Problem Statement

Problem Statement 3: Adaptive Intelligent Tax Filing System

Problem Definition:

Current tax preparation systems inadequately address the diverse cognitive and technological needs of various user demographics. This deficiency leads to widespread filing errors, compliance issues, and the exclusion of vulnerable populations from efficient tax services.

Background & Context:

The inherent complexity of tax regulations poses significant barriers for individual filers. Studies indicate that 60% of taxpayers still require professional assistance, even when utilizing digital tools. Existing solutions employ static interfaces that fail to adapt to user capabilities, resulting in suboptimal outcomes across different age groups and technical proficiency levels.

Research Objective:

To develop an adaptive agentic artificial intelligence system that dynamically adjusts assistance levels based on user demographics, preferences, and real-time interaction patterns, while rigorously maintaining regulatory compliance and data security standards.

Technical Scope:

- **Adaptive Intelligence Architecture**: A multi-agent system featuring personalized interaction modalities.
- **Security Framework**: Tokenized data processing incorporating granular permission controls.
- **Natural Language Interface**: A conversational AI capable of supporting multi-generational communication patterns.
- **Compliance Integration**: Real-time validation of tax regulations and accuracy verification.

Expected Contributions:

1. A novel adaptive UI/UX framework specifically designed for financial applications across diverse demographic segments.
2. A secure multi-party computation model tailored for the processing of sensitive financial data.
3. An Explainable AI (XAI) implementation to ensure transparent automated decision-making.
4. An empirical evaluation of age-adaptive human-AI interaction within financial services.

Success Metrics:

- User task completion rates across various age demographics.
- System accuracy compared to professional tax preparation services.

- User trust and satisfaction indices.
- Security audit compliance scores.
- Improvements in processing time efficiency.

Innovation Impact:
This research aims to address critical gaps in inclusive financial technology design while simultaneously advancing the field of adaptive human-AI interaction systems. Its applications extend beyond tax preparation, offering broader implications for intelligent financial services.

research

An Agentic AI Framework for Adaptive and Inclusive Tax Filing: A Research Proposal

Problem Definition/Introduction

The Systemic Challenge of Tax Complexity

The United States tax system presents a formidable challenge to individual taxpayers, rooted in the profound complexity of its governing statutes. The Internal Revenue Code comprises an astonishing 9,834 distinct sections, which are further elaborated by a six-volume set of corresponding regulations. This complexity is not merely a function of volume; it is a structural issue stemming from the code's expression in natural language, which is often ambiguous and open to interpretation. This inherent ambiguity creates what the National Taxpayer Advocate has designated as a "Most Serious Problem," a fundamental flaw that actively undermines public trust in the tax system, discourages voluntary compliance, and imposes severe burdens on taxpayers attempting to meet their obligations. The intricacy of the law makes it exceedingly difficult for ordinary citizens to comprehend the rules that govern their financial responsibilities, leading to confusion, alienation, and a perception that thesystem is inequitable. This foundational complexity is the primary source of friction, error, and inefficiency in the American tax administration process, establishing a systemic barrier that technology has yet to overcome.

The Failure of Static Interfaces in Financial Technology

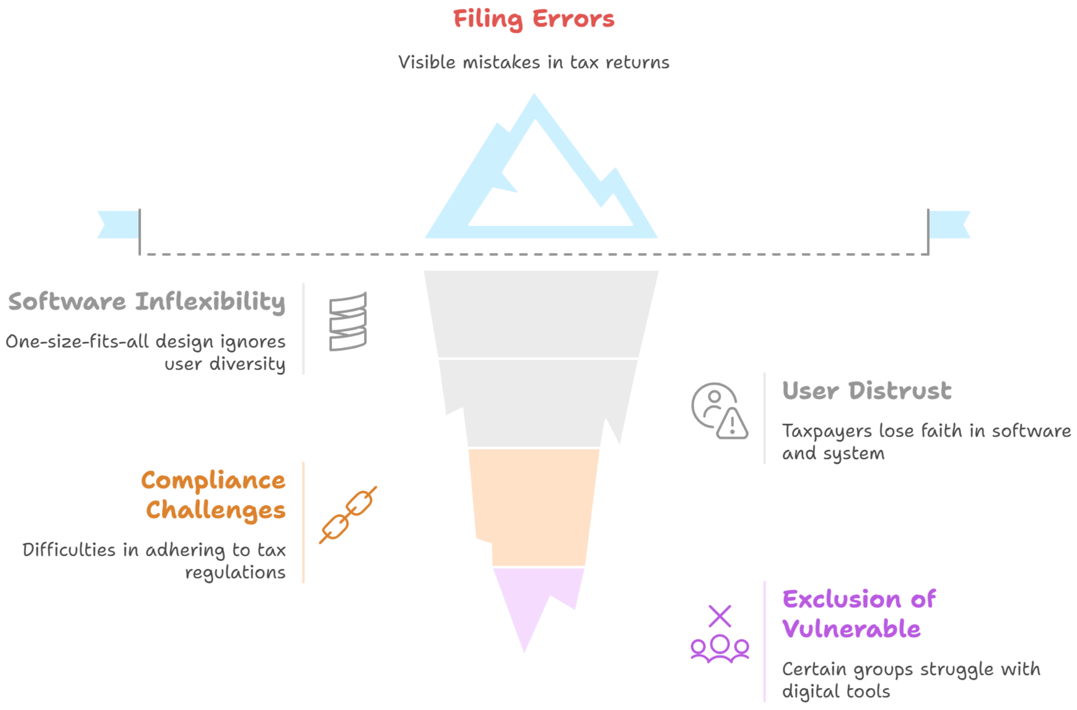
In response to this complexity, a vast market of digital tax preparation software has emerged, with over 93% of individual tax returns now being filed electronically through these tools. However, the predominant design paradigm for this software is static and inflexible. These systems employ "one-size-fits-all" user interfaces that fail to account for the vast diversity in cognitive abilities, technological proficiencies, and financial literacy across the user population [User Query]. This rigid approach to interface design represents a critical failure in financial technology (FinTech). It presupposes a uniform, idealized user, an assumption that is demonstrably false and leads to suboptimal outcomes for large segments of the population, including older adults, individuals with disabilities, and those with limited technical experience [User Query]. Research in the field of Human-Computer Interaction (HCI) confirms that for applications with significant complexity, a single static user interface inherently degrades usability because it cannot effectively meet the varied needs of all users. This mismatch between system design and user reality is a central driver of filing errors and non-compliance.

The Consequence: Exclusion, Errors, and Non-Compliance

The convergence of a Byzantine tax code with rigid, non-adaptive software interfaces has created a landscape fraught with filing errors, significant compliance challenges, and the de facto exclusion of vulnerable populations from efficient tax services [User Query]. The inadequacy of these digital tools is starkly illustrated by the fact that an estimated 60% of taxpayers still require professional assistance, even when using the software, signaling a widespread failure of these products to fulfill their core purpose [User Query]. Compounding this issue is a critical liability structure: the individual taxpayer, not the software provider, is held legally and financially responsible for any accuracy-related penalties, even when the errors originate from bugs within the software itself. This arrangement places an immense burden of risk on users, where software fallibility can lead directly to personal financial loss.

This system has created a pernicious, self-reinforcing cycle of distrust. The initial complexity of the tax code alienates taxpayers and fosters a sense of unfairness. This complexity, in turn, makes it extraordinarily difficult to create verifiably correct software, leading to what researchers term the "oracle problem"—a situation where the ideal, correct output for any given tax scenario is fundamentally unknowable. This leads to software that is prone to bugs, particularly for taxpayers in non-standard situations, such as those with very low income or disabilities. When users encounter these software failures, they are the ones who bear the financial penalties. This experience—being punished for the failure of a tool they are effectively forced to use by the system's complexity—deepens their distrust not only in the software but in the entire tax administration apparatus. This erosion of trust contributes directly to reduced voluntary compliance, completing a vicious cycle that a simple technical patch cannot break. A truly effective solution must therefore not only improve accuracy but also actively rebuild user trust by being adaptive, transparent, and fundamentally supportive.

Digital tax software's static design leads to deeper issues.


Filing Errors
Visible mistakes in tax returns
Software Inflexibility
One-size-fits-all design ignores user diversity
User Distrust
Taxpayers lose faith in software and system
Compliance Challenges
Difficulties in adhering to tax regulations
Exclusion of Vulnerable
Certain groups struggle with digital tools

Motivation

The Onerous Burden on Individual Taxpayers

The practical consequences of tax code complexity are severe, imposing what the National Taxpayer Advocate terms "onerous compliance burdens" on individuals and businesses. Taxpayers are forced to dedicate excessive time, cognitive energy, and financial resources to the annual process of preparing and filing returns. This system inherently creates inequity, as it rewards taxpayers who can afford to purchase expensive software or hire professional tax advisors, while discriminating against those who lack such resources. The human cost of this complexity is not abstract. In one case documented by the Taxpayer Advocate, a filer spent an average of 13 hours and $240 simply to determine that she was not entitled to certain family support credits—a result that runs contrary to the intent of Congress in creating those credits. This example underscores a profound disconnect between public policy goals and the lived reality of taxpayers, highlighting the urgent need for a more efficient and humane system.

Documented Deficiencies and the "Oracle Problem" in Tax Software

The shortcomings of existing tax software are not merely anecdotal; they have been documented in academic research. A key contribution from Trivedi et al. is the identification of the "oracle problem," a fundamental challenge in which the inherent ambiguity of the tax code makes it impossible to define a single, verifiable "correct" output for every complex tax situation. Their work went beyond theory, uncovering tangible bugs in open-source tax software that demonstrate the practical failure of these systems. The problem is exacerbated by the dynamic nature of tax law. Regulations change annually, posing a significant and continuous maintenance challenge for software providers. The current state-of-the-art process for updating tax software relies on manual code analysis and expert interpretation of legal amendments, a method that is described as both "time-consuming and error-prone". This combination of inherent ambiguity and constant change makes it almost certain that existing software contains undiscovered errors that put taxpayers at risk.

The Marginalization of Vulnerable Populations

The failures of the current tax filing ecosystem are not distributed equally; they disproportionately impact the most vulnerable members of society.

Elderly Users

Older adults face a unique confluence of challenges during tax season. Their financial situations often become more complex with age, involving new income sources such as pensions, retirement account distributions, and Social Security benefits, alongside potentially large and complicated healthcare expenses. Navigating these complexities is made more difficult by the fact that tax laws specific to seniors, such as the Credit for the Elderly or Disabled, are themselves intricate and subject to change. Furthermore, age-related cognitive decline can make the entire process of financial management feel daunting and overwhelming. Many seniors report discomfort and lack of familiarity with the digital tools and online portals that are now central to the tax filing process. While valuable in-person assistance programs like Tax Counseling for the Elderly (TCE) and Volunteer Income Tax Assistance (VITA) exist, they are separate from the primary digital filing ecosystem and are not always accessible to those who need them most. This leaves many older adults to grapple alone with complex software that is ill-suited to their specific financial and cognitive needs.

Users with Disabilities

The tax software industry has a documented history of failing to provide accessible products for users with disabilities. A landmark, albeit dated, 2002 review of market leaders TaxACT and TurboTax found the software to be fundamentally unusable for blind individuals relying on screen readers. The review detailed a litany of accessibility failures, including non-standard interface controls that were invisible to screen readers, unlabeled buttons that made navigation impossible, and inconsistent layouts that created profound confusion. While the IRS has since made significant progress in providing its own forms and publications in accessible formats like Braille and large print , the commercial software that serves as the primary gateway to the e-filing system remains a significant barrier. This is not just a matter of interface design; research has shown that the underlying logic of tax software is more likely to contain bugs when processing returns for taxpayers who are disabled. This is particularly concerning given the complexity of tax rules surrounding disability income, dependents with disabilities, and related credits, which creates a high-risk environment for costly errors. Tax software providers themselves acknowledge the challenge of meeting accessibility and inclusion standards for users with disabilities and low technology literacy.

Table 1: Comparative Analysis of Current Tax Preparation Software Limitations

Software Name	**Overall Usability Rating (PCMag)**	**Cost Structure**	**Key Strengths**	**Documented Weaknesses**	**Specific Accessibility Issues**	**Vulnerable Populations Adversely Affected**
Intuit TurboTax	5.0/5…	Premium Pricing; Free version for limited cases	Top-notch user experience; Easy-to-understand content; Excellent help resources	Some help responses from community members, not Intuit experts; High cost compared to competitors	Main application body unreadable by screen readers; Interview format unusable for blind users (2002 review)	Users with visual impairments; Users needing complex disability-related calculations
H&R Block	4.5/5…	Tiered pricing; Robust free option	Strong context-sensitive help; Good user experience; AI Tax Assist tool available in paid tiers	Downgrading tiers is cumbersome and requires contacting support, losing progress	Fails to adequately address complex disability credit and income scenarios in its online help articles	Users with disabilities needing to understand complex rules for credits and income reporting

FreeTaxUSA	4.5/5…	Free for federal filing; State returns cost $14.99	Excellent value; Clean, professional interface; Supports prior-year filing easily	Lacks robust help system and access to live professionals compared to premium services	Not explicitly reviewed for accessibility, but focus on budget users may deprioritize specialized accessibility features	Low-income filers; Users who cannot afford professional assistance for complex questions
TaxACT	4.0/5…	Tiered pricing; Mobile-friendly site	Excels at simplicity; Good navigation system and contextual support	Best for simpler financial scenarios; Not as deep as competitors for complex returns	Nonstandard buttons not spoken by screen readers; Inconsistent menu bar access; Inaccessible tables (2002 review)	Users with visual impairments; Users with complex returns that exceed the software's depth
Open-Source Software	N/A	Free	Community-driven; Transparent code base	Found to have real bugs, especially when returns were close to zero dollars or when a taxpayer was disabled	Varies by project, but often lacks resources for comprehensive accessibility testing	Low-income individuals; Taxpayers with disabilities

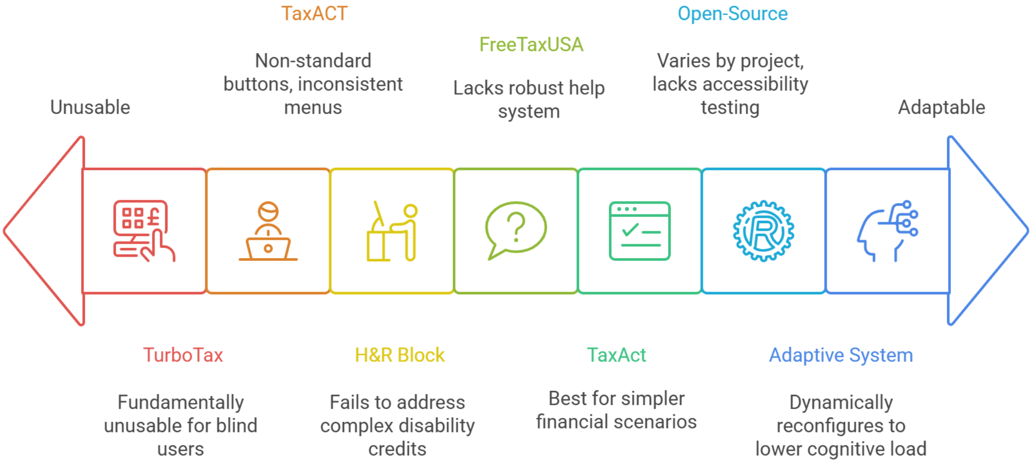
The Imperative for Inclusive Financial Technology (FinTech)

The persistent issues outlined above reveal a critical and systemic gap in the design of inclusive FinTech. As financial services, from banking to investing to taxation, become increasingly digitized, a corresponding ethical and commercial responsibility arises to ensure these platforms are accessible and usable by all segments of the population. This includes individuals with visual, motor, and cognitive impairments, as well as older adults who may face challenges related to declining cognitive abilities, limited mobility, or a lack of familiarity with digital technologies. Designing for these populations is not a niche concern; it is a fundamental aspect of user-centered design, requiring thoughtful incorporation of accessibility features like large, clear fonts, high-contrast interfaces, simplified layouts, and full compatibility with assistive technologies like screen readers.

This project is motivated by the urgent need to address what can be described as the "accessibility debt" of the FinTech industry. In the rapid push to digitize financial services, development has often prioritized speed-to-market and advanced features over foundational accessibility and cognitive inclusivity. This has resulted in an accumulation of "debt," where platforms are built on architectures that are inherently difficult, if not impossible, to retrofit for users with diverse needs. The long-standing nature of these problems, as evidenced by the 2002 accessibility review of TurboTax, shows this is not a new issue but a persistent failure. This debt is particularly pronounced in the area of cognitive accessibility, which is more complex to define and address than technical compliance. Issues such as the cognitive overload caused by information-dense interfaces or the anxiety triggered by complex and unfamiliar systems are rarely prioritized in mainstream software design. This research seeks to do more than simply add accessibility features as a patch; it aims to fundamentally pay down this debt. An

adaptive system, as proposed here, represents a paradigm shift from reactive compliance to proactive inclusion. Instead of offering a single, static interface that meets a minimum standard of accessibility, the proposed system will dynamically reconfigure itself to lower cognitive load, simplify navigation, and provide support tailored to the user's specific abilities and context. This moves beyond merely making a system usable to making it genuinely helpful and empowering for everyone.

Tax software accessibility ranges from unusable to highly adaptable.


TaxACT
Non-standard buttons, inconsistent menus
FreeTaxUSA
Lacks robust help system
Open-Source
Varies by project, lacks accessibility testing
Unusable
Adaptable
TurboTax
Fundamentally unusable for blind users
H&R Block
Fails to address complex disability credits
TaxAct
Best for simpler financial scenarios
Adaptive System
Dynamically reconfigures to lower cognitive load

Project Domain

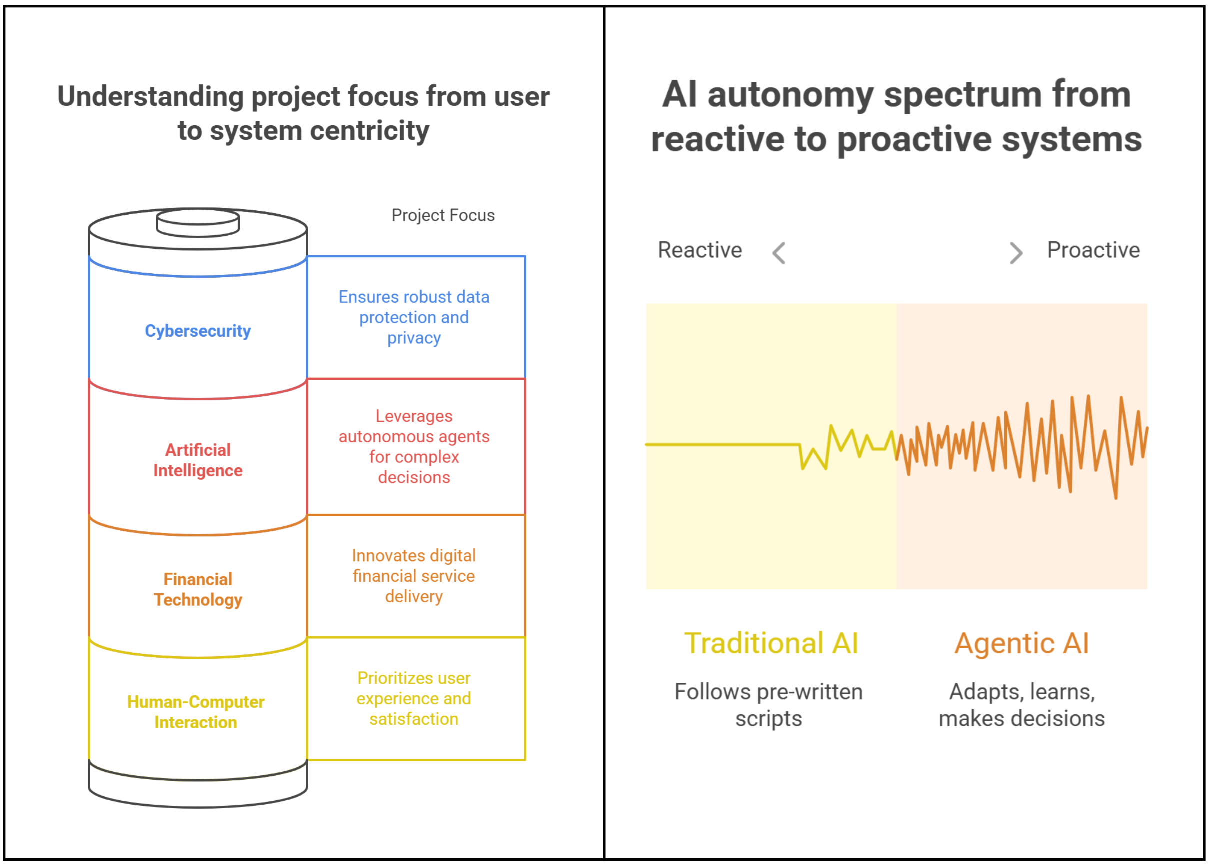
The Intersection of FinTech, AI, HCI, and Cybersecurity

This research is strategically positioned at the confluence of four critical and rapidly evolving technological domains. Each domain contributes a necessary perspective and set of tools to address the multifaceted problem of tax filing.

- **Financial Technology (FinTech):** The project directly targets a core process within the financial services industry—personal taxation. It aims to innovate the digital delivery of this service, aligning with the broader trend of leveraging technology to improve financial processes for both institutions and consumers.
- **Artificial Intelligence (AI):** The project proposes to leverage a sophisticated subfield of AI known as agentic AI. This moves beyond the simple automation and reactive chatbots common in FinTech today, aiming instead for a system of autonomous, goal-driven agents capable of proactive assistance and complex decision-making.
- **Human-Computer Interaction (HCI):** A user-centered philosophy is central to the project's design. It will employ principles and techniques from HCI, including adaptive user interfaces (AUI), conversational AI, and Explainable AI (XAI), to create an experience that is not only functional but also usable, trustworthy, and satisfying for the end-user.
- **Cybersecurity:** Given the extremely sensitive nature of personal financial and tax data, a robust cybersecurity framework is non-negotiable. The project must address the heightened security and privacy risks that arise from handling this data and from deploying autonomous AI agents, which introduce novel attack vectors.

The Emergence of Agentic AI in High-Stakes Environments

Agentic AI is redefining the potential of artificial intelligence in critical applications. Unlike traditional AI, which is often reactive or purely assistive, agentic AI systems are designed to proactively engage with users, adapt to their preferences, and make autonomous decisions to achieve specified goals. This represents a significant leap from simple automation (following a pre-written script) to true autonomy (dynamically figuring out the script as circumstances change). This capability allows agentic systems to simulate human-like decision-making and manage complex, multi-step tasks in real-time with minimal human oversight. As a result, agentic AI is being actively explored for deployment in high-stakes domains where the consequences of failure are significant. These include managing global IT infrastructure , providing autonomous cybersecurity threat response , and even participating in core financial decision-making processes within major banks and insurance firms.


Understanding project focus from user to system centricity
Project Focus
Cybersecurity
Ensures robust data protection and privacy
Artificial Intelligence
Leverages autonomous agents for complex decisions
Financial Technology
Innovates digital financial service delivery
Human-Computer Interaction
Prioritizes user experience and satisfaction
AI autonomy spectrum from reactive to proactive systems
Reactive
Proactive
Traditional AI
Follows pre-written scripts
Agentic AI
Adapts, learns, makes decisions

The Critical Role of Human-Centered Design in Financial Systems

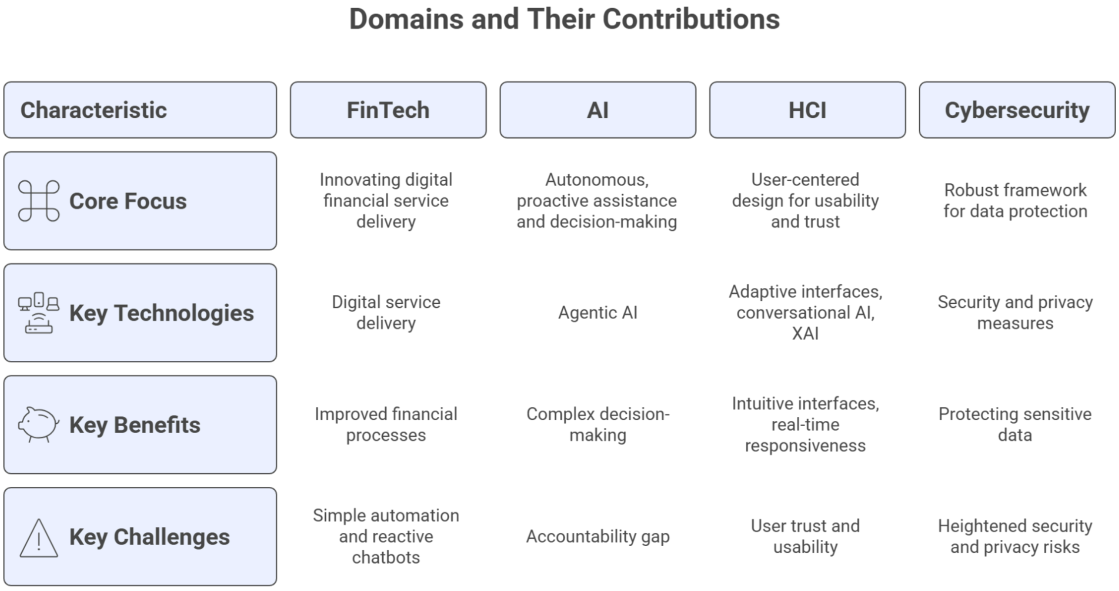
The ultimate success of any advanced AI system in the financial sector is not determined by its technical prowess alone, but by the degree to which it earns user trust. Decades of HCI research have shown that trust is not granted automatically; it is built upon a foundation of clear communication, transparency in decision-making, perceived competence, and demonstrable fairness. The opaque, "black box" nature of many sophisticated AI models acts as a significant barrier to trust, which is why the development of Explainable AI (XAI) has become a "strategic imperative" in the financial industry. Similarly, the overall user experience (UX) has been identified as a key competitive differentiator in FinTech, with studies confirming that intuitive interfaces, real-time responsiveness, and contextual personalization dramatically improve customer perceptions of digital financial services. This project therefore places these human-centered principles at its core, operating on the premise that technical capability devoid of user trust and usability is ultimately an ineffective and failed endeavor.

The introduction of agentic AI into this domain creates a novel and critical challenge: the "accountability gap." In traditional software, the lines of responsibility, while sometimes contentious, are relatively clear: a developer writes the code, a user provides the input, and liability for errors is assigned, often to the user. Agentic AI disrupts this model by introducing autonomy. The AI agent can take actions and make decisions "on behalf of humans" without an explicit command or a predefined, hard-coded roadmap for every possible situation. This raises profound new questions about risk ownership and accountability. As one analysis asks, "Who's accountable when AI systems take action?". This ambiguity creates a gap in the chain of responsibility. If the user did not directly command the action, and the developer did not explicitly code for that specific action in that specific context, who is responsible for the outcome? This project proposes that this accountability gap cannot be closed by a single solution but requires a holistic, integrated framework. It necessitates

Explainable AI (XAI) to provide auditable, "human-readable reasoning and forensic replay" of the agent's decisions. It requires thoughtful

HCI design to manage user expectations, provide appropriate levels of control, and ensure the user has a clear mental model of the agent's capabilities and autonomy. Finally, it demands

robust, secure logging that treats AI agents as distinct "non-human actors with unique identities" within the system, whose actions can be traced and verified. The proposed system is therefore designed as a cohesive whole, integrating technology, transparency, and interaction design to explicitly address and close this new accountability gap.



Domains and Their Contributions

Characteristic	FinTech	AI	HCI	Cybersecurity
Core Focus	Innovating digital financial service delivery	Autonomous, proactive assistance and decision-making	User-centered design for usability and trust	Robust framework for data protection
Key Technologies	Digital service delivery	Agentic AI	Adaptive interfaces, conversational AI, XAI	Security and privacy measures
Key Benefits	Improved financial processes	Complex decision-making	Intuitive interfaces, real-time responsiveness	Protecting sensitive data
Key Challenges	Simple automation and reactive chatbots	Accountability gap	User trust and usability	Heightened security and privacy risks

Project Aim and Objectives

Primary Aim

The primary aim of this research is to design, develop, and empirically evaluate a novel adaptive intelligent tax filing system. This system will leverage agentic artificial intelligence to provide a personalized, inclusive, secure, and compliant tax preparation experience for a diverse population of individual taxpayers, with a particular focus on addressing the needs of vulnerable user groups.

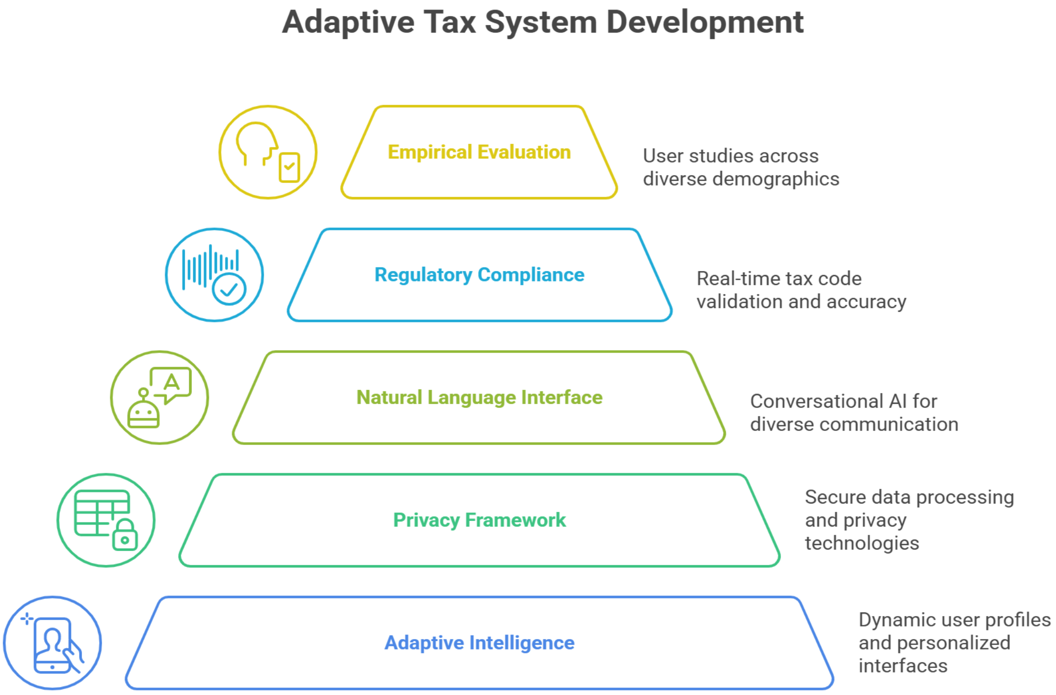
Research Objectives

To achieve this aim, the project will pursue the following five core research objectives:

1. **Develop a Multi-Agent Adaptive Intelligence Architecture:** To design and prototype a system of coordinated AI agents capable of building a dynamic user profile based on behavior

and preferences, adapting the user interface and level of assistance in real-time, and managing the complex underlying tax logic. This architecture is intended to move beyond the limitations of static interfaces by providing truly personalized and context-aware interaction modalities [User Query].

2. **Engineer a Privacy-Preserving Security Framework:** To design and implement a robust security and privacy model using state-of-the-art cryptographic techniques. This includes the use of tokenized data processing to minimize the exposure of sensitive information and the application of privacy-enhancing technologies like Secure Multi-Party Computation (SMPC) to enable collaborative analytics without data disclosure. The framework will also incorporate granular permission controls to manage access in scenarios involving caregivers or multiple authorized users.
3. **Implement a Multi-Generational Natural Language Interface:** To build and train a sophisticated conversational AI capable of understanding and responding to a wide spectrum of communication patterns. This interface must be able to process everything from the precise, formal language of tax professionals to the colloquial, sometimes ambiguous queries of lay users across different generations and levels of financial literacy. This natural language interface will serve as a primary mechanism for simplifying complexity and delivering explanations.
4. **Ensure Real-Time Regulatory Compliance and Verification:** To integrate a dedicated compliance module that performs continuous, real-time validation of all calculations and logic against the most current version of the tax code. This objective involves leveraging advanced software verification techniques, specifically metamorphic testing, to systematically test the system's logical correctness and ensure the highest degree of accuracy, thereby directly addressing the "oracle problem" that plagues current software.
5. **Empirically Evaluate Human-AI Interaction Across Demographics:** To conduct rigorous, user-centered evaluation studies with participants from diverse demographic segments. These studies will place special emphasis on recruiting older adults and individuals with disabilities to measure the system's effectiveness, efficiency, usability, and its impact on critical psychological factors such as user trust and satisfaction. The goal is to gather empirical evidence on the real-world performance and inclusivity of the adaptive system.


Adaptive Tax System Development
Empirical Evaluation
User studies across diverse demographics
Regulatory Compliance
Real-time tax code validation and accuracy
Natural Language Interface
Conversational AI for diverse communication
Privacy Framework
Secure data processing and privacy technologies
Adaptive Intelligence
Dynamic user profiles and personalized interfaces

Project Scope

In-Scope

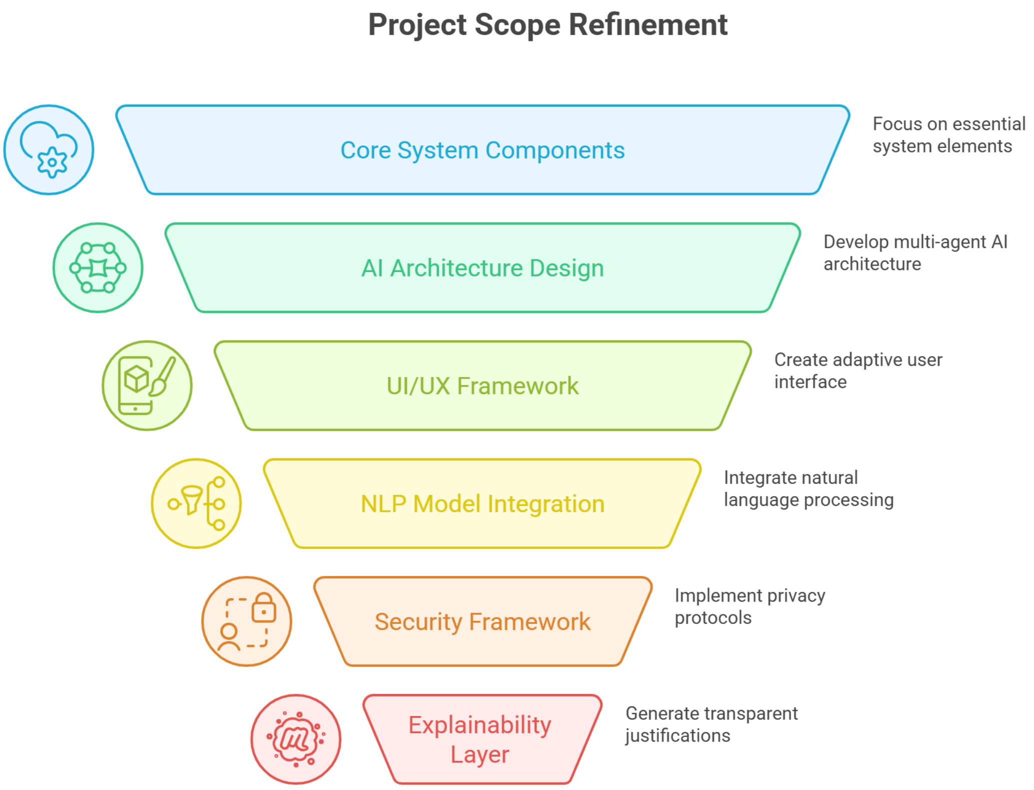
The research will focus on the complete lifecycle of the core system components as defined in the objectives, from theoretical design through to prototyping and empirical evaluation. The following elements are considered in-scope:

- The design and implementation of the multi-agent AI architecture, including the individual agents and their coordination mechanisms.
- The development of the adaptive UI/UX framework and the logic that drives its real-time adaptations.
- The fine-tuning and integration of the natural language processing (NLP) model that powers the conversational interface.
- The implementation of the security framework, with a specific focus on the practical application of SMPC protocols and data tokenization for privacy preservation.
- The creation of the explainability (XAI) layer responsible for generating transparent justifications for the system's actions and calculations.
- The design and execution of the empirical evaluation protocol, including recruitment of human subjects and analysis of collected data.

Out-of-Scope

To maintain a clear and achievable research focus, the following activities are explicitly defined as out-of-scope for this project:

- The project will not engage in the creation of new tax legislation or the interpretation of legally ambiguous or "gray" areas of the tax code. The system will be designed to operate strictly based on the tax law as published and interpreted by the IRS.
- This research will not result in a full-scale commercial product or the establishment of a for-profit enterprise. The primary outputs will be a research prototype, a set of validated frameworks and design principles, and academic publications.
- The system will not provide certified financial or legal advice. It is designed as a highly advanced assistive tool. All user interactions will be framed as such, with clear disclaimers that the ultimate responsibility for the submitted tax return remains with the user.


Project Scope Refinement
Core System Components
Focus on essential system elements
AI Architecture Design
Develop multi-agent AI architecture
UI/UX Framework
Create adaptive user interface
NLP Model Integration
Integrate natural language processing
Security Framework
Implement privacy protocols
Explainability Layer
Generate transparent justifications

Key Contributions

Upon successful completion, this project is expected to make four significant contributions to the fields of FinTech, AI, and HCI:

1. **A Novel Adaptive UI/UX Framework for Financial Applications:** The project will produce a new, empirically validated framework for designing financial technology interfaces that can dynamically adapt to user demographics, cognitive load, and technical proficiency. This framework will have broad applicability to other complex financial applications beyond tax preparation [User Query].
2. **A Secure Multi-Party Computation Model for Sensitive Financial Data:** The research will demonstrate a practical and effective application of Secure Multi-Party Computation (SMPC) for enabling privacy-preserving analytics in a consumer-facing FinTech context, showcasing its feasibility and benefits for enhancing user trust and providing value-added features.
3. **An Explainable AI Implementation for Financial Decision-Making:** The project will deliver a "glass box" implementation of automated tax preparation. It will provide transparent, human-understandable reasoning for its calculations and recommendations, directly addressing the critical trust deficit that currently exists in automated financial systems.
4. **An Empirical Model of Age-Adaptive Human-AI Interaction:** The project will produce a validated set of design principles and evaluation metrics specifically for creating AI systems that can effectively and inclusively serve older adults in complex, high-stakes digital tasks. This will provide a much-needed evidence base for designing the next generation of inclusive AI.

Literature Survey

The State of Agentic Artificial Intelligence

From Automation to Autonomy in Enterprise Systems

The field of artificial intelligence is undergoing a significant evolution from systems that merely automate tasks to those that exhibit true autonomy. This new paradigm is defined by agentic AI, which represents a shift from "following a script" to "figuring out the script as it goes". Agentic AI systems are characterized by their capacity to function autonomously while continuously adapting to complex and dynamic environments. A typical agentic architecture leverages a large language model (LLM) as its cognitive "brain," maintains a memory of past interactions (state), and can dynamically interact with its environment, including other software tools and APIs. These capabilities enable agentic systems to perform complex, multi-step operations that were previously the exclusive domain of human experts. For example, in enterprise settings, they are being developed to manage IT service desks—autonomously triaging tickets and resolving issues—and to optimize global supply chains by identifying disruptions and initiating corrective actions with minimal human intervention. It is important to note, however, that the term "agentic" is sometimes used loosely in the market, and a critical review of the literature suggests that many currently available systems are more akin to sophisticated "workflow puppets" than truly autonomous agents.

Agentic AI in Financial Services: Opportunities and Risks

Within the financial services sector, agentic AI holds the potential to revolutionize operations and customer interactions. It can be applied to a wide range of tasks, including real-time fraud detection, personalized spending analysis, and proactive customer support. The Bank of England acknowledges the significant potential of agentic AI to enhance core financial decision-making processes in banks and insurance companies, leading to greater efficiency and product availability. The primary opportunity lies in the ability to deliver hyper-personalized services at scale, simulating the kind of bespoke advice previously available only from human advisors. However, this potential is balanced by substantial risks. The autonomous nature of these systems introduces new vectors for malfunction and systemic disruption, where a flaw in a widely used agent could have cascading effects on financial markets. Furthermore, the potential for malicious use, such as deploying autonomous agents for market manipulation or sophisticated disinformation campaigns, is a serious concern. Consequently, user trust remains the central challenge to adoption. This trust is contingent not just on performance, but on the system's transparency, its guarantees of data privacy, and the perceived fairness of its autonomous decisions.

The Duality of Agentic AI in Cybersecurity: Ally and Adversary

The dual-use nature of agentic AI is nowhere more apparent than in the domain of cybersecurity. It is simultaneously a powerful new class of ally and a formidable new class of adversary. On the defensive side, agentic AI is enabling the development of autonomous security platforms that can detect, decide, and respond to cyber threats at "machine speed," often without direct human intervention. Google's "Big Sleep" agent, which reportedly foiled an imminent exploit autonomously, is cited as a pioneering example of this capability. This creates a new paradigm of proactive, AI-first threat prevention. On the offensive side, however, malicious actors will inevitably weaponize agentic AI to create more sophisticated attacks, such as adaptive malware that can learn and evade detection, or intelligent fraud bots that can mimic human behavior with terrifying accuracy. This dynamic sets the stage for a future "machine battle," where defensive AI agents are pitted against offensive ones. This new reality introduces novel security risks that traditional systems were not designed to handle, such as memory poisoning (corrupting an agent's learned knowledge), goal manipulation (tricking an agent into pursuing a harmful objective), and excessive agency (where an agent's autonomy is exploited to cause damage). This duality makes robust governance essential, including the implementation of verifiable digital identities for all AI agents and the strict enforcement of the principle of least privilege to limit the potential damage an agent can cause.

Human-Computer Interaction for Complex Financial Tasks

Principles of Adaptive User Interfaces (AUI) for Cognitive Accessibility

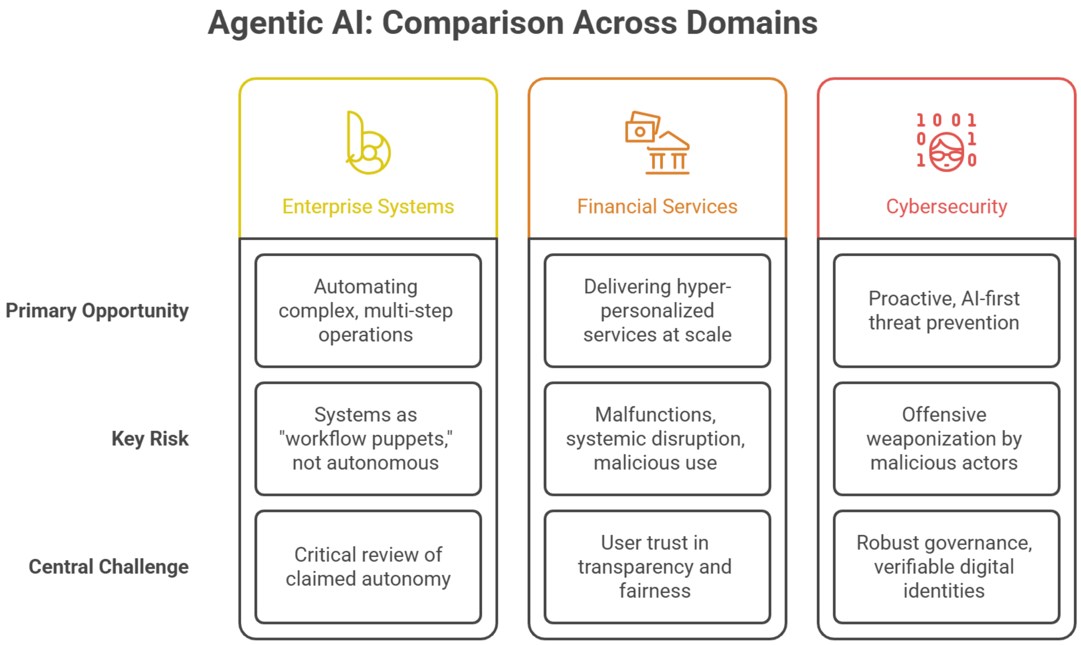
Adaptive User Interfaces (AUIs) are dynamic systems that automatically modify their layout, content, and interaction patterns based on a model of the user's behavior, context, and proficiency level. The fundamental goal of an AUI is to enhance the user experience by reducing cognitive load, improving task efficiency, and increasing accessibility for a diverse range of users. The system makes adaptations based on a set of trigger variables, which can include user performance metrics like error rates, estimates of cognitive workload, and the specific context of the task being performed. However, the very nature of AUIs creates a tension with established usability principles. The dynamic, changing nature of an adaptive interface can violate users' expectations of predictability and consistency, and can reduce their sense of control over the system. This tension is particularly acute when designing for users with cognitive disabilities, for whom a consistent and predictable interface is of paramount importance. Therefore, designing a successful AUI is a delicate balancing act. It requires a flexible, modular architecture that allows for adaptation while also providing the user with ultimate control, transparency about why changes are being made, and the ability to accept, reject, or reverse any system-initiated adaptations.

Conversational AI for Financial Literacy and Advice

Natural Language Interfaces (NLIs) are rapidly emerging as a transformative technology for making complex data systems accessible to non-technical users. By allowing users to ask questions in everyday language instead of structured query languages like SQL, NLIs democratize access to data and empower a broader range of people to perform analysis and gain insights. In the financial domain, this technology holds immense promise for simplifying tasks like portfolio analysis and tax preparation. However, finance also presents unique and difficult challenges for NLIs. These include the need to understand highly specialized, domain-specific terminology (e.g., EBITDA, amortization), the requirement for absolute quantitative precision in calculations, and the ability to disambiguate user queries that may be vague or context-dependent. To overcome these challenges, researchers are developing advanced techniques beyond the capabilities of general-purpose LLMs. These include domain-specific fine-tuning on corpora of financial and legal documents, retrieval-augmented generation (RAG) to ground responses in verified data sources, and sophisticated prompt engineering strategies. Academic and industry workshops associated with top-tier NLP conferences such as ACL and EMNLP, like FinNLP and NLP4ConvAI, are serving as crucial hubs for advancing this research, with a strong focus on key problems like mitigating model hallucinations, ensuring factual accuracy, and developing frameworks for building reliable and personalized financial chatbots.

Frameworks for Evaluating User Experience in Adaptive Systems

The evaluation of adaptive systems presents a significant methodological challenge for the HCI community. Traditional usability testing methods are often inadequate because their core assumption—that the system provides a uniform response to all users—is violated by the very nature of adaptation. An AUI provides a personalized output for each user, which complicates direct comparisons and requires a more nuanced evaluation framework. A comprehensive evaluation must therefore extend beyond objective performance metrics like task efficiency (time) and effectiveness (error rate). It must also incorporate measures of the subjective user experience, including user satisfaction, the perceived usefulness of the system, and, critically, the perceived appropriateness of the adaptations themselves. A user-centered evaluation (UCE) methodology is considered essential, which involves engaging with real users throughout the iterative design and development process to gather feedback early and often. Key challenges that any evaluation framework must address include assessing the negative "usability side effects" that occur when the system makes an incorrect adaptation, and measuring the impact of adaptation on the user's sense of control and the system's predictability. A state-of-the-art UX evaluation framework for intelligent environments should therefore be holistic, assessing the classic usability components of learnability, efficiency, memorability, errors, and satisfaction, while also capturing the user's broader emotional responses, beliefs, and perceptions about the intelligent system.



Agentic AI: Comparison Across Domains

	Enterprise Systems	Financial Services	Cybersecurity
Primary Opportunity	Automating complex, multi-step operations	Delivering hyper-personalized services at scale	Proactive, AI-first threat prevention
Key Risk	Systems as "workflow puppets," not autonomous	Malfunctions, systemic disruption, malicious use	Offensive weaponization by malicious actors
Central Challenge	Critical review of claimed autonomy	User trust in transparency and fairness	Robust governance, verifiable digital identities

Comprehensive Literature Review: Key Findings and Research Gaps

This literature review synthesizes key findings and identifies research gaps across four critical areas relevant to an Adaptive Intelligent Tax Filing System: Tax System Complexity & User Burdens, Agentic AI & Advanced Systems, Human-Computer Interaction (HCI) & User Experience, and Explainability, Security, and Privacy.

I. Tax System Complexity & User Burdens:

This section explores the inherent difficulties within existing tax systems and their impact on taxpayers.

S. No.	**Author/Authors, Year**	**Title**	**Journal/Source**	**Findings & Relevance**	**Research Gap**
1	National Taxpayer Advocate, 2022	The Complexity of the Tax Code Burdens Taxpayers and the IRS Alike	Annual Report to Congress	Establishes tax code complexity as a primary, systemic problem causing widespread burden, distrust, and inequity. This is the core problem statement for the research.	Current solutions have failed to adequately mitigate the impact of this complexity on diverse individual taxpayers.
2	Wilson, G., 2024	Holding tax software accountable	Technical Report	Identifies the "oracle problem" (unverifiable correctness) and finds that software has bugs disproportionately affecting vulnerable users, who unfairly bear the liability.	A need for new software verification methods (like metamorphic testing) and fairer liability models.

3	Trivedi, A., et al., 2023	Technical Challenges in Maintaining Tax Prep Software with Large Language Models	arXiv	Shows that manually updating tax software is slow and error-prone. While LLMs show promise, they struggle with correctness and frequent law changes.	An automated, verifiable method is needed to ensure software correctness against changing regulations.
4	American Foundation for the Blind, 2002	Taxing Both Income and Patience: Reviews of TaxACT and TurboTax	AccessWorld Magazine	A landmark review demonstrating that major tax software was fundamentally inaccessible to screen reader users, highlighting a long-standing industry failure.	Despite 20+ years, a significant "accessibility debt" remains in commercial tax software.
5	Giebel, C. et al., 2023	The digitalisation of finance management skills in dementia...	PLOS ONE	Highlights the digital divide for older adults and those with cognitive decline, noting their discomfort with complex financial tech. Validates the need for cognitive accessibility.	FinTech largely ignores the specific cognitive needs of older adults, creating usability barriers.

II. Agentic AI & Advanced Systems:

This section focuses on the capabilities and implications of agentic AI within technological systems.

S. No.	Author/Authors, Year	Title	Journal/Source	Findings & Relevance	Research Gap
6	McKinsey, 2024	AI Agents and Agentic Systems in Global IT Management	Taylor & Francis Online	Defines agentic AI as systems that can autonomously "figure out the script" to solve complex, multi-step problems, validating the architectural choice for this project.	The application of agentic AI in consumer-facing, high-stakes domains like personal finance is still nascent.
7	HUMAN Security, n.d.	Agentic AI & Cybersecurity: A Fundamental Evolution	HUMAN Security	Describes agentic AI as both a powerful defensive tool and a new class of threat, introducing novel risks like goal manipulation and memory poisoning.	Security frameworks must evolve to address the unique vulnerabilities introduced by autonomous AI agents.
8	Linklaters, n.d.	Understanding Agentic AI: The Power of Autonomy	Linklaters	Discusses the "accountability gap" created by autonomous AI, raising critical questions about risk and liability when an agent acts without direct human command.	A holistic framework combining XAI, HCI, and secure logging is needed to close the accountability gap.

9	Bank of England, 2025	Financial stability in focus, April 2025	Bank of England	Acknowledges the potential of agentic AI to revolutionize financial services but warns of systemic risks if flaws in widely used agents cause cascading failures.	The stability and safety of deploying autonomous financial agents at scale is a major open research question.

III. Human-Computer Interaction (HCI) & User Experience:

This section examines the design principles and challenges related to user interaction with adaptive intelligent systems.

S. No.	**Author/Authors, Year**	**Title**	**Journal/Source**	**Findings & Relevance**	**Research Gap**
10	Akiki, P. A., et al., 2014	Adaptive Model-Driven User Interface Development Systems	ACM Computing Surveys	Provides a foundational overview of Adaptive User Interfaces (AUIs), highlighting the core challenge: balancing personalization with user control and predictability.	A lack of empirically validated AUI frameworks for complex financial applications that cater to diverse cognitive needs.

11	Fadhil, A., 2024	Usability and User Experience Evaluation in Intelligent Environments...	Intl. Journal of HCI	Argues that evaluating adaptive systems requires a holistic approach beyond classic metrics, incorporating user emotions, beliefs, and perceptions of the AI's intelligence.	Standard UX evaluation methods are insufficient for adaptive systems; new models are needed.
12	Paternò, F., & Santoro, C., n.d.	Adaptive User Interfaces for People with Cognitive Disabilities	PMC	Emphasizes that for users with cognitive disabilities, interface consistency and predictability are paramount, creating a direct tension with the dynamic nature of AUIs.	A need for AUI design principles that specifically resolve the conflict between adaptation and the need for consistency for cognitively vulnerable users.
13	Gajos, K., et al., 2009	Design Space and Evaluation Challenges of Adaptive Graphical User Interfaces	AI Magazine	Details the "usability side effects" of incorrect adaptations and the challenge of measuring the impact on a user's sense of control.	Methodologies to systematically measure and mitigate the negative consequences of flawed AI-driven adaptations.

IV. Explainability, Security, and Privacy:

This section delves into crucial aspects of trust, safety, and data protection within intelligent systems.

S. No.	Author/Authors, Year	Title	Journal/Source	Findings & Relevance	Research Gap
14	Phan, H. & Hoang, A., 2021	Explainable AI in Finance: an Overview	arXiv	Positions Explainable AI (XAI) as a "strategic imperative" in finance for building user trust and meeting legal requirements like GDPR's "Right to Explanation."	The application of XAI to explain complex tax calculations in simple, consumer-friendly terms is a novel research area.
15	Lindell, Y., 2021	Secure Multiparty Computation	Comm…	Provides a comprehensive overview of Secure Multi-Party Computation (SMPC), a cryptographic method for joint data analysis while preserving privacy.	The practical application of SMPC in consumer-facing FinTech to enable features like privacy-preserving benchmarking is underexplored.
16	Bodipudi, A., 2024	Explainable AI in Financial Institutions for Fraud and Risk Mitigation	Euro. J…	Shows how XAI techniques like SHAP and LIME are used to create audit trails and transparently justify high-stakes financial decisions (e.g., loan denials).	While used for institutions, there is a gap in applying these rigorous XAI techniques to empower individual consumers in understanding their own financial data.

17	Tizpaz-Niari, S., et al., 2023	Automated Metamorphic Specification Generation for Tax...	arXiv	Proposes using LLMs to automatically generate metamorphic tests from legal text, offering a scalable solution to the "oracle problem" for tax software verification.	The integration of LLM-generated metamorphic testing into a real-time compliance module for a live application.
18	PYMNTS, 2025	Agentic AI Turns Enterprise Cybersecurity Into a Machine Battle	PYMN…	Foresees a future of "machine battles" where defensive and offensive AI agents compete, requiring a new paradigm of AI-first threat prevention.	The development of security protocols specifically designed to protect AI agents from adversarial AI attacks.

Security and Privacy in Modern FinTech

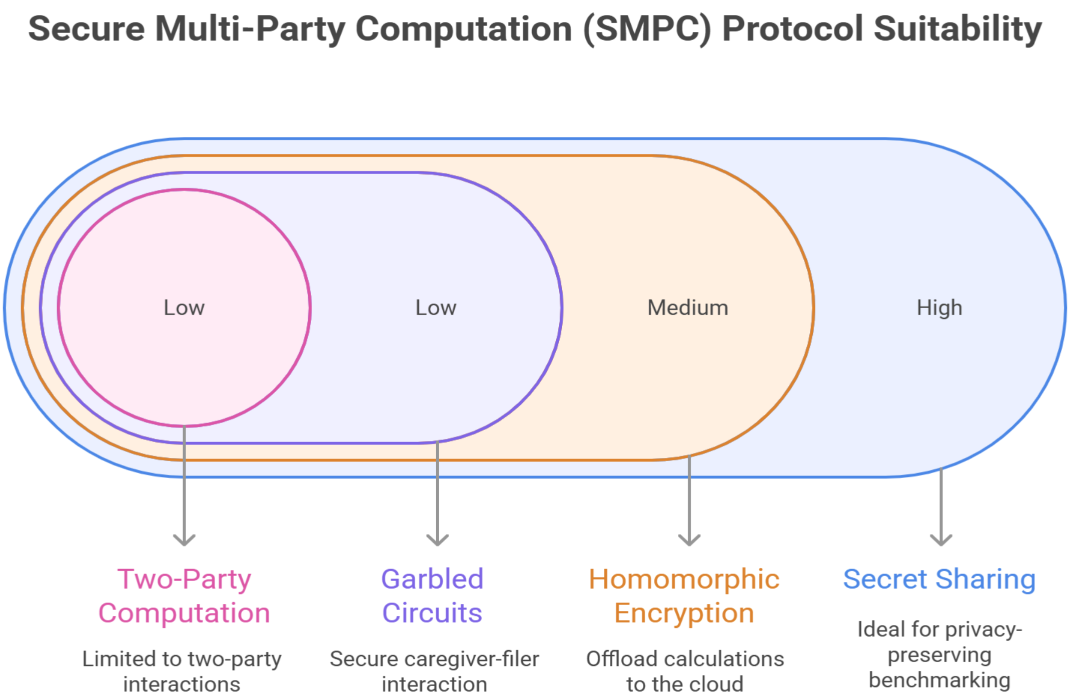
Secure Multi-Party Computation (SMPC) for Privacy-Preserving Analytics

Secure Multi-Party Computation (SMPC) is a powerful cryptographic paradigm that fundamentally changes how collaborative data analysis can be performed. It comprises a set of protocols that allow multiple, non-trusting parties to jointly compute a function over their combined private data without ever revealing that raw data to one another. This approach provides robust, mathematical guarantees of privacy and correctness, and enables decentralized trust, eliminating the need for a central, trusted third party to hold and process the sensitive data. The most common protocols used to achieve this are Garbled Circuits, which are particularly well-suited for two-party computations, and Secret Sharing (such as Shamir's Secret Sharing), which distributes "shares" of a secret among multiple parties such that no individual share reveals information on its own. In the financial sector, SMPC has significant applications. It can be used by a consortium of banks to collaboratively train a more accurate fraud detection model on their combined transaction data, or by insurance companies to identify fraudulent claims patterns, all without sharing their confidential customer information. While historically viewed as too computationally expensive for practical use, recent algorithmic advancements and hardware improvements are making SMPC increasingly feasible for real-world problems. It is now considered a key enabling technology for performing data-driven collaboration while maintaining strict compliance with privacy regulations like GDPR and HIPAA.

Table 2: Taxonomy and Application of Secure Multi-Party Computation (SMPC) Protocols

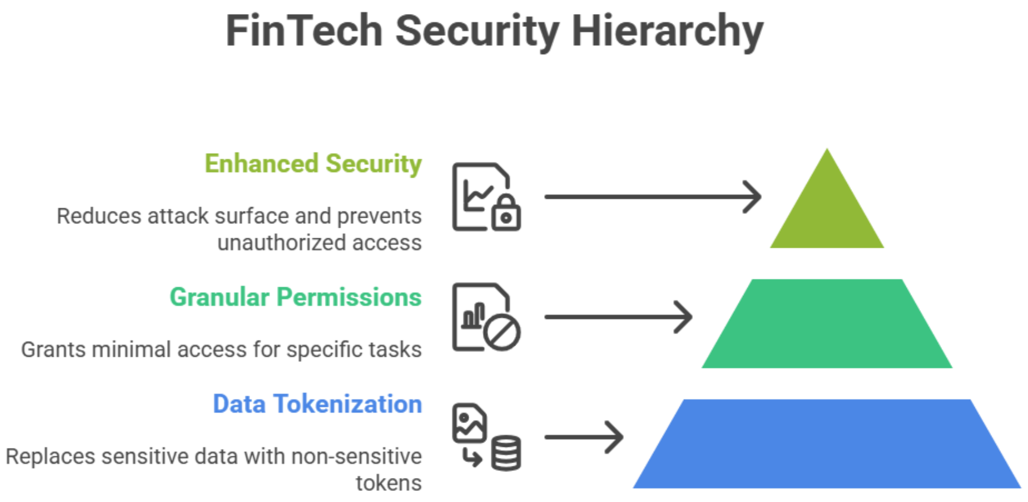
Protocol Type	**Core Principle**	**Number of Parties**	**Security Guarantees**	**Primary Advantage**	**Primary Disadvantage**	**Suitability for Proposed Tax System**
Garbled Circuits	One party "garbles" a circuit representing the function; the other evaluates it with encrypted inputs.	Typically 2 (2PC)	Priva… ▾	Very strong security model for two-party scenarios.	High communication overhead; less efficient for many parties.	Low: Tax system is primarily a single-user application, but this could be used for secure caregiver-filer interaction.
Secret Sharing (e.g., Shamir's)	Data is split into multiple "shares"; computation is performed on shares. A threshold of shares is needed for reconstruction.	2 or more (MPC)	Priva… ▾	Computationally efficient compared to Garbled Circuits; scalable to more parties.	Requires multiple rounds of interaction; security relies on a majority of parties being honest.	High: Ideal for privacy-preserving benchmarking (e.g., "How do my deductions compare to anonymous filers like me?") without centralizing data.

Homomorphic Encryption	Allows computations (e.g., addition, multiplication) to be performed directly on encrypted data.	1 or more	Privacy ▾	Non-interactive; one party can encrypt data and send it to an untrusted server for computation.	Extremely high computational cost; limited to certain types of operations.	Medium: Could be used to offload specific calculations to the cloud while keeping data encrypted, but likely too slow for real-time interaction.
Two-Party Computation (2PC)	General category for any protocol involving exactly two parties.	2	Priva… ▾	Simplified protocol structure; lower overhead than general MPC.	Limited to bilateral exchanges.	Low: Similar to Garbled Circuits, its application is limited to specific two-party interactions within the system.


Secure Multi-Party Computation (SMPC) Protocol Suitability
Low
Low
Medium
High
Two-Party Computation
Limited to two-party interactions
Garbled Circuits
Secure caregiver-filer interaction
Homomorphic Encryption
Offload calculations to the cloud
Secret Sharing
Ideal for privacy-preserving benchmarking

Tokenization and Granular Permission Controls

While not a focus of the provided academic literature, the principles of data tokenization and granular permission controls are foundational best practices in modern FinTech security, as specified in the project's technical scope [User Query]. Tokenization is a process that replaces highly sensitive data elements, such as a Social Security Number or bank account number, with a non-sensitive equivalent known as a "token." This token has no extrinsic or exploitable meaning or value, and it serves as a reference to the original data, which is stored securely in a separate, isolated environment. This technique dramatically reduces the system's attack surface, as the main application logic interacts only with the valueless tokens, not the sensitive data itself. Complementing this is the principle of granular permission controls, which is an application of the security concept of "least privilege." This ensures that any entity interacting with the system—whether a human user, a caregiver granted partial access, or an autonomous AI agent—is only granted access to the absolute minimum data and functionality required to perform its specific, authorized task. In a system designed to accommodate multiple users or agents with different roles, this is critical for preventing unauthorized data access and ensuring privacy.


FinTech Security Hierarchy
Enhanced Security
Reduces attack surface and prevents unauthorized access
Granular Permissions
Grants minimal access for specific tasks
Data Tokenization
Replaces sensitive data with non-sensitive tokens

Trust, Transparency, and Compliance

The Role of Explainable AI (XAI) in Calibrating User Trust

Explainable AI (XAI) is a subfield of AI research dedicated to developing methods that can render the decisions and predictions of complex, "black box" models understandable to human users. In high-stakes domains such as finance, where an unexplained or incorrect AI decision can have severe legal and financial repercussions, XAI is not merely a desirable feature but a "strategic imperative". Its primary function is to calibrate user trust. By providing insight into

why an AI made a particular decision, XAI empowers a human-in-the-loop to make an informed judgment about when to trust and delegate to the AI, and when to be skeptical and override its recommendation. A range of XAI techniques have proven effective in financial contexts. Model-agnostic methods like SHAP (SHapley Additive exPlanations) and LIME (Local Interpretable Model-agnostic Explanations) are used to provide feature attribution, highlighting which input data points were most influential in a given decision. Inherently transparent models, such as Explainable Boosting Machines (EBMs), offer a direct view into their decision-making logic without sacrificing significant predictive accuracy. By deploying these techniques to provide clear, plain-language explanations for outcomes like loan application denials or fraud alerts, financial institutions can significantly improve customer communication, reduce complaints, demonstrate fairness, and build a foundation of trust with their users.

Table 3: Framework for Evaluating Explainable AI (XAI) Techniques in a Financial Context

XAI Technique	Explanation Type	Key Benefit in Finance	Key Limitation	Trust-Building Mechanism	Implementation in Proposed System

SHAP (SHapley Additive exPlanations)	Local/…	Provides precise feature attribution values, creating clear audit trails for regulatory compliance.	Can be computationally intensive for complex models and large datasets.	Enhances transparency by showing the "why" behind a calculation (e.g., a specific credit).	Used by the Interaction Agent to generate on-demand explanations for any line item on the tax return (e.g., "Why is this my tax liability?").
LIME (Local Interpretable Model-Agnostic Explanations)	Local, …	Generates simple, localized explanations that are easy for non-experts to understand.	Explanations are only for a single prediction and may not reflect global model behavior.	Fosters trust by providing immediate, context-specific justifications for system actions.	Used to explain proactive suggestions (e.g., "We suggest this deduction because you entered self-employment income.").
Explainable Boosting Machines (EBMs)	Global,…	The model itself is transparent ("glass box"), allowing direct inspection of how each feature contributes to the outcome.	May have slightly lower predictive accuracy than complex "black box" models like deep neural networks.	Builds foundational trust through inherent transparency; there is no "black box" to explain.	The core Tax Logic Agent could be built as an EBM, making its entire calculation process auditable and transparent by design.

Counterfactual Explanations	Local, … ▾	Provides actionable insights by showing what would need to change for a different outcome (e.g., "To qualify for this credit, your income would need to be Rs.5000 lower").	Can be difficult to generate for very complex, high-dimensional data.	Empowers users by giving them a clear path to achieving a different, desired outcome.	Used in the NLI to answer "what-if" questions from the user, helping with tax planning and understanding eligibility rules.

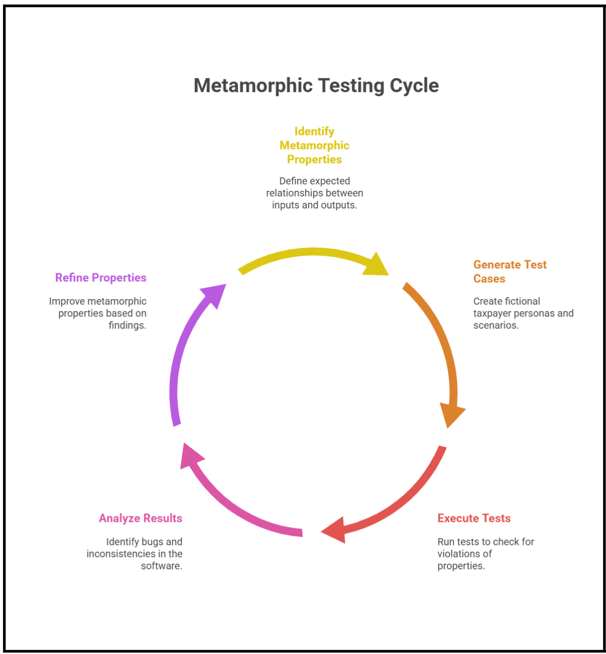
Methodologies for Verifying Tax Software Correctness (Metamorphic Testing)

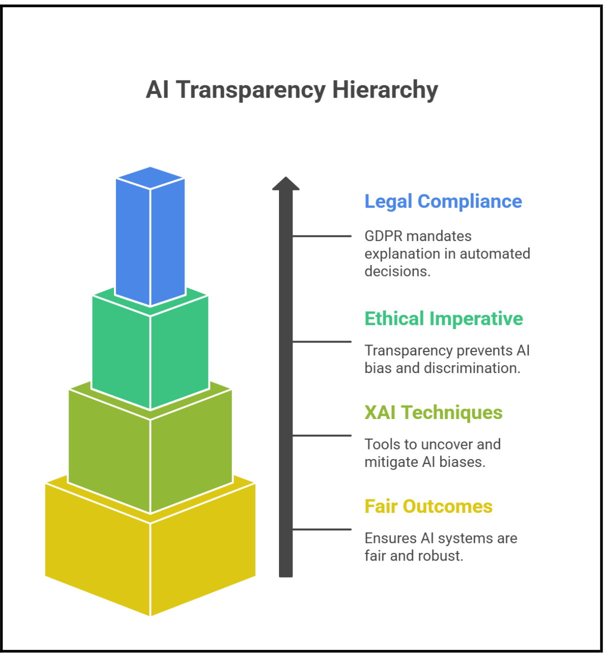
A fundamental challenge in ensuring the quality of tax preparation software is the absence of a complete "test oracle." That is, due to the complexity and ambiguity of the tax code, there is no definitive, pre-existing dataset of inputs and their guaranteed-correct outputs against which software can be comprehensively tested. This "oracle problem" renders traditional software testing methods, which rely on comparing program output to a known correct answer, insufficient. In response to this challenge, metamorphic testing has emerged as a leading and innovative solution for verifying the correctness of legal-critical software like tax programs. The core idea of metamorphic testing is to check for violations of expected relationships between the outputs of different, but related, program inputs. Instead of checking if Input A produces the correct Output B, it checks if a slight, predictable change from Input A to Input A' creates a corresponding, predictable change in the output. For example, a metamorphic property derived from tax law would state that if two taxpayers have identical financial profiles, except that one is blind, the tax software

must calculate a higher standard deduction for the blind taxpayer. By systematically generating thousands of such "metamorphic properties" based on the text of IRS publications and creating fictional taxpayer personas to test them, researchers can effectively identify bugs and logical inconsistencies in the software without needing a ground-truth dataset of correct tax returns. This approach holds the potential to transform the natural language of law into a set of formal, testable specifications, thereby increasing the fairness and impartiality of the software that implements it.

The Legal and Ethical Imperative for Explainability

The drive for transparency in AI is not just a matter of good user experience; it is increasingly a legal and ethical requirement. Landmark data privacy regulations, most notably the European Union's General Data Protection Regulation (GDPR), include provisions that have been interpreted as a "Right to Explanation" for individuals subject to automated decision-making. This creates a direct legal impetus for financial institutions to adopt interpretable AI systems, particularly for high-stakes decisions like credit scoring, loan approvals, and fraud detection. Beyond mere compliance, however, there is a profound ethical imperative for transparency. Opaque AI models can inadvertently learn and perpetuate societal biases present in their training data, leading to discriminatory outcomes. For example, a lending model might use ZIP codes as a proxy for race, resulting in biased loan approvals. XAI techniques are critical tools for uncovering and mitigating such biases, allowing developers and regulators to audit the decision-making process and ensure that AI systems are not only effective and compliant but also fundamentally fair and ethically robust.


Metamorphic Testing Cycle
Identify Metamorphic Properties
Define expected relationships between inputs and outputs.
Generate Test Cases
Create fictional taxpayer personas and scenarios.
Execute Tests
Run tests to check for violations of properties.
Analyze Results
Identify bugs and inconsistencies in the software.
Refine Properties
Improve metamorphic properties based on findings.


AI Transparency Hierarchy
Legal Compliance
GDPR mandates explanation in automated decisions.
Ethical Imperative
Transparency prevents AI bias and discrimination.
XAI Techniques
Tools to uncover and mitigate AI biases.
Fair Outcomes
Ensures AI systems are fair and robust.

Methodology

Phase 1: System Architecture and Component Design

This initial phase will focus on the design and prototyping of the system's core architecture, translating the conceptual framework into a functional blueprint. The methodology will be grounded in a multi-agent systems approach and model-driven UI development.

The Multi-Agent System (MAS)

A Multi-Agent System (MAS) will be designed to modularize the system's intelligence and responsibilities, drawing on the concept of agentic systems that can autonomously coordinate to manage complex tasks.[32] The MAS will consist of three primary, interacting agent types:

- **User Profiling & Adaptation Agent:** This agent will be the heart of the system's personalization capabilities. It will be responsible for creating and continuously updating a dynamic user model. This model will be built from multiple data streams, including implicit interaction patterns (e.g., typing speed, error frequency, time spent on a page, help requests), explicit user preferences (e.g., user-selected font size, preferred interaction style), and initial demographic information. Using this rich, evolving profile, the agent will make real-time decisions about when and how to adapt the interface. It will signal the UI Engine to execute these changes, such as simplifying a complex screen for a struggling user or offering more advanced options to an expert. The agent's logic will be carefully designed to balance the benefits of personalization with the critical need for interface predictability and user control, addressing the known usability challenges of adaptive systems.[3, 52]
- **Tax Logic & Compliance Agent:** This agent will serve as the system's authoritative source of truth for all tax-related matters. It will encapsulate the core computational logic of tax preparation. Its knowledge base will be an updatable database of tax regulations, sourced directly from IRS publications. The primary function of this agent is to perform all necessary calculations with perfect accuracy and to ensure that every step of the filing process strictly adheres to current tax law. To guarantee its correctness, this agent will be subjected to a continuous and rigorous testing regimen based on the metamorphic testing methodology.[2, 4]
- **Interaction & Explanation Agent:** This agent will be the primary interface between the user and the system's complex internal workings. It will power both the Natural Language Interface (NLI) and the Explainable AI (XAI) layer. It will manage the flow of the conversation, translating the user's natural language queries into structured commands that the Tax Logic Agent can execute. Critically, it will also perform the reverse translation: taking the structured outputs from the Tax Logic Agent (e.g., calculated numbers, logical decisions) and rendering them as clear, human-understandable explanations in plain language.[41, 48]

The Adaptive UI Engine

The user interface will be implemented using a model-driven UI framework, which separates the interface logic from the application logic, allowing for dynamic adaptation.[68] The UI will be constructed from a library of modular, reusable components (e.g., input fields, informational pop-ups, navigation bars) that can be dynamically composed, rearranged, simplified, or augmented by the User Profiling & Adaptation Agent. To cater to the widest possible range of users, we will design and implement several distinct interaction modalities:

- **Novice Mode:** A highly guided, step-by-step, question-and-answer style of interaction. This mode will feature extensive, context-sensitive help, proactive suggestions, and simplified language to minimize cognitive load for first-time filers or users with low technical confidence.
- **Expert Mode:** A more direct, form-based interface that mirrors the structure of traditional tax forms. This mode is designed for tax professionals or experienced filers who prefer to navigate directly to specific sections and input data without extensive guidance.
- **Accessibility-First Mode:** A dedicated mode designed from the ground up based on WCAG principles and best practices for cognitive and visual accessibility.[11, 28] This mode will feature a high-contrast color scheme, enlarged default fonts, simplified navigation structures with clear focus indicators, and will be rigorously tested for full compatibility with leading screen-reading software.

A core principle of the UI design will be user control. The system will allow users to manually switch between modes at any time. Furthermore, when the system proposes an adaptive change, it will be presented as a clear, non-intrusive suggestion that the user can choose to accept or reject, thus addressing the critical need for user control and predictability in adaptive systems.[3, 50]

The Natural Language Core

The system's conversational capabilities will be powered by a state-of-the-art Large Language Model (LLM). To ensure its effectiveness in the highly specialized domain of taxation, the base LLM will be fine-tuned on a carefully curated dataset. This process of domain adaptation is crucial for the model to learn the specific vocabulary, syntax, and semantics of financial and legal language.[41] The fine-tuning dataset will include official IRS publications, the text of relevant sections of the tax code, and a large corpus of synthetic query-answer pairs relevant to tax filing. The NLI will be designed to handle two primary types of queries: data retrieval queries (e.g., "What is the 2024 standard deduction for a single filer over 65?") and explanatory queries (e.g., "Why is my refund lower this year than last year?"). To combat the risk of model hallucination and ensure all information provided to the user is factually correct, we will implement factuality-aware alignment methods during training and a retrieval-augmented generation (RAG) architecture at inference time. This will ground all of the model's responses in the verified knowledge base of the Tax Logic Agent.[55]

Phase 2: Security and Compliance Framework Implementation

This phase will focus on building the critical infrastructure for ensuring data privacy, security, and regulatory compliance.

Implementing SMPC Protocols for Privacy-Preserving Analytics

To provide advanced, value-added features without compromising user privacy, the system will incorporate an SMPC protocol. A specific use case for this is providing users with benchmarking information, for example, allowing a user to see how their charitable deductions compare to the statistical average for anonymous filers in their same income bracket and geographic region. To implement this, we will likely utilize a secret-sharing-based SMPC protocol, as it offers a favorable balance between computational efficiency and security for this type of statistical analysis.[46] This architecture ensures that valuable context can be provided to the user without their private financial data ever being pooled, centralized, or revealed to any other party, including the system operator.[39, 64]

Integrating a Real-Time Tax Regulation Validation Module

The Tax Logic Agent will be equipped with a dedicated, real-time compliance validation module. The core of this module will be a comprehensive suite of metamorphic properties derived directly from IRS publications and the text of the tax code.[2, 43] These properties will be encoded as automated tests. For example, one such test would verify that adding a dependent child to a return correctly triggers the Child Tax Credit calculation. This test suite will be run continuously as a form of regression testing every time the system's logic or the underlying tax code database is updated. This methodology provides a robust and systematic way to ensure correctness and prevent the introduction of bugs, directly addressing the "oracle problem" and the challenge of maintaining accuracy in a constantly changing regulatory environment.[4]

Developing the Explainable AI (XAI) Layer

The Interaction & Explanation Agent will be responsible for generating transparent justifications for the system's outputs. This will be achieved by implementing model-agnostic XAI techniques, primarily SHAP, to analyze the decisions of the Tax Logic Agent.[48] For any system-generated calculation, deduction, credit, or final tax liability, the user will have the option to request an explanation. In response, the system will provide a clear, natural language summary that attributes the outcome to specific user inputs. For example, it might state: "Your standard deduction was increased by $1,950. This is because you indicated in the 'Basic Information' section that you are over the age of 65".[8] This functionality makes the AI's reasoning process transparent, which is essential for building user trust and for satisfying the emerging legal and ethical imperatives for explainability in automated financial systems.[31, 48]

Phase 3: Empirical Evaluation and Validation

The final phase of the project will be dedicated to the rigorous empirical evaluation of the developed prototype with human subjects. This evaluation will use a multi-stage, mixed-methods approach to gather comprehensive data on the system's performance and user experience.

User Study Design

- **Participants:** A stratified sample of participants will be recruited to ensure the study population reflects the diversity of the tax-filing public. Recruitment will target key demographic variables, including age (with specific cohorts for 18-30, 31-59, and 60+), self-rated technical proficiency (novice, intermediate, expert), and ability. The ability group will specifically include users who rely on screen readers for navigation and users with self-identified cognitive challenges, such as ADHD or age-related cognitive decline. This focus on diverse populations is central to evaluating the project's core goal of inclusivity.[5, 9, 10]
- **Tasks:** Participants will be provided with a set of realistic, fictional taxpayer profiles and asked to complete their tax returns using the software. These scenarios will be designed to cover a range of complexities, from a simple return with only W-2 income to more complex cases involving self-employment income, retirement distributions, and eligibility for disability-related credits.
- **Conditions:** The study will employ a between-subjects design with three conditions. One group will use the fully adaptive intelligent system. A second group will use a leading commercial tax software package (e.g., TurboTax) as a baseline control. A third group will

use a non-adaptive version of our own system (with the adaptation features turned off) to allow us to isolate and measure the specific impact of the adaptive interface.

Success Metrics and Data Collection

Data collection will be guided by established UX evaluation frameworks and the project's specific success metrics.[45] We will collect both quantitative and qualitative data:

- **Quantitative Metrics:**
  - **Task Completion Rate:** The percentage of participants who successfully complete the filing task in each condition.
  - **Task Completion Time:** The time taken to complete the task (a measure of efficiency).
  - **System Accuracy:** The number of errors in the final generated tax return when compared against a "gold standard" return prepared by a professional tax accountant.
  - **User Satisfaction & Trust Indices:** Standardized, validated questionnaires will be administered post-task, including the System Usability Scale (SUS) for general usability, and a custom questionnaire designed to measure user trust, perceived transparency, and perceived competence, based on factors identified in the literature.[35, 36]
- **Qualitative Data:**
  - **Think-Aloud Protocol:** During the tasks, participants will be encouraged to "think aloud," verbalizing their thoughts, confusions, and decision-making processes. These sessions will be recorded for later analysis.
  - **Post-Session Interviews:** Semi-structured interviews will be conducted after the task to gather in-depth qualitative feedback on the user's experience, their perception of the system's intelligence and adaptivity, and their overall trust in the system.

Security Auditing and Penetration Testing

In parallel with the user studies, the system prototype will undergo a comprehensive security audit conducted by an independent third party. This audit will include penetration testing designed to rigorously assess the robustness of the security framework. Testers will be tasked with attempting to breach the SMPC protocol, exploit the agentic system through methods like goal manipulation or adversarial prompt injection, and circumvent the data tokenization and granular permission controls.[33, 34] The system's performance will be measured against standard security compliance scores and frameworks, providing a final validation of its security posture.

Secure Multi-Party Computation (SMPC) protects private data during collaborative calculations.

Technical Development Plan and Technology Stack

To translate this research into a functional prototype, we will adopt an Agile development methodology, organized into a series of two-week sprints. This iterative approach allows for flexibility, continuous feedback, and the progressive refinement of our system.

Development Flow: An Agile & Iterative Plan

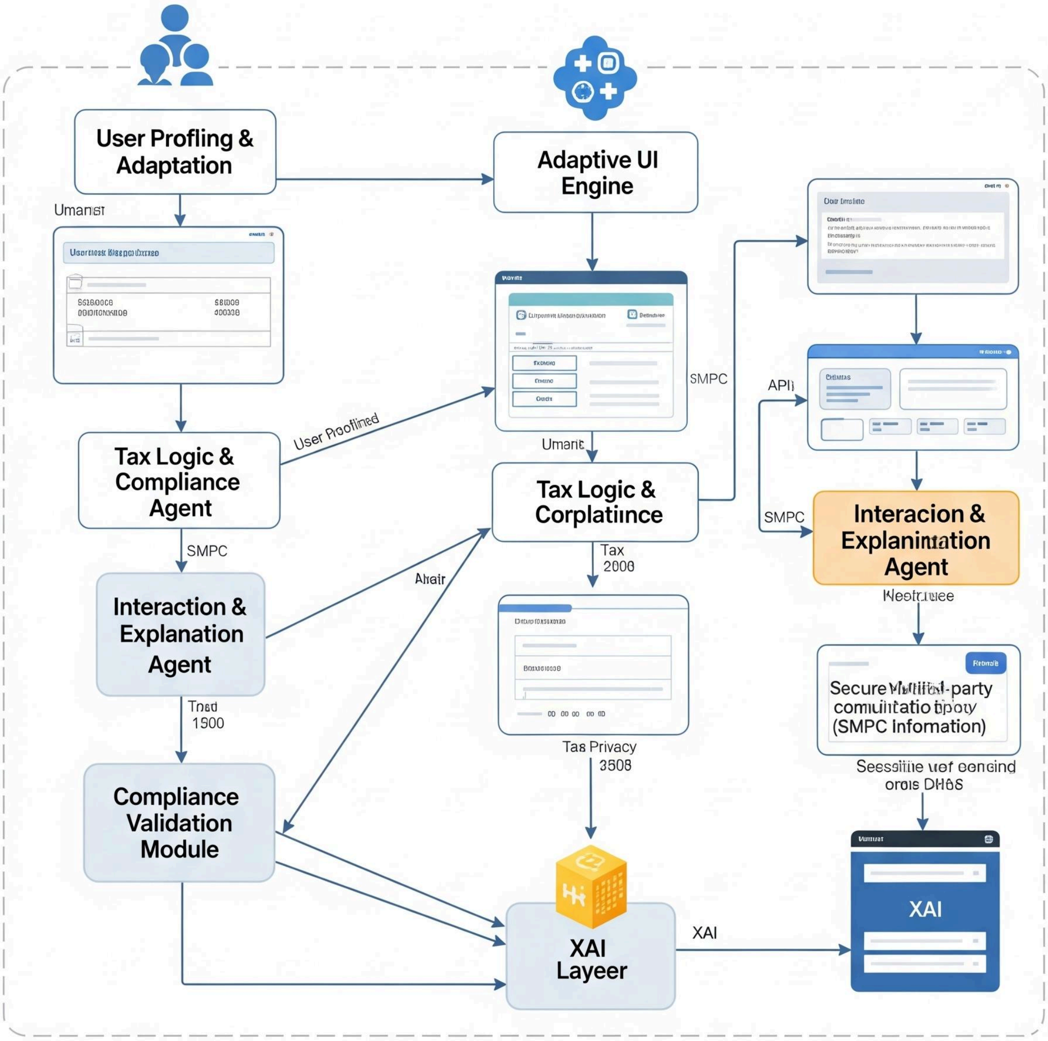
- **Sprints 1-2 (Foundation & Architecture):** Focus on setting up the core infrastructure. This includes establishing the secure cloud environment, defining the database schema in PostgreSQL, and building the initial backend API endpoints with FastAPI. The basic framework for the AI agents using AutoGen will also be created.
- **Sprints 3-4 (Core Feature Implementation):** The primary goal is to develop the non-adaptive version of the application. This involves building the initial UI modes (Novice, Expert, Accessibility) in Vue.js and implementing the core logic of the Tax Logic & Compliance Agent.
- **Sprints 5-6 (AI & Security Integration):** This phase focuses on bringing the "intelligence" online. We will fine-tune the Llama 3 model on our tax corpora and integrate it into the Interaction Agent. Concurrently, the XAI layer (using SHAP) and the SMPC privacy module will be developed and connected to the backend.
- **Sprints 7-8 (Adaptation & Refinement):** The final development sprints will be dedicated to implementing the adaptive logic within the User Profiling & Adaptation Agent. This involves connecting user interaction data to the adaptive UI engine. This period will also be dedicated to rigorous internal testing, bug fixing, and incorporating feedback from preliminary user trials.

Proposed Technology Stack

The selection of our technology stack is guided by the principles of performance, security, developer productivity, and a strong open-source ethos.

- **Frontend: Vue.js** for building the dynamic and adaptive user interface, coupled with **Tailwind CSS** for rapid, utility-first styling.
- **Backend & API: Python**, with the **FastAPI** framework, for its high performance, async capabilities, and automatic data validation.
- **AI Agent Framework: AutoGen** to structure and orchestrate the conversational flow between our specialized AI agents.
- **Database: PostgreSQL** for its robustness, reliability, and strong support for structured financial data.
- **Natural Language Processing (NLP): Fine-tuning an open-source model like Llama 3** on a curated corpus of tax documents to create a specialized, expert model.
- **Explainable AI (XAI):** Python libraries such as **SHAP** and **LIME** to provide model-agnostic explanations for the AI's calculations.
- **Deployment & Operations: Docker** for containerizing the application components, orchestrated via **Kubernetes**, and hosted on a major cloud provider like **AWS or GCP** to ensure scalability and reliability.

Adaptive Intelligent Tax Filing System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