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INSTITUTO DE INFORMÁTICA
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Improving Internet Cartography from a Different Point of View

PhD Work Plan

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1 INTRODUCTION

Context. The flattening of the Internet causes inter-domain traffic to bypass transit providers and flows directly between edge networks (LABOVITZ et al., 2010). The need for guarantees in traffic delivery with efficiency and resilience (YAP et al., 2017; SCHLINKER et al., 2017; MARCOS et al., 2018) drives Autonomous Systems (ASes) to interconnect at peering infrastructures, such as colocation facilities and Internet Exchange Points (IXPs) (GIOTSAS et al., 2015). These infrastructures simplify interconnection among networks within a region, improving network performance due to lower latency and routing efficiencies (CHATZIS et al., 2013b).

Motivation. A key point to achieve the goals of network performance and resilience is to understand what is occurring in the physical topology of the Internet. Even though mapping the Internet with precision is a challenging problem due to the growing complexity of networking infrastructure and security and commercial sensitivities (GIOTSAS et al., 2015), it is an essential task. Getting geolocation inferences about peering interconnection (e.g., multilateral agreements (GIOTSAS et al., 2013)) and topology (e.g. routers and switches (SCHEITLE et al., 2017; HUFFAKER; FOMENKOV; CLAFFY, 2014)) can enhance the understanding of the dynamics of Internet traffic (MARCOS et al., 2018), improve traffic delivery (YAP et al., 2017; SCHLINKER et al., 2017) and infrastructure planning (CALDER et al., 2013) and increase responsiveness to outages and attacks (GIOTSAS et al., 2017).

Recent work focus either in generating geolocation inferences about peering interconnections or topology elements. In the first group, (GIOTSAS et al., 2015; AUGUSTIN; KRISHNAMURTHY; WILLINGER, 2009) provide accurate results to geolocate interconnections, but can not scale to large scenarios with several facilities, IXPs, and ASes, given a large amount of decentralized active probing campaigns needed. For the latter, (GHARAIBEH et al., 2017) show that current commercial and public databases are not accurate in geolocating router at neither country- nor city-level. (HUFFAKER; FOMENKOV; CLAFFY, 2014; SCHEITLE et al., 2017) proposes methods to accurately geolocate routers based on geography-related strings in hostnames and validate the results with active measurements from different decentralized probes. However, their scope is restricted since only a small subset of routers have apparent geographic hints in their DNS names.

In this context, IXPs emerge as potential candidates to improve the mapping of the Internet. These infrastructures play a global role, since they have large volume of information on data and control plan, see traffic from a significant fraction of the Internet (CHATZIS et al., 2013a) and are increasingly being deployed all over the world, supporting a growing number of network members and peering interconnections (GIOTSAS et al., 2017).

Proposal. This work seeks to investigate the potential of IXPs as anchors to improve the Internet mapping and generate geolocation inferences of peering interconnections and topology elements. Our goal is to develop a precise and systematic approach to increase geolocation knowledge while making it scalable, automatized and low-cost. First, we aim to enhance geolocation inferences in developing regions such as Latin America, which show rich, but weakly examined, peering infrastructures (IX..., 2018; BRITO et al., 2016), following recent work (FANOU; FRANCOIS; ABEN, 2015; FANOU; VALERA; DHAMDHERE, 2017). Next, we aim to extend our methodology to other worldwide available IXPs and develop a better understanding of the geolocation characteristics of these infrastructures in the Internet Topology.

Expected contributions. We expect that leveraging IXPs as scalable vantage points will enable higher visibility and knowledge about the geolocation of peering interconnections and network elements. The broader vision will allow us to identify gaps in existing physical and measurements (BGP) infrastructures, observe how the connectivity between ASes varies in developing areas (e.g., Latin America) and across different regions, increase knowledge about redundancy, and investigate approaches to identify IXPs not present in public databases. Recent events ('ROUTER..., 2018; ROUTER..., 2015) show how failure in topology elements can delay or even cause disruption in services, affecting thousands of people. Mapping network topology and peering interconnections precisely could help to troubleshoot and diminish the time to repair similar problems.

Outline of the proposal. Chapter 2 provides background and terminology. Chapter 3 presents the state-of-the-art and the main related work. In Chapter 4, we present the proposal work. Chapter 5 provides the expected results and main contributions. In Chapter 6, we show the expected methodology, set of steps and schedule. Finally, in Chapter 7, we present the expected coursework of the Ph.D. course.

2 BACKGROUD

2.1 Peering Infrastructures

2.1.1 Internet Exchange Points

(CHATZIS et al., 2013b; CHATZIS et al., 2015; INTERNET. . . , 2015)

2.1.2 Colocations Facilities

(GIOTSAS et al., 2015; KOTRONIS et al., 2017)

3 RELATED WORK

Body of related work separeted in categories:

3.1 Peering infrastructures and operation

(AGER et al., 2012; RICHTER et al., 2014; CHATZIS et al., 2013a; BRITO et al., 2016)

3.2 Relationship between ASes

(GIOTSAS et al., 2014; GIOTSAS et al., 2015; LUCKIE et al., 2013)

3.3 Mapping of peering interconnections and infrastructures

(AUGUSTIN; KRISHNAMURTHY; WILLINGER, 2009; NOMIKOS; DIMITROPOULOS, 2016)

(GIOTSAS et al., 2015) propose an algorithm to infer the physical interconnection facility where an interconnection occurs among all possible candidates. Uses data from PeeringDB, PCH, IXP, ASes and Network Operating Centers (NOCs) sites and lists provided in regional consortia of IXPs to build an initial mapping between AS, IXP, and facilities. Measurements from RIPE Atlas, Looking Glass, iPlane and CAIDA Ark.

Methodology provides accurate results for the interfaces that resolve to a facility in a low number of iterations. Key insight is that the type of peering for an interconnection sufficiently constrains the number of candidate facilities to identify the specific facility where a given interconnection occurs.

Unable to scale to large scenarios involving several colocation facilities, IXPs, and ASes, given a large amount of active probing campaigns needed. Initial process of mapping networks and IXPs to facilities, required by the methodology, is extremely manual and time-consuming to be developed/updated. Methodology is very sensitive to missing or incorrect information and could yield inaccurate results.

3.4 Mapping of topology elements

(GHARAIBEH et al., 2017; HUFFAKER; FOMENKOV; CLAFFY, 2014; SCHEITLE et al., 2017)

4 PROPOSED WORK

Based on studies on the characteristics of Internet Exchange Points, it is shown that they are promising candidates for the emergence of new solutions involving Internet mapping. Their central roles in topology enable higher visibility and knowledge about the network, showing potential in generating geolocation inferences.

This Ph.D. work plan seeks to investigate new techniques to explore IXPs as anchors to improve the Internet mapping and generate geolocation inferences of peering interconnections and topology elements. Our goal is to develop a precise and systematic approach to increase geolocation knowledge while making it scalable, automatized, and low-cost and examine the accuracy of using these infrastructures as vantage points. We plan to produce a tool that can be used by researchers for the development of new researches and by network operators to apply to practical situations.

First, we aim to enhance geolocation inferences in developing regions such as Latin America, which show rich, but weakly examined, peering infrastructures (IX..., 2018; BRITO et al., 2016). Next, we aim to extend our methodology to other worldwide available IXPs and develop a better understanding of the geolocation characteristics of these infrastructures in the Internet Topology.

Data to be used. To reach these goals, we will use different data sources publicly available. We will employ targeted traceroutes performed by IXPs as anchors at scale along with BGP information. In order to improve our measurements, we will also leverage other vantage points as RIPE Atlas (RIPE..., 2018), Looking Glass (Periscope (GIOTSAS; DHAMDHERE; CLAFFY, 2016)) and CAIDA Ark (CAIDA..., 2018). To obtain information about peering infrastructures, we will use datasets as PeeringDB (PEERINGDB..., 2018), PCH (PACKET..., 2018), Inflect (INFLECT..., 2018), IXP, ASes, and Network Operating Centers (NOCs) websites and lists provided in regional consortia of IXPs.

Data processing and implementation The collection of control plane information (BGP) and measurements campaigns tends to generate a significant amount of data. In order to process all data efficiently and without imposing resource and performance overheads to the IXP, we plan to use cloud environments (e.g., Azure) capable of dealing with a massive volume of data.

Validation. To validate the obtained results, we plan to contact network operators, IXPs and ASes to generate a ground truth dataset. To improve the validations, we intend to use privileged data from inside the IXPs as flow samples and BGP information and leverage other sources of data as BGP communities.

Risks and limitations. There are a few challenges and risks in the proposed research. Due to the low representation of existing measurement projects in developing areas (e.g., Latin America), there could be gaps in infrastructure and methodologies which could affect our geolocation inferences. We could face performance problems as IXPs not being good vantage points (VP) to improve Internet mapping or providing inaccurate results when using few IXPs given that their visibility, individually, may not perfect. Besides that, we could also face bureaucratic challenges as IXPs could not see a clear advantage of being used as VPs.

Research Questions. In this work, we aim to answer the following research questions: Can IXPs be used as vantage points to generate geolocation inferences about peering interconnections and Internet topology? What and how many are necessary to have a precise vision of the Internet? What are the implications of using this approach concerning computational cost, network traffic, and privacy? Can we discover gaps in physical and measurements (BGP) infrastructure? How can new data sources improve the Internet mapping? Is it possible to be precise using less information than related work? How is it possible to measure in a scalable and automatized way?

5 EXPECTED RESULTS

5.1 Main Contributions of the Thesis

The following contributions are expected with the development of the proposed work:

1. Analysis of the potential of Internet Exchange Points to be used as scalable vantage points to map and generate geolocation inferences, as well as its strengths and limitations;
2. Formalization of a methodology to improve the mapping of peering interconnections by exploiting the characteristics of the Internet Exchange Points, introducing new datasets and scalability;
3. Development of a prototype of the proposed methodology, allowing its applicability in practical situations and the development of new researches.

5.2 Publications

Table 5.1: Journals related to PhD

Journal	**Impact Factor**	**Qualis**
Communications of the ACM		A1
IEEE/ACM Transactions on Networking		A1
Elsevier Computer Networks		A1
ACM CCR		B1

Table 5.2: Conferences related to PhD

Conference	**Acceptance Rate**	**H-index**	**Qualis 2016**
ACM Internet Measurements (IMC) Conference	24.7%		A1
Network Traffic Measurement and Analysis Conference (TMA)	39.2%		
Passive and Active Network Measurement Conference (PAM)	40.8%		A2
ACM Special Interest Group on Data Communication (SIGCOMM) Conference	18%		A1
ACM International Conference on emerging Networking EXperiments and Technologies (CoNEXT)	17.2%		A1
IEEE Conference on Computer Communications (INFOCOM)	20.9%		A1
USENIX Symposium on Networked Systems Design and Implementation (NSDI)	15.4%		A1

6 METHODOLOGY

6.1 Set of Steps

1. **Monitoring and study of state-of-the-art**: We will perform an in-depth state-of-the-art study and monitoring of themes related to the work during all the duration of the Ph.D. Also, in the initial period of the course, we will conduct a detailed examination and reproduction of the main related existing methodologies.
2. **Methodology modeling**: in this step, we will develop a systematic methodology using IXPs as vantage points to map and produce geolocation inferences, seeking to answer the proposed research questions. Also at this stage, we will analyze the potential data to be used and design the data collection campaigns and data preparation.
3. **Data collection**: in this phase, we will perform the data collection designed in the previous step. At this stage, we will execute active measurements campaigns and collect data already available from different sources.
4. **Data preparation**: in this point, the collected data will be preprocessed and prepared, including the combination of data from different sources, to serve as input for the proposed methodology.
5. **Methodology evaluation**: in this step, we will use de collected and preprocessed data to evaluate and validate the effectiveness of the developed methodology, identifying its features and limitations.
6. **Methodology validation**: the final step of the study, we will validate the obtained results of the proposed methodology. For the validation, we plan to contact network operators and IXPs, use privileged data from inside the IXPs as flow samples, make use of ground-truth datasets and include other sources of information to improve the verification of our results.

6.2 Schedule

1. In-depth state-of-the-art study and monitoring about themes related with thesis;
2. Development of a systematic methodology using IXPs as vantage points to map and produce geolocation inferences;
3. Qualification Exam;
4. Examination of proficiency in a foreign language;
5. Data collection and preprocessing
6. Period reserved for doctorate sandwich;
7. Evaluation, review and reassessment of the proposed methodology;
8. Validation the obtained results of the proposed methodology;
9. Thesis Proposal Defense;
10. Improvement of the methodology considering the results obtained in previous activities, also considering contributions and recommendations of the evaluation committee of the thesis proposal;
11. Thesis writing;
12. Thesis defense;
13. Participation in conferences and symposia related to the theme of the thesis;
14. Writing and submitting articles for conferences and periodicals based on the results obtained during the studies and evaluations, related to the theme of this doctoral proposal.

6.3 Collaboration

joint work with UCSD. expands existing relationship. Second year of PhD expected to be located at CAIDA/UCSD. Funding to be determined.

Table 6.1: Schedule of activities during the Ph.D. period

Activities	2019/1	2019/2	2020/1	2020/2	2021/1	2021/2	2022/1	2022/2
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7 COURSEWORK

This chapter presents the expected coursework to be taken in PhD course. Table 7.1 shows the courses and the number of credits that will be taken during the PhD. All courses sums a total of 20 credits, agreeing with the minimum required for the PhD.

Table 7.1: Courses to be taken in PhD

Code	**Period**	**Period**	**Credits**
CMP410	Teaching Practice I	2019/1	1
CMP230	Computer System Security	2019/1	4
CMP182	Computer Network	2019/1	4
CMP411	Teaching Practice II	2019/2	1
CMP267	Novel Internet Architectures and Paradigms	2019/2	4
CMP223	Computer System Performance Analysis	2019/2	4
CMP600	Qualification Exam	2019/2	2

REFERENCES

AGER, B. et al. Anatomy of a large european ixp. In: **Proceedings of the ACM SIGCOMM 2012 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication**. New York, NY, USA: ACM, 2012. (SIGCOMM '12), p. 163–174. ISBN 978-1-4503-1419-0. Disponível em: <http://doi.acm.org/10.1145/2342356.2342393>.

AUGUSTIN, B.; KRISHNAMURTHY, B.; WILLINGER, W. Ixps: Mapped? In: **Proceedings of the 9th ACM SIGCOMM Conference on Internet Measurement**. New York, NY, USA: ACM, 2009. (IMC '09), p. 336–349. ISBN 978-1-60558-771-4. Disponível em: <http://doi.acm.org/10.1145/1644893.1644934>.

BRITO, S. H. B. et al. Dissecting the largest national ecosystem of public internet exchange points in brazil. In: . [S.l.: s.n.], 2016.

CAIDA. Archipelago (Ark) Measurement Infrastructure. 2018. <http://www.caida.org/projects/ark/>.

CALDER, M. et al. Mapping the expansion of google's serving infrastructure. In: **Proceedings of the 2013 Conference on Internet Measurement Conference**. New York, NY, USA: ACM, 2013. (IMC '13), p. 313–326. ISBN 978-1-4503-1953-9. Disponível em: <http://doi.acm.org/10.1145/2504730.2504754>.

CHATZIS, N. et al. On the benefits of using a large ixp as an internet vantage point. In: **Proceedings of the 2013 Conference on Internet Measurement Conference**. New York, NY, USA: ACM, 2013. (IMC '13), p. 333–346. ISBN 978-1-4503-1953-9. Disponível em: <http://doi.acm.org/10.1145/2504730.2504746>.

CHATZIS, N. et al. There is more to ixps than meets the eye. **SIGCOMM Comput. Commun. Rev.**, ACM, New York, NY, USA, v. 43, n. 5, p. 19–28, nov. 2013. ISSN 0146-4833. Disponível em: <http://doi.acm.org/10.1145/2541468.2541473>.

CHATZIS, N. et al. Quo vadis open-ix? **SIGCOMM Comput. Commun. Rev.**, ACM, New York, NY, USA, v. 45, n. 1, p. 12–18, jan. 2015. ISSN 0146-4833. Disponível em: <http://doi.acm.org/10.1145/2717646.2717650>.

FANOU, R.; FRANCOIS, P.; ABEN, E. On the diversity of interdomain routing in africa. In: MIRKOVIC, J.; LIU, Y. (Ed.). **Passive and Active Measurement**. Cham: Springer International Publishing, 2015. p. 41–54. ISBN 978-3-319-15509-8.

FANOU, R.; VALERA, F.; DHAMDHERE, A. Investigating the causes of congestion on the african ixp substrate. In: **Proceedings of the 2017 Internet Measurement Conference**. New York, NY, USA: ACM, 2017. (IMC '17), p. 57–63. ISBN 978-1-4503-5118-8. Disponível em: <http://doi.acm.org/10.1145/3131365.3131394>.

GHARAIBEH, M. et al. A look at router geolocation in public and commercial databases. In: **Proceedings of the 2017 Internet Measurement Conference**. New York, NY, USA: ACM, 2017. (IMC '17), p. 463–469. ISBN 978-1-4503-5118-8. Disponível em: <http://doi.acm.org/10.1145/3131365.3131380>.

GIOTSAS, V.; DHAMDHERE, A.; CLAFFY, k. Periscope: Unifying Looking Glass Querying. In: **Passive and Active Network Measurement Workshop (PAM)**. [S.l.: s.n.], 2016.

GIOTSAS, V. et al. Detecting peering infrastructure outages in the wild. In: **Proceedings of the Conference of the ACM Special Interest Group on Data Communication**. New York, NY, USA: ACM, 2017. (SIGCOMM '17), p. 446–459. ISBN 978-1-4503-4653-5. Disponível em: <http://doi.acm.org/10.1145/3098822.3098855>.

GIOTSAS, V. et al. Inferring complex as relationships. In: **Proceedings of the 2014 Conference on Internet Measurement Conference**. New York, NY, USA: ACM, 2014. (IMC '14), p. 23–30. ISBN 978-1-4503-3213-2. Disponível em: <http://doi.acm.org/10.1145/2663716.2663743>.

GIOTSAS, V. et al. Mapping peering interconnections to a facility. In: **Proceedings of the 11th ACM Conference on Emerging Networking Experiments and Technologies**. New York, NY, USA: ACM, 2015. (CoNEXT '15), p. 37:1–37:13. ISBN 978-1-4503-3412-9. Disponível em: <http://doi.acm.org/10.1145/2716281.2836122>.

GIOTSAS, V. et al. Inferring multilateral peering. In: **Proceedings of the Ninth ACM Conference on Emerging Networking Experiments and Technologies**. New York, NY, USA: ACM, 2013. (CoNEXT '13), p. 247–258. ISBN 978-1-4503-2101-3. Disponível em: <http://doi.acm.org/10.1145/2535372.2535390>.

HUFFAKER, B.; FOMENKOV, M.; CLAFFY, k. Drop: Dns-based router positioning. **SIGCOMM Comput. Commun. Rev.**, ACM, New York, NY, USA, v. 44, n. 3, p. 5–13, jul. 2014. ISSN 0146-4833. Disponível em: <http://doi.acm.org/10.1145/2656877.2656879>.

INFLECT Data Center and Peering Mapping. 2018. <https://inflect.com>.

INTERNET Exchange Points: An Internet Society Public Policy Briefing. 2015. <https://www.internetsociety.org/wp-content/uploads/2015/10/ISOC-PolicyBrief-IXPs-20151030_nb.pdf>.

IX.BR - Brazilian Public IXP Project. 2018. <https://ix.br/intro>.

KOTRONIS, V. et al. Shortcuts through colocation facilities. In: **Proceedings of the 2017 Internet Measurement Conference**. New York, NY, USA: ACM, 2017. (IMC '17), p. 470–476. ISBN 978-1-4503-5118-8. Disponível em: <http://doi.acm.org/10.1145/3131365.3131388>.

LABOVITZ, C. et al. Internet inter-domain traffic. In: **Proceedings of the ACM SIGCOMM 2010 Conference**. New York, NY, USA: ACM, 2010. (SIGCOMM '10), p. 75–86. ISBN 978-1-4503-0201-2. Disponível em: <http://doi.acm.org/10.1145/1851182.1851194>.

LUCKIE, M. et al. As relationships, customer cones, and validation. In: **Proceedings of the 2013 Conference on Internet Measurement Conference**. New York, NY, USA: ACM, 2013. (IMC '13), p. 243–256. ISBN 978-1-4503-1953-9. Disponível em: <http://doi.acm.org/10.1145/2504730.2504735>.

MARCOS, P. et al. Dynam-ix: a dynamic interconnection exchange. In: **ACM CoNEXT'18**. [S.l.: s.n.], 2018.

NOMIKOS, G.; DIMITROPOULOS, X. traixroute: Detecting ixps in traceroute paths. In: SPRINGER. **International Conference on Passive and Active Network Measurement**. [S.l.], 2016. p. 346–358.

PACKET Clearing House. 2018. <https://pch.net>.

PEERINGDB. IXPs and colocation database. 2018. <https://www.peeringdb.com>.

RICHTER, P. et al. Peering at peerings: On the role of ixp route servers. In: **Proceedings of the 2014 Conference on Internet Measurement Conference**. New York, NY, USA: ACM, 2014. (IMC '14), p. 31–44. ISBN 978-1-4503-3213-2. Disponível em: <http://doi.acm.org/10.1145/2663716.2663757>.

RIPE NCC. RIPE Atlas. 2018. <https://atlas.ripe.net/>.

ROUTER cockup grounds United Airlines flights WORLDWIDE. 2015. <https://www.theregister.co.uk/2015/07/08/router_failure_united_airlines_flights/>.

'ROUTER Issue' Causes Delays at California DMVs. 2018. <https://www.nbcsandiego.com/news/local/California-DMV-Reports-Technical-Outage-493863461.html>.

SCHEITLE, Q. et al. Hloc: Hints-based geolocation leveraging multiple measurement frameworks. In: **2017 Network Traffic Measurement and Analysis Conference (TMA)**. [S.l.: s.n.], 2017. p. 1–9.

SCHLINKER, B. et al. Engineering egress with edge fabric: Steering oceans of content to the world. In: **Proceedings of the Conference of the ACM Special Interest Group on Data Communication**. New York, NY, USA: ACM, 2017. (SIGCOMM '17), p. 418–431. ISBN 978-1-4503-4653-5. Disponível em: <http://doi.acm.org/10.1145/3098822.3098853>.

YAP, K.-K. et al. Taking the edge off with espresso: Scale, reliability and programmability for global internet peering. In: **Proceedings of the Conference of the ACM Special Interest Group on Data Communication**. New York, NY, USA: ACM, 2017. (SIGCOMM '17), p. 432–445. ISBN 978-1-4503-4653-5. Disponível em: <http://doi.acm.org/10.1145/3098822.3098854>.