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APR

SUNDAY

RESEARCH DAY 2024

Department of Computer Science and Engineering

Invited Lecture CSE Research Day 2024

10:00 AM, 07 APRIL 2024,
RM101, Rajeev Motwani Building

Variability and Reliability in Brain Networks

Prof Nitin Gupta

Associate Professor and *SwarnaJayanti Fellow*,
Dept of BSBE, IIT Kanpur

Abstract: Connections between neuronal populations in some parts of the brain may be pre-specified genetically, and in other parts may form randomly during the development of the brain. The randomness in the connections is not surprising in areas that are involved in learning but was not expected in areas involved in innate sensory preferences. Experimental data, however, suggest that the wiring in brain areas involved in innate preferences also shows substantial variability across individuals of the same species. In this talk, I will present the experimental evidence for reliability in the output and variability in the wiring of the insect olfactory system, and our ongoing work on understanding how the brain architecture achieves reliability despite the variability.

Speaker Bio: Nitin's lab focuses on understanding the brain mechanisms that determine an animal's innate behavioral preferences to smells, using the techniques of electrophysiology, imaging, behavioral assays, genetic manipulations, and computational modeling. A part of his lab also works on developing automated digital interventions for mental health problems. He received a bachelor's degree in CSE from IIT Kanpur in 2004 and a PhD in bioinformatics and systems biology from UCSD in 2009. After a brief postdoc stint in psychology at UCSD and another postdoc in experimental neuroscience at the National Institutes of Health, he joined IIT Kanpur as a faculty member in BSBE in July 2014.

Research Presentations

Cybersecurity and Cyber-physical Systems

Research Presentations

Gourav Takhar

Title: SR-SFLL: Structurally Robust Stripped Functionality Logic Locking

TL;DR: SR-SFLL uses the power of modern satisfiability and synthesis engines to secure Intellectual Property (IP) against piracy attacks (specifically structural analysis-based attacks).

Abstract: Logic locking was designed to be a formidable barrier to IP piracy: given a logic design, logic locking modifies the logic design such that the circuit operates correctly only if operated with the "correct" secret key. However, strong attacks (like SAT-based attacks) soon exposed the weakness of this defense. Stripped functionality logic locking (SFLL) was recently proposed as a strong variant of logic locking. SFLL was designed to be resilient against SAT attacks, which was the bane of conventional logic locking techniques. However, all SFLL-protected designs share certain "circuit patterns" that expose them to new attacks that employ structural analysis of the locked circuits. In this work, we propose a new methodology—Structurally Robust SFLL (SR-SFLL)—that uses the power of modern satisfiability and synthesis engines to produce semantically equivalent circuits that are resilient against such structural attacks. On our benchmarks, SR-SFLL was able to defend all circuit instances against both structural and SAT attacks, while all of them were broken when defended using SFLL. Further, we show that designing such defenses is challenging: we design a variant of our proposal, SR-SFLL(0), that is also robust against existing structural attacks but succumbs to a new attack, SyntAk (also proposed in this work). SyntAk uses synthesis technology to compile SR-SFLL(0) locked circuits into semantically equivalent variants that have structural vulnerabilities. SR-SFLL, however, remains resilient to SyntAk.

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Research Presentations

Title: Privacy Preserving Auto Completion

TL;DR: We encrypt database data for security. Accessing encrypted data without revealing indices is achieved through oblivious random-access computation. To maintain index secrecy in systems, data is split into shares across servers, preserving both user and system privacy.

Abstract: In the realm of cyber security, when we store data in a database, we encrypt it to keep it safe. But when we access this data, even if someone knows which part of the database we're looking at (like an index), they still can't see what's inside because it's encrypted. However, the fact that we're accessing certain parts of the database multiple times could give away what's important in it. So, to keep this index hidden too, we use something called oblivious random-access computation. When you search something on Google, like "IIT," you get suggestions like "IIT Kanpur," "IIT Mumbai," etc. These suggestions come from a special way of storing data called tries, which use indexing. To keep these indexes secret, we split the database into coded parts and spread them across different servers. Each server gets a part of the data but can't talk to the others. When you search "IIT," your search is split into parts and sent to different servers. After some calculations, the servers send back suggestions without revealing the actual search term. This way, both your privacy and the search engine's privacy are protected, and Google doesn't know what you searched for. That's how privacy-preserving auto-completion works.

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Title: Online Multi-Robot Coverage Path Planning

TL;DR: We proposed three centralized online coverage path planning algorithms to address scalability w.r.t. the workspace size and the robot count. Only the first two are horizon-based, where path planning and path execution interleave. But, in the last one, both can happen in parallel.

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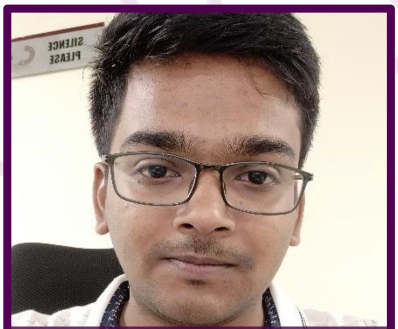
Research Presentations



Suraj Mandal

Title: An alternative to Cooley-Tukey: Implementing Low Latency NTT implementation for Post-Quantum Cryptography

TL;DR: In this work we have deviated from the traditional Cooley-Tukey approach and proposed a different technique for implementation of higher-radix NTT multiplication units for Post-Quantum cryptographic algorithms.

Abstract: Large-degree polynomial multiplication is an integral component of post-quantum secure lattice-based cryptographic algorithms like CRYSTALS-Kyber and CRYSTALS-Dilithium. The computational complexity of large-degree polynomial multiplication can be reduced significantly through Number Theoretic Transformation (NTT). Recent works have explored either radix-2 or radix-4 based NTT multiplication units. But in time-critical applications, radix-2 or radix-4 based NTT multiplication units are inefficient due to the required latency cycles for NTT operations. One way to lower the required latency cycles is to increase number of parallel radix-2 or radix-4 butterfly units (BFUs). But increment of parallel butterfly units results in longer critical path. In this work, we have adopted an efficient technique for the implementation of higher radix architectures. We have tested our approach with implementation of NTT multiplication unit for three different post-quantum cryptographic algorithms. Our new technique for higher-radix architecture proves to achieve superior area-delay product (ADP) as well as superior frequency than the existing lower latency NTT implementations.

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Neelofar Hassan

Title: Machine Learning Attacks on Challenge-Response Obfuscations in Strong PUFs

TL;DR: PUFs can be modeled with very high accuracy using machine learning and deep learning. Hence, recently, challenge/response obfuscation-based countermeasures have been proposed. In this work, we have targeted two such PUF architectures, namely RSO and Mn (s1,s2,s3) PUFs.

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Research Presentations

Nikhil Singh

Title: Frugal Actor-Critic: Sample Efficient Off-Policy Deep Reinforcement Learning Using Unique Experiences

TL;DR: This work presents a new algorithm for sample-efficient synthesis of feedback controllers. The algorithm focuses on selecting unique samples and adding them to the buffer during the exploration reinforcement learning.

Abstract: Efficient utilization of the replay buffer plays a significant role in the off-policy actor-critic reinforcement learning (RL) algorithms used for model-free control policy synthesis for complex dynamical systems. We propose a method for achieving sample efficiency, which focuses on selecting unique samples and adding them to the replay buffer during the exploration with the goal of reducing the buffer size and maintaining the independent and identically distributed (IID) nature of the samples. Our method is based on selecting an important subset of the set of state variables from the experiences encountered during the initial phase of random exploration, partitioning the state space into a set of abstract states based on the selected important state variables, and finally selecting the experiences with unique state-reward combination by using a kernel density estimator. We formally prove that the off-policy actor-critic algorithm incorporating the proposed method for unique experience accumulation converges faster than the vanilla off-policy actor-critic algorithm. Furthermore, we evaluate our method by comparing it with two state-of-the-art actor-critic RL algorithms on several continuous control benchmarks available in the Gym environment. Experimental results demonstrate that our method achieves a significant reduction in the size of the replay buffer for all the benchmarks while achieving either faster convergent or better reward accumulation compared to the baseline algorithms.

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Research Presentations

Indranil Thakur

Title: Catch Me If You Can: Secure Camouflaged Computing
TL;DR: Fully Homomorphic Encryption is the perfect solution for processing data in untrusted environments but faces issues like slow encryption and large ciphertext. Transciphering frameworks, using Symmetric Key Cryptography, tackle these hurdles for practical implementation.

Abstract: In today's digital world, data is frequently processed in untrusted environments. This necessity arises when organizations migrate their computing environment from on-premise to the Cloud Service Providers or engage in collaborative data activities without fully trusting each other. As a result, there is a growing demand to ensure data protection while the data are being processed. Computation Over Encrypted Data (COED) techniques such as Fully Homomorphic Encryption (FHE) have emerged as the perfect solution for this problem. However, FHE suffers from two technical problems in comparison to the traditional encryption schemes: slow encryption speed and large ciphertext expansion. This hinders practical implementation due to limited client-side resources. Transciphering frameworks overcome these limitations with the help of Symmetric Key Cryptography (SKC).
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Prem Raj

Title: Object-agnostic versus object-centric robotic grasp-planning

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Research Presentations

Kush Shah

Title: TEASE: A Leak-resilient Protocol for Strong PUFs via Statistically Deficient Data Release

TL;DR: We show how to generate challenge response pairs for hardware authentication applications based on PUFs that are leak resilient – even if leaked, the adversary may learn only a provably deficient model of the PUF architecture.

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Research Presentations

Theoretical Computer Science

Research Presentations

Koustav Bhanja

Title: Sensitivity Oracles For Steiner Mincuts

TL;DR: We design two compact data structures that can report a Steiner mincut after the failure of edges in a graph. These results provide a generalization to the existing results of global mincut and (s,t)-mincut, which are just special cases of Steiner mincut.

Abstract: Let G be a graph on n vertices. A Steiner set S is a subset of vertices. Steiner mincut is a fundamental concept, which is also a generalization of (s,t)-mincut ($|S|=2$) and global mincut ($|S|=n$). We address the problem of designing a compact data structure that can efficiently report a Steiner mincut and its capacity after the failure of a set of edges in G, which is called a Sensitivity Oracle for Steiner Mincut. We present two Sensitivity Oracles for Steiner Mincuts. 1. Single Edge Failure in Weighted graphs: The existing results are only for (s,t)-mincut [Ann. Opr. Res.1991, NETWORKS2019]. For Steiner mincut, we first design a simple $O(n^2)$ space Sensitivity Oracle. Unfortunately, it turns out that any Sensitivity Oracle must occupy $\Omega(n^2)$ space to report the capacity of Steiner mincut. For any minimum cut, every existing Sensitivity Oracle occupies the same or better space for reporting the capacity than reporting a cut. Surprisingly, for reporting Steiner mincut, we present an $O\big(n(n-|S|+1)\big)$ space Sensitivity Oracle, which occupies only subquadratic space if $|S|$ is close to n, and hence it breaks the $O(n^2)$ bound on space. 2. Dual Edge Failure in Unweighted Graphs: A dual edge Sensitivity Oracle has been designed for both (s,t)-mincut [TALG23] and global mincut [STOC95]. As a generalization and to unify the existing results, we provide the following first results for Steiner mincut.2.1. There is an $O\big(n(n-|S|+1)\big)$ space dual edge Sensitivity Oracle for Reporting cut in $O(n)$ time. 2.2. There is an $O\big((n-|S|)^2+n\big)$ space dual edge Sensitivity Oracle for Reporting capacity in $O(1)$ time. 2.3. we also provide an $\Omega\big((n-|S|)^2\big)$ space lower bound on space, irrespective of the query time. To arrive at our results in (2), we design a compact data structure for Steiner cuts of capacity min+1 by generalizing 3-STAR Lemma of Dinitz and Vainshtein [SICOMP 2000], which are of independent interest.

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Research Presentations

Bhargav C S

Title: Border Complexity and Circuit Factorization

TL;DR: We show that low degree factors of small size circuits are in the class VNP. We also show that VNP is closed under factoring over finite fields.

Abstract: The border, or the approximative, model of algebraic computation ($\overline{\mathrm{VP}}$) is quite popular due to the Geometric Complexity Theory (GCT) approach to $\mathrm{P} \neq \mathrm{NP}$ conjecture, and its complex analytic origins. On the flip side, the definition of the border is inherently *existential* in the field constants that the model employs. In this work we resolve this issue by giving a constructive, or a *presentable*, version of border circuits and state its applications. We make border presentable by restricting the circuit C to use only those constants, in the function field $\mathbb{F}_q(\epsilon)$, that it can generate by the ring operations on $\{\epsilon, 1/\epsilon\} \cup \mathbb{F}_q$ within poly-size circuit. This model is more expressive than VP as it affords exponential-degree in ϵ; and analogous to the usual border, we define new border classes called $\overline{\mathrm{VP}}_\epsilon$ and $\overline{\mathrm{VNP}}_\epsilon$. We prove that both these (now called *presentable* border) classes lie in VNP. The heart of our technique is a newly formulated *exponential interpolation* over a finite field, to bound the Boolean complexity of the coefficients before deducing the algebraic complexity. It attacks two factorization problems which were open before. We make progress on (Conj. 8.3 in Bürgisser 2000, FOCS 2001) and completely solve (Conj. 2.1 in Bürgisser 2000; Chou,Kumar,Solomon CCC 2018): 1. Each poly-degree irreducible factor, with multiplicity coprime to field characteristic, of a poly-size circuit (of possibly *exponential*-degree) is in VNP. 2. For *all* finite fields, and *all* factors, VNP is closed under factoring. Consequently, factors of VP are *always* in VNP. The prime characteristic cases were open before due to the inseparability obstruction (i.e., when the multiplicity is not coprime to q).

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Research Presentations

Anindya Ganguly

Title: VDOO: A Short, Fast, Post-quantum Multivariate Signature Scheme

TL;DR: In the post-quantum era, our new multivariate signature scheme offers shortest and fastest. Rigorously tested parameters withstand all existing attacks. At NIST security levels I, III, and V, our signatures sizes are 96, 226, and 316 bytes - the smallest for similar security.

Abstract: Hard lattice problems are predominant in constructing post-quantum cryptosystems. However, we need to continue developing post-quantum cryptosystems based on other quantum hard problems to prevent a complete collapse of post-quantum cryptography due to a sudden breakthrough in solving hard lattice problems. Solving large multivariate quadratic systems is one such quantum hard problem. Unbalanced Oil-Vinegar is a signature scheme based on the hardness of solving multivariate equations. In this work, we present a post-quantum digital signature algorithm VDOO (Vinegar-Diagonal-Oil-Oil) based on solving multivariate equations. We introduce a new layer called the diagonal layer over the oil-vinegar-based signature scheme Rainbow. This layer helps to improve the security of our scheme without increasing the parameters considerably. Due to this modification, the complexity of the main computational bottleneck of multivariate quadratic systems i.e. the Gaussian elimination reduces significantly. Thus, making our scheme one of the fastest multivariate quadratic signature schemes. Further, we show that our carefully chosen parameters can resist all existing state-of-the-art attacks. The signature sizes of our scheme for the National Institute of Standards and Technology's security level of I, III, and V are 96, 226, and 316 bytes, respectively. This is the smallest signature size among all known post-quantum signature schemes of similar security.

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Research Presentations

Computer Systems

Title: Prosper: Program Stack Persistence in Hybrid Memory Systems

TL;DR: Prosper is a hardware-software (OS) co-designed checkpoint approach for stack persistence. Prosper tracks stack changes at sub-page byte granularity in hardware, allowing symbiosis with OS to realize efficient checkpoints of the stack region in hybrid memory system.

Abstract: A persistent and crash-consistent execution state is essential for systems to guarantee resilience against power failures and abrupt system crashes. The availability of non-volatile memory (NVM) with read/write latency comparable to DRAM allows designing efficient checkpoint mechanisms for process persistence. Operating system (OS) level checkpoint solutions require capturing the change in the execution state of a process in an efficient manner. One of the crucial components of the execution state of any process is its memory state consisting of mutable stack and heap segments. Tracking modifications to the program stack is interesting because of its unique grow/shrink usage pattern and activation record write characteristics. Moreover, the stack is used in a programmer-agnostic manner where the compiler makes use of the support provided by the underlying ISA to use the stack and the OS manages the memory used by the stack region in an on-demand fashion. In this work, we show the benefit of a checkpoint-based mechanism for stack persistence and the inefficiency of adapting existing generic memory persistence mechanisms for the stack region. We propose *Prosper*, a hardware-software (OS) co-designed checkpoint approach for stack persistence. *Prosper* tracks stack changes at sub-page byte granularity in hardware, allowing symbiosis with OS to realize efficient checkpoints of the stack region. *Prosper* significantly reduces (on average ~4x) the amount of data copied during checkpoint and improves the overall checkpoint time with minimum overhead (less than 1% on average). Integrating *Prosper* with existing state-of-the-art memory persistence mechanisms (such as SSP) for heap provides 2.6x improvement over solely using the state-of-the-art mechanism for the entire memory area persistence.

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Research Presentations

Title: rc.live: Relentless Live Migration of Application Containers for Reduced Downtime

TL;DR: Application containers are very popular in cloud environments. During live migration of an application container, a downtime is observed for the application running inside container which degrades the application performance. Our work focuses on to reduce this downtime.

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Research Presentations

Data Science, AI and Machine Learning

Research Presentations

Title: Automated Cognate Detection as a Supervised Link Prediction Task with Cognate Transformer

TL;DR: We introduce an end-to-end transformer-based architecture inspired by protein language models for automated cognate detection problem. We also view this task as a supervised link prediction task where the model outputs cognate clusters.

Abstract: Identification of cognates across related languages is one of the primary problems in historical linguistics. Automated cognate identification is helpful for several downstream tasks including identifying sound correspondences, proto-language reconstruction, phylogenetic classification, etc. Previous state-of-the-art methods for cognate identification are mostly based on distributions of phonemes computed across multilingual wordlists and make little use of the cognacy labels that define links among cognate clusters. In this paper, we present a transformer-based architecture inspired by computational biology for the task of automated cognate detection. Beyond a certain amount of supervision, this method performs better than the existing methods, and shows steady improvement with further increase in supervision, thereby proving the efficacy of utilizing the labeled information. We also demonstrate that accepting multiple sequence alignments as input and having an end-to-end architecture with link prediction head saves much computation time while simultaneously yielding superior performance.

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Title: Using Physics Priors For Human Like Game Playing

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Dhanajit Brahma

Title: A Probabilistic Framework for Lifelong Test-Time Adaptation

TL;DR: PETAL, a probabilistic approach, tackles lifelong test-time adaptation utilizing a student-teacher framework and model regularization. Additionally, it prevents drift with data-driven parameter restoration. PETAL outperforms existing methods in various lifelong TTA benchmarks.

Abstract: Test-time adaptation (TTA) is the problem of updating a pre-trained source model at inference time given test input(s) from a different target domain. Most existing TTA approaches assume the setting in which the target domain is *stationary*, i.e., all the test inputs come from a single target domain. However, in many practical settings, the test input distribution might exhibit a lifelong/continual shift over time. Moreover, existing TTA approaches also lack the ability to provide reliable uncertainty estimates, which is crucial when distribution shifts occur between the source and target domain. To address these issues, we present PETAL (Probabilistic lifElong Test-time Adaptation with seLf-training prior), which solves lifelong TTA using a probabilistic approach, and naturally results in (1) a student-teacher framework, where the teacher model is an exponential moving average of the student model, and (2) regularizing the model updates at inference time using the source model as a regularizer. To prevent model drift in the lifelong/continual TTA setting, we also propose a data-driven parameter restoration technique which contributes to reducing the error accumulation and maintaining the knowledge of recent domains by restoring only the irrelevant parameters. In terms of predictive error rate as well as uncertainty-based metrics such as Brier score and negative log-likelihood, our method achieves better results than the current state-of-the-art for online lifelong test-time adaptation across various benchmarks, such as CIFAR-10C, CIFAR-100C, ImageNetC, and ImageNet3DCC datasets. The source code for our approach is accessible at https: //github.com/dhanajitb/petal.

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Research Presentations

Nitesh Trivedi

Title: Achieving Fairness in Machine Learning Models via Feature Weighing

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Abhinav Joshi

Title: Causal Commonsense Reasoning Framework via Closed Observational Graphs

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Bhavya Gupta

Title: NLP for Schizophrenia: Improving verbal fluency assessment in multi-lingual and cross-lingual settings

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Research Presentations

Divyaksh Shukla

Title: Multi-ModER: Multilingual Multimodal Emotion Recognition for India

TL;DR: Realtime Multimodal multilingual Emotion Recognition system for Indian settings. We create a dataset on 7 Indian languages containing codemixed conversations annotated with 27 emotion labels. We present real-time emotion recognition models that predict emotions causally.

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Vaibhav Sharma

Title: Embodied AI: Controlling Agents via Natural Language Instructions

TL;DR: In this work we train embodied agents that learn via interactions with the environment just like humans do. Our aim is to enable these agents to interact using natural language, and to employ LLMs for generating action plans. These plans are then executed by RL trained agents.

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Dhananjay Ghumare

Title: Unifying LLMs & Knowledge Graphs for the Legal Domain

TL;DR: LLM and KGs can help naive users understand complex legal documents and open the world of law to every individual.

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Research Presentations

Sanjeet Singh

Title: Generation and De-Identification of Indian Clinical Reports using LLMs

TL;DR: The primary focus of this work is to address clinical data scarcity and remove personal information from clinical data. We utilize LLMs to generate Indian clinical data and we develop a de-identification technique to protect privacy while preserving valuable data for research.

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Romit Mohanty

Title: iSign: A benchmark for Indian Sign Language

TL;DR: iSign introduces a benchmark of large dataset for Indian Sign Language Processing with 5 tasks including 2 novel ones. Our experiments highlight weaknesses in current models, emphasizing the need for more robust models.

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Utsav Singh

Title: PEAR: Primitive Enabled Adaptive Relabeling for boosting Hierarchical Reinforcement Learning

TL;DR: We effectively leverage expert demonstrations using our adaptive relabeling based approach to deal with non-stationarity in the context of hierarchical reinforcement learning.

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Ajita Shree

Title: scDREAMER: atlas-level integration of single-cell datasets using deep generative model paired with adversarial classifier

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