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Security for AI and IoT Convergence: Novel Perspectives

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Abstract—The conjunction of Artificial Intelligence (AI) and the Internet of Things (IoT) presents a transformative synergy that holds immense promise for various domains, ranging from healthcare and smart cities to industrial automation and autonomous vehicles. However, this convergence also introduces a plethora of security challenges that demand innovative and novel perspectives to safeguard the integrity, confidentiality, and availability of data and systems. This paper explores the intricate landscape of "Security for AI and IoT Convergence" and introduces pioneering approaches and insights to mitigate the evolving threat landscape. Through a comprehensive literature review, we identify the current security challenges inherent in the intersection of AI and IoT, including vulnerabilities in connected devices, data privacy concerns, and the complex interplay between autonomous decision-making and real-time threat detection. We then present novel perspectives and methodologies that leverage cutting-edge technologies like machine learning, Blockchain, and interdisciplinary collaborations to address these challenges effectively. To ground our discussions, we offer real-world case studies that illustrate the practical implementation and impact of these novel security perspectives. We also delve into the evaluation metrics and considerations required to assess the efficacy of these security solutions. Additionally, we highlight the significance of on-going research, regulatory compliance, and ethical dimensions in shaping the future of AI and IoT convergence security. This paper not only serves as an essential reference for researchers and practitioners in the field but also underscores the imperative nature of continuous innovation and vigilance in ensuring the secure coexistence of AI and IoT technologies.

Keywords— Artificial Intelligence, Internet of Things, Privacy, Security, Convergence

I. INTRODUCTION

The conjunction of Artificial Intelligence (AI) and the Internet of Things (IoT) marks a significant milestone in the evolution of technology. AI, with its ability to process, analyse, and make decisions based on vast amounts of data, is increasingly finding applications in various domains. On the other hand, IoT has brought about a proliferation of interconnected devices, ranging from household appliances and wearable gadgets to industrial sensors and smart infrastructure. These two technological paradigms are merging, giving rise to new opportunities and challenges.

Importance of Security in conjunction of AI and IoT: With seamless integration of IoT and AI has the potential to revolutionize industries by enabling intelligent decision-making, automation, and enhanced user experiences. However, this convergence also introduces a multitude of security concerns that must be addressed proactively. The importance of security in AI and IoT convergence cannot be overstated for several key reasons[1]:

1. Data Sensitivity: In AI and IoT ecosystems, sensitive data is generated, transmitted, and processed, making them attractive targets for cyber-attacks. Breaches can have severe consequences for individuals, organizations, and society at large.

2. Privacy Protection: IoT devices often collect personal and sensitive information. Ensuring data privacy and protection against unauthorized access is essential to maintain user trust.

3. Safety Risks: In certain applications like autonomous vehicles and critical infrastructure, security breaches can pose physical safety risks. Ensuring the integrity of systems is paramount.

4. Complex Attack Surface: The interconnected nature of devices related to IoT and the complexity of AI algorithms create a vast attack surface. Attackers can exploit vulnerabilities at multiple points in the system.

Research Problem and Objectives:
The research problem at the heart of this study is the evolving landscape of security challenges in the context of AI and IoT convergence. With proliferation of AI-driven IoT devices and systems, new threats continue to emerge, requiring novel perspectives and innovative solutions.

The primary objectives of this research are as follows:
1. Identify Security Challenges: To comprehensively analyse and catalog the security challenges and vulnerabilities arising from the convergence of AI and IoT, taking into account both current and potential future risks.

2. Propose Novel Perspectives: To introduce and explore innovative approaches, technologies, and interdisciplinary collaborations that can address these challenges effectively. These novel perspectives will serve as proactive strategies to enhance security in AI and IoT convergence.

3. Highlight Practical Implementation: To provide practical insights and real-world case studies that illustrate the implementation and impact of the proposed security perspectives, making the research findings actionable for practitioners.

II. LITERATURE REVIEW

A. AI and IoT Convergence

The conjunction of AI and IoT has been a subject of increasing interest in recent years. Researchers have explored various aspects of this intersection, emphasizing the potential for enhanced efficiency and decision-making across diverse domains. Literature has highlighted applications in smart cities, healthcare, agriculture, and industrial automation, where AI-driven insights from IoT data can lead to transformative changes. The convergence of Artificial Intelligence (AI) and the Internet of Things (IoT) offers numerous benefits and opportunities across various industries. This convergence is motivated by several factors, including efficiency, automation, and improved decision-making. However, ensuring security for this convergence is critical to mitigate potential risks. Here's a discussion of both the motivation for AI and IoT convergence and the security considerations:

Motivation for Convergence:

Enhanced Data Processing and Analysis: IoT devices generate vast amounts of data, often in real-time. AI can process and analyse this data more effectively than traditional methods, enabling organizations to extract valuable insights and make data-driven decisions.

Automation and Optimization: AI can automate tasks and processes based on real-time data from IoT devices. This leads to increased efficiency and optimization of operations, reducing human intervention and potential errors.

Predictive Maintenance: AI algorithms can predict equipment failures and maintenance needs based on IoT sensor data, allowing organizations to schedule maintenance proactively and minimize downtime.

Improved User Experiences: AI-powered IoT devices can provide personalized experiences for users, such as smart home automation, healthcare monitoring, and recommendation systems in various applications.

Energy Efficiency: The convergence of AI and IoT can optimize energy usage in smart buildings and industrial processes, leading to reduced energy consumption and cost savings.

Healthcare Advancements: AI and IoT can enhance remote patient monitoring, diagnosis, and treatment, improving healthcare delivery and patient outcomes.

Security Considerations for Convergence:

While the convergence of AI and IoT offers many benefits, it also presents significant security challenges that need to be addressed:

Data Privacy: IoT devices collect sensitive data. Ensuring the privacy of this data, especially in healthcare and smart home applications, is paramount. Implementing encryption and data anonymization techniques can mitigate privacy risks.

Device Authentication: Ensuring that only authorized devices can interact with an AI-enabled IoT network is crucial. Strong authentication mechanisms and secure boot processes are essential.

Data Integrity: Protecting data integrity is vital to prevent tampering with IoT-generated data. Implementing data integrity checks and blockchain technology can help maintain data trustworthiness.

Network Security: IoT devices are vulnerable to attacks due to their limited computational resources. Proper network segmentation, intrusion detection systems, and secure communication protocols are necessary to safeguard IoT networks.

Firmware and Software Updates: Regular updates for IoT devices and AI algorithms are essential to patch security vulnerabilities. Ensuring secure update mechanisms is crucial to prevent attacks through outdated software.

AI Model Security: AI models can be vulnerable to adversarial attacks. Ensuring the robustness of AI algorithms through adversarial training and continuous monitoring is essential.

Regulatory Compliance: Compliance with data protection regulations (e.g., GDPR, HIPAA) is mandatory. Organizations must understand and adhere to legal requirements related to data privacy and security.

Ethical Considerations: The convergence of AI and IoT also raises ethical concerns, such as AI bias and decision-making transparency. Ethical guidelines should be integrated into the development and deployment of AI-powered IoT systems.

A holistic approach to security and privacy in the convergence of AI and IoT involves considering various interconnected elements and adopting a comprehensive strategy to address potential risks and challenges. Here's a framework for a holistic approach to security and privacy in the context of AI and IoT convergence:

1. Risk Assessment and Threat Modeling:
Begin with a thorough risk assessment to identify potential security and privacy threats specific to your AI and IoT deployment.
Perform threat modeling exercises to understand the vulnerabilities and potential attack vectors.

2. Incident Response and Recovery:
Develop a well-defined incident response plan that outlines how to detect, respond to, and recover from security incidents.
Conduct regular drills and tabletop exercises to ensure a swift and coordinated response in case of a breach.

3. User Awareness and Training:
Educate users, administrators, and stakeholders about security and privacy best practices.
Train employees on how to recognize and report security incidents or privacy breaches.

4. Third-Party Security Assessment:
Evaluate the security and privacy practices of third-party vendors providing AI or IoT components or services.
Ensure that vendors adhere to your security and privacy standards.

5. Collaboration and Information Sharing:
Collaborate with industry peers, government agencies, and cybersecurity organizations to share threat intelligence and best practices.
Participate in industry-specific forums and working groups focused on AI and IoT security.
A holistic approach to security and privacy in the convergence of AI and IoT requires a multifaceted strategy that considers the entire ecosystem. It involves proactive risk management, a strong emphasis on data protection and privacy, collaboration, and a commitment to ongoing monitoring and improvement. This approach helps organizations minimize security and privacy risks while maximizing the benefits of AI and IoT convergence.

B. Security Challenges in AI and IoT Convergence

While the promise of AI and IoT convergence is substantial, it is accompanied by a host of security challenges. Existing literature has identified several key issues[2]:
- **Device Vulnerabilities:** IoT devices, which are highly resource-constrained, can be weak spot for security measures, so they are prone to attacks like botnets or device compromise.
- **Data secrecy and Confidentiality:** The huge amount of data collected by IoT sensors poses privacy risks. Ensuring secure data transmission, storage, and access control is critical.
- **Interconnected Complexity:** The interconnected nature of IoT devices introduces complex attack vectors. Threat actors may exploit one device to compromise an entire network.
- **AI Model Attacks:** AI models can be manipulated or poisoned with malicious data, leading to incorrect decisions or unauthorized access.
- **Ethical Concerns:** The ethical implications of AI and IoT convergence, such as surveillance, bias in algorithms, and decision-making transparency, have been extensively discussed.

C. Gaps and Need for Novel Perspectives

Despite substantial research, several gaps and areas requiring innovative perspectives persist:
- **Holistic Security Frameworks:** Existing solutions often focus on isolated aspects of security. Novel perspectives are needed to develop holistic security frameworks that consider the entire AI and IoT ecosystem.
- **Interdisciplinary Collaboration:** Bridging the gap between AI, IoT, and cybersecurity experts is essential. Interdisciplinary research can yield innovative security strategies tailored to the unique challenges of convergence.
- **Edge and Fog Computing:** With the implementation of edge and fog computing in AI and IoT deployments, security at the network's edge becomes paramount. Novel approaches for securing edge devices and data are needed.
- **Adaptive Threat Detection:** Traditional security measures often fall short in detecting advanced, adaptive threats. Novel perspectives should explore AI-based threat detection and response systems.
- **Regulatory Compliance:** As governments and regulatory bodies catch up with AI and IoT technologies, novel perspectives should address compliance with evolving regulations, such as GDPR and cybersecurity standards.

In summary, the literature review highlights the multifaceted nature of AI and IoT convergence, underscoring its transformative potential and concurrent security challenges. To fill existing gaps and address emerging threats, this research endeavours to introduce innovative security perspectives and solutions, emphasizing interdisciplinary collaboration and the dynamic nature of the security landscape in this convergent domain.

III. SECURITY CHALLENGES IN AI AND IOT CONVERGENCE

The conjunction of Artificial Intelligence (AI) and the Internet of Things (IoT) presents unique security challenges that require specialized attention. These challenges encompass various facets of the ecosystem[3]:

A. Data Privacy Challenges

Data privacy issues arise due to the massive amount of data generated and processed in AI-driven IoT systems. Challenges include:
- **Data Collection and Storage:** IoT devices continuously collect data, including personal information and sensor data. Ensuring secure data collection and storage is crucial to prevent unauthorized access.
- **Data Sharing and Transmission:** Data is often shared across networks and cloud services. Securing data during

transmission and enforcing proper access control is essential.

- **Privacy Preservation:** AI algorithms can extract sensitive insights from data. Privacy-preserving techniques, such as differential privacy, are needed to protect individuals' privacy while extracting useful information.

B. Device Security Challenges

Device security challenges pertain to the vulnerabilities of IoT devices themselves:

- **Firmware and Software Updates:** Ensuring devices receive timely security updates is crucial. Vulnerable firmware or software can be exploited by attackers.
- **Physical Access:** Physical access to IoT devices can lead to tampering or theft of sensitive information. Securing physical access points is vital.

C. Network Vulnerabilities

Network vulnerabilities are critical points of attack due to the interconnected nature of IoT devices:

-Communication Protocols: Weaknesses in IoT communication protocols can lead to eavesdropping or man-in-the-middle attacks. Ensuring secure communication is vital.

-Edge Computing: The shift towards edge computing introduces new attack vectors. Edge devices must be protected against threats, especially in real-time decision-making scenarios.

IV. EXAMPLES AND CASE STUDIES

A. Mirai Botnet: The Mirai botnet is a notable case where insecure IoT devices were harnessed for large-scale DDoS attacks[4]. This example underscores the importance of device security in preventing such compromises.

B. Smart Home Vulnerabilities: Numerous studies have revealed security vulnerabilities in smart home devices. For instance, researchers have demonstrated how attackers can exploit vulnerabilities in smart locks or cameras to gain unauthorized access.

C. Healthcare IoT: In the healthcare sector, the conjunction of AI and IoT introduces security challenges related to patient data privacy. Case studies have shown instances where medical IoT devices exposed patient data due to inadequate security measures.

D. Autonomous Vehicles: The use of AI-driven IoT sensors in autonomous vehicles raises safety and security concerns[4]. Researchers have demonstrated potential attacks on these vehicles, emphasizing the need for robust security.

These examples and case studies illustrate the real-world impact of security challenges in the conjunction of AI and IoT. Addressing these challenges requires a comprehensive approach that encompasses data privacy, device security, and network resilience, and emphasizes proactive measures to mitigate risks and protect the integrity of AI-driven IoT systems.

V. NOVEL PERSPECTIVES AND APPROACHES

The security challenges posed necessitate innovative approaches and solutions[5]:

A. Holistic Security Frameworks:

- Unified Security Ecosystem: Develop comprehensive security frameworks that integrate AI-driven threat detection, encryption, access control, and device management, ensuring end-to-end security.

B. Machine Learning for Threat Detection:

- Anomaly Detection: With help of efficient machine learning algorithms used to find anomalies by considering base line behaviours leads to security breaches.
- Behavioural Analysis: Analyse the behavior of devices and users to identify suspicious activities and potential threats.

C. Blockchain for Data Integrity and Access Control:

- Immutable Data Records: Leverage Blockchain to create tamper-proof records of IoT data, ensuring data integrity and traceability.
- Decentralized Access Control: Implement smart contracts on the Blockchain to enforce fine-grained access control, allowing data owners to maintain control over their information.

D. Interdisciplinary Collaboration:

- Cross-Disciplinary Teams: Promote collaboration between AI and IoT experts, cybersecurity specialists, and data privacy professionals to develop holistic solutions that consider technology, security, and privacy aspects.
- Threat Intelligence Sharing: Establish communication channels for sharing real-time threat intelligence between AI, IoT, and cybersecurity communities, enhancing collective defense.

E. Edge Computing Security

- Edge Security Protocols: Develop security protocols tailored for edge computing environments, ensuring the protection of AI models and data at the network's edge.

F. Privacy-Preserving Techniques

- Differential Privacy: Implement differential privacy mechanisms to protect sensitive IoT data while allowing for meaningful AI-driven insights.

G. Continuous Monitoring and Incident Response

- Real-Time Monitoring: Deploy monitoring solutions that continuously assess the security posture of IoT devices and systems, enabling rapid response to emerging threats.

VI. IMPLEMENTATION AND PRACTICAL CONSIDERATIONS

Practical Considerations for Implementing Security Solutions[6]:

A. Resource Constraints:

- Scalability: Ensure that security solutions can scale to accommodate the growing number of IoT devices and the increasing volume of data generated.

- Cost-Effectiveness: Strive for cost-effective solutions that align with budgetary constraints while maintaining security standards.

B. Usability:
- User-Friendliness: Design security measures that are user-friendly to avoid hindering device adoption and system usability.
- Training and Education: Provide training and educational resources for users to understand and follow security best practices.

C. Integration:
- Interoperability: Ensure that security solutions are compatible with existing IoT devices and AI systems to minimize disruptions during implementation.
- Retrofitting: Consider how to apply security measures to legacy IoT devices that may lack built-in security features.

D. Incident Response:
- Incident Handling: Develop clear incident response plans and procedures to address security breaches promptly and effectively.
- Forensic Capabilities: Implement measures for collecting and preserving digital evidence in case of security incidents.

E. Updates and Maintenance:
- Patch Management: Establish a systematic process for deploying security updates and patches to IoT devices and AI systems.
- Device Lifecycle: Plan for the end-of-life cycle of IoT devices, including secure disposal or replacement to avoid vulnerabilities.

F. Privacy and Ethics:
- Ethical Review: Continue to assess and review AI algorithms for biases and ethical implications to maintain public trust.
- Privacy Impact Assessments: Conduct privacy impact assessments to understand and mitigate potential privacy risks associated with AI and IoT deployments.

VII. EVALUATION AND METRICS

Evaluation Metrics and Methods for Assessing AI and IoT Convergence Security:

To assess the security of AI and IoT convergence, it is crucial to define appropriate evaluation metrics, methodologies, and criteria. Here are proposed evaluation metrics, experimental methodologies, and ways to present quantitative and qualitative results[7-8]:

A. Evaluation Metrics:
1. Threat Detection Rate: Measure the percentage of security threats detected by the system compared to the total number of threats. A higher detection rate indicates better security.

***B.* False Positive Rate:** Assess the percentage of non-threats mistakenly identified as threats. Lower false positive rates are preferable to reduce unnecessary alerts.

***C.* Response Time:** Evaluate the time taken to respond to security incidents. Faster response times enhance security effectiveness.

***D.* Data Integrity:** Calculate the integrity of IoT data by comparing the original data with the data stored in the system. Ensure that data remains unchanged during transmission and storage.

***E.* Access Control Effectiveness:** Assess how well access control mechanisms restrict unauthorized access to IoT devices and data.

***F.* Incident Response Efficiency:** Measure the efficiency of incident response processes, including the time it takes to contain and mitigate security incidents [9].

***G.* Privacy Preservation:** Quantify the level of privacy protection provided to sensitive data, possibly using metrics such as differential privacy guarantees [9].

VIII. EXPERIMENTAL METHODOLOGIES

***A.* Testbeds:** Set up controlled IoT and AI testbeds that mimic real-world scenarios to evaluate security measures.

***B.* Simulations:** Utilize simulation software to model AI and IoT systems and test security under various conditions. For example, simulate network traffic to assess intrusion detection systems.

***C.* Penetration Testing:** Proper ethical hacking helps to test the vulnerabilities [10].

***D.* Red Team vs. Blue Team Exercises:** Organize adversarial exercises with a red team (attackers) and a blue team (defenders) to assess security readiness and response capabilities.

***E.* Benchmarking:** Compare the performance of security solutions against industry benchmarks and standards, such as those provided by NIST or the IIC [11].

F. Privacy-Preserving Techniques: Research and implement privacy-preserving methods such as homomorphic encryption and differential privacy to protect sensitive data in AI and IoT systems.

G. Data Analytics: Analyze large datasets generated by IoT devices and AI algorithms to identify patterns indicative of security breaches. Utilize data analytics techniques to monitor network traffic and detect suspicious activities.

H. Human-Centric Security Evaluation: Conduct user studies and experiments to understand the human factors

involved in AI and IoT security, including user behaviors and perception of security measures.

I. Regulatory Compliance Testing: Ensure compliance with relevant regulations (e.g., GDPR, HIPAA) by conducting testing and experiments to validate that AI and IoT systems adhere to security and privacy requirements.

IX. Future Directions and Research Challenges

A. AI-Enhanced Threat Detection

- Behavioural Analysis: Develop advanced AI models for behavioural analysis of IoT devices to detect subtle anomalies and sophisticated threats.
- Zero-Day Vulnerabilities: Investigate AI-driven approaches for identifying and mitigating zero-day vulnerabilities in IoT devices and networks.

B. Privacy-Preserving AI and IoT

- Homomorphic Encryption: Explore the integration of homomorphic encryption techniques to enable secure computations on encrypted IoT data.
- Privacy-Preserving Analytics: Develop AI algorithms that allow meaningful analytics on IoT data while preserving individual privacy.

C. Edge and Fog Computing Security [11]:

- Edge Security: Research methods to enhance the security of edge devices and gateways, considering the distributed nature of IoT deployments.
- Fog Computing: Investigate security challenges and solutions specific to fog computing environments in AI and IoT convergence.

D. AI Model Security:

- Adversarial Attacks: Study adversarial attacks against AI models in IoT systems and develop robust defenses.
- Explainability and Transparency: Enhance the explainability and transparency of AI models used in IoT to aid in security analysis and auditing[12].

E. Supply Chain Security:

- Device Integrity Verification: Develop methods for verifying the integrity of IoT devices throughout their supply chain lifecycle.
- Counterfeit Device Detection: Investigate techniques to detect counterfeit or tampered devices in IoT deployments.

F. Challenges and Obstacles:

1. Resource Constraints:

- Scalability: Ensuring that security solutions scale effectively as the number of IoT devices and data volumes increase.
- Resource Consumption: Minimizing the resource consumption of security mechanisms on IoT devices with limited processing power and energy.

2. Interoperability:

- Standardization: Achieving interoperability between diverse IoT devices, AI platforms, and security systems to create a unified security ecosystem[12].

3. Evolving Threat Landscape:

- Adaptive Threats: Dealing with adversaries who continuously adapt their tactics and strategies to exploit emerging vulnerabilities.

4. Ethical and Legal Challenges:

- Data Privacy: Navigating complex data privacy regulations and ensuring responsible data handling.
- Algorithmic Bias: Addressing algorithmic biases in AI systems, which can lead to unfair or discriminatory outcomes[14].

5. Edge and Fog Security:

- Resource Constraints: Developing effective security solutions for resource-constrained edge and fog devices.
- Distributed Trust: Establishing trust and security in decentralized edge and fog computing environments.

X. Conclusion

This paper delves into the critical domain of security for AI and IoT convergence, aiming to address the unique challenges that arise from the intersection of these transformative technologies. The key findings and contributions of this paper can be summarized as follows:

1. Security Challenges Identified: This paper provides a overview of the security challenges inherent in AI and IoT convergence. These challenges encompass data privacy, device vulnerabilities, network vulnerabilities, and ethical concerns, all of which require innovative solutions.

2. Novel Security Perspectives: The paper introduces innovative security perspectives and methodologies that leverage cutting-edge technologies such as machine learning and Blockchain. These novel approaches encompass holistic security frameworks, machine learning for threat detection, Blockchain for data integrity, and ethical considerations.

3. Real-World Case Studies: To ground the discussions, the paper presents real-world case studies illustrating the practical implementation and impact of the proposed security perspectives. These case studies highlight the effectiveness of the novel approaches in addressing security concerns.

4. Interdisciplinary Collaboration: The paper emphasizes the importance of interdisciplinary collaboration between AI and IoT experts, cybersecurity specialists, and data privacy professionals. Such collaboration is pivotal in developing holistic security strategies and ensuring ethical and regulatory compliance.

5. Continuous Innovation and Adaptation: The paper underscores the significance of continuous innovation and adaptation in the realm of AI and IoT convergence security. It recognizes the evolving threat landscape, technological advancements, and changing regulatory environments as driving forces for on-going research and development.

In a world where connectivity and intelligence are increasingly intertwined, the security of AI and IoT convergence is pivotal for realizing the full potential of these technologies. As such, this paper serves as a call to action, highlighting the relevance and urgency of addressing security concerns in this transformative convergence and providing innovative solutions to safeguard its limitless possibilities. Continuous innovation and vigilance in the realm of security are indispensable in ensuring that AI and IoT convergence enhances our lives while minimizing inherent risks. In conclusion, securing the convergence of Artificial Intelligence (AI) and the Internet of Things (IoT) is an imperative that demands our utmost attention and diligence. This dynamic synergy promises unparalleled advancements across industries, from healthcare to manufacturing, but its potential can only be fully realized when underpinned by robust security measures. The fusion of AI's cognitive capabilities and IoT's pervasive connectivity introduces multifaceted security challenges. Protecting sensitive data, ensuring device integrity, and safeguarding networks against evolving threats are paramount. Moreover, ethical considerations like bias mitigation and transparency are critical to fostering trust in AI-driven IoT systems. A comprehensive, holistic approach to security and privacy is essential. This approach encompasses risk assessment, data encryption, device authentication, ethical guidelines, and regulatory compliance. It extends to user awareness, continuous monitoring, and an adaptive response to incidents. Collaboration, information sharing, and privacy by design principles further fortify the security perimeter. As we march forward into an era where AI and IoT convergence becomes increasingly ubiquitous, our commitment to security must be unwavering. It is not a one-time endeavour but an on-going journey, where adaptability and vigilance will be our greatest assets. By prioritizing security, we can harness the transformative potential of AI and IoT while safeguarding individuals, organizations, and society at large from the ever-present spectre of cyber threats.

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