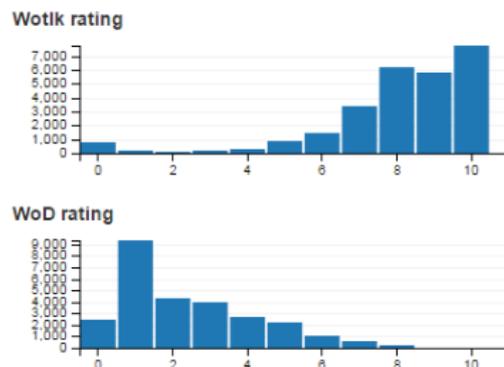

FIGURE 47. Rate WoW expansion (1/2).

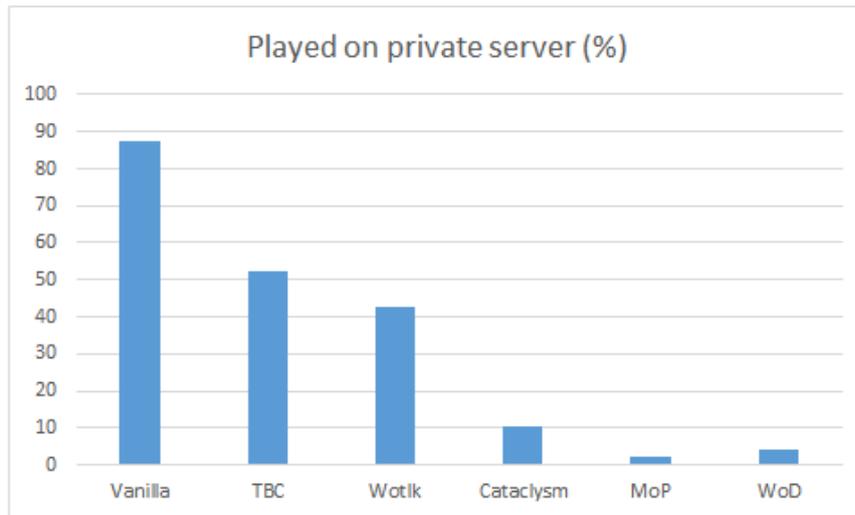FIGURE 48. Rate WoW expansion (2/2).

FIGURE 49. Played on private server.

8.4.6 Legacy realms longevity

A legitimate question raised when speaking about legacy realms is the longevity. Setting up a different game version requires huge investments that would not be worth it if players are not truly engaged in this different game/content.

Data from the survey shows that players are actually willing to play on legacy realms for more than a year in 70% of the cases. Answering a question of a survey is not something engaging, and these numbers could effectively change in the case of a real legacy server Release.

However, this trend is confirmed by the analysis of Nostalrius accounts created during the year it ran. An analysis of active accounts shows that after 7 months, 30% of the created accounts are still active, which is huge for an entirely free to play server.
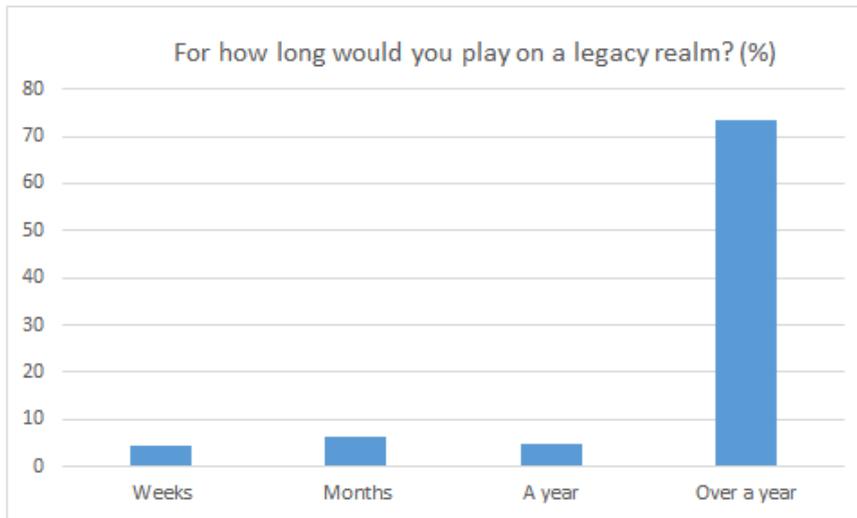
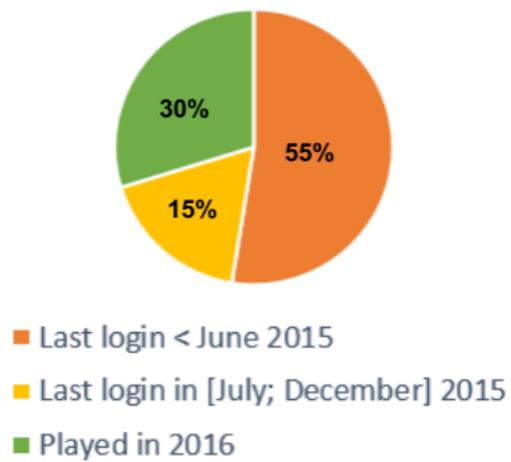FIGURE 50. For how long would you play on Blizzard legacy realms ?

FIGURE 51. Account created in March-April 2015.

8.5 Nostalrius video making

8.5.1 The replay functionality

In order to provide content release trailers, videos were recorded while players were testing upcoming content on the PTR server. All of these videos were then processed in order to create the final video trailer announcing the upcoming release.

However, this required the presence of a staff member during the whole process to capture a video stream that could be used for the video trailer. It was not always possible to ask players to recreate a specific scene to film it, during the video editing process, so we would sometimes find out that the viewing angles were not optimal.

In order to have more flexibility for our video recording, a system had been developed to record everything happening all around a character. Every packet the server sends to a client is dumped into a specific file. This kind of video recording takes a few MB per minute, a few orders of magnitude less than raw videos. These saved sequences can then be replayed ingame, with a custom speed if needed. As an example, the picture below shows a sequence replayed in fast-motion, creating unique video effects never seen before.

8.5.2 Using the client as a 3D rendering program

As the server was fully controllable, sequences could be replayed easily, entire new scenes could be created, and we could create custom actions if needed like movements for example.

The weak point was the client: it was never designed as a video 3D rendering system and we had to modify it deeply to make some special effects for our videos. Through reverse engineering and the help of several cheating software, most of the effects we needed had been achieved.

First, the "Cheat Engine" software was used to slow down the entire game time, allowing us to create slow motion videos. Technically, this software hooks the time related functions at the Windows API level to artificially speed up or slow down the entire game time lapse.

Secondly, "ReShade" had been used to alter the game post-processing by adding new shaders, or effects.

The Nostalrius Dev team eventually also worked to provide dedicated code injection tools to achieve a complete control over some rendering elements specific to the 1.12.1 client, such as:

- Control over some of the camera variables (field of view, fog distance).
- Control over the camera movement (smooth movement with spline interpolation between given input points, turning around a point, etc.).

As an example, the Nostalrius Blackwing Lair release trailer (https://www.youtube.com/watch?v=o4KRU6F-Y8Y) contains most of these features:

- ReShade post processing.
- Slow motion movement.
- Advanced camera motion.

8.6   SWOT

FIGURE 52. SWOT.