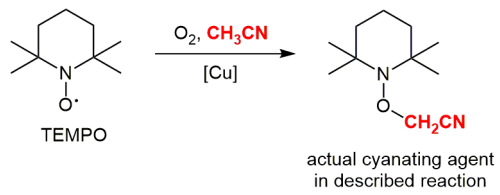
Synform

People, Trends and Views in Chemical Synthesis

2015/10

Acetonitrile as a Cyanating Reagent: Copper-Catalyzed Cyanation of Arenes

Highlighted article by Y. Zhu, M. Zhao, W. Lu, L. Li, Z. Shen



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Thieme

Dear Readers,

This new issue of SYNFORM is dominated by Asian chemistry; in fact all the four articles are dedicated to recent publications and researchers based in Asian countries: Korea, Japan, P. R. of China and India. This is not a case, because Asian chemistry – and science in general – nowadays plays a major role in academic publishing, both in terms of quantity and quality, so it's not surprising to see that a full issue of SYNFORM is dedicated to researchers based in Asian institutions and to the cutting-edge research that is produced by Asian labs. The first article is from the Hong lab (Korea) and provides an insight on a novel strategy for functionalizing C–H bonds in cyclopropanes. The second contribution comes from the Kanai lab (Japan) and describes a novel boron-catalyzed Mannich-type reaction that allows for the enantiocontrolled preparation of β-amino acids. The third article zooms in on the use of acetonitrile as a reagent for introducing a cyano group on aromatic C–H functions, which was discovered in the Shen lab (P. R. of China). Finally, the Young Career Focus features Dr. N. T. Patil, a young up-and-coming Asian chemist from India.

After this indigestion of Asia, I think I am going to cook Italian tonight...

Enjoy your reading!

In this issue

Literature Coverage
Asymmetric C–H Functionalization of Cyclopropanes Using an Isoleucine-NH_2 Bidentate Directing Group . A136

Literature Coverage
Chemoselective Boron-Catalyzed Nucleophilic Activation of Carboxylic Acids for Mannich-Type Reactions A140

Literature Coverage
Acetonitrile as a Cyanating Reagent: Copper-Catalyzed Cyanation of Arenes A144

Young Career Focus
Dr. Nitin T. Patil (CSIR – National Chemical Laboratory, India) A146

Coming soon..... A148

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If you have any questions or wish to send feedback, please write to Matteo Zanda at: synform@outlook.com

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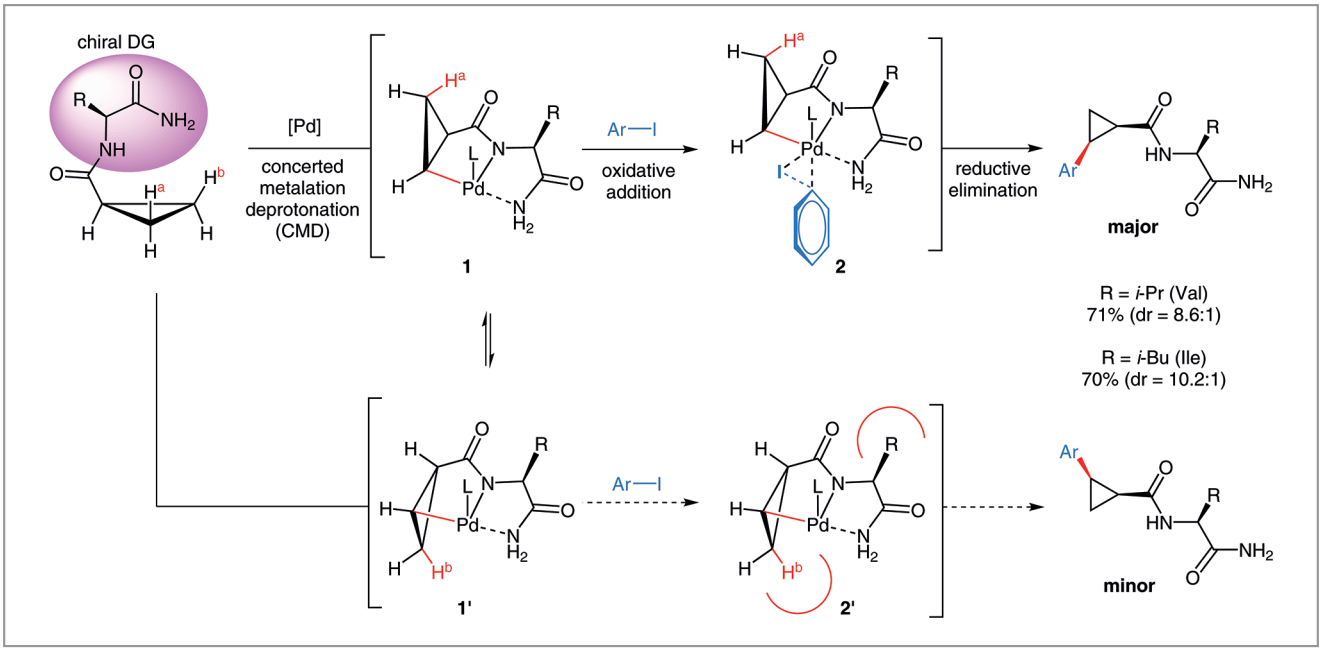
Asymmetric C–H Functionalization of Cyclopropanes Using an Isoleucine-NH_2 Bidentate Directing Group

Chem. Sci. **2015**, *6*, 3611–3616

Since the original discovery by the Daugulis group (*J. Am. Chem. Soc.* **2005**, *127*, 13154), powerful bidentate directing groups such as 8-aminoquinoline and picolinamide auxiliaries have been widely used for the activation of both C(sp^2)–H and C(sp^3)–H bonds. In order to improve convenience and efficiency of the method, the development of new types of bidentate directing groups has been the subject of intensive research involving many research groups. Despite the impressive achievements in catalytic asymmetric C–H activation through installation of chiral auxiliaries, stereoselective functionalization of C(sp^3)–H bonds controlled by chiral bidentate directing groups still remains elusive. The laboratory of Professor Sungwoo Hong at the Korea Advanced Institute of Science and Technology (KAIST, Daejeon, Korea) has been particularly interested in selective C–H functionalization of medicinally important privileged structures. Professor Hong said: "We hypothesized that an appropriate chiral bidentate directing group embedded in the substrate could induce high levels of stereocontrol during C–H functionalization via a steric repulsion model. A range of chiral auxiliaries, such as ester, tetrazole, and amino acid amide groups, were investigated for feasibility as directing groups on C(sp^3)–H arylation." Intriguingly, revealed Professor Hong, the amino acid amide moiety was identified as the most efficient chiral bidentate directing group to achieve both high reactivity and diastereoselectivity. Systematic investigation of substrate-bound α-amino acid auxiliaries resulted in catalytic asymmetric C–H functionalization of cyclopropanes enabled by amino acid amide as chiral bidentate directing groups. Professor Hong explained: "Following the discovery that the N-unsubstituted $CONH_2$ moiety was crucial for achieving both high reactivity and diastereoselectivity, we further explored the effect of steric bulk at the α-position of amino acid amides on the selectivity of the process. The use of an Ile-NH_2 auxiliary embedded in the substrate was able to provide excellent levels of asymmetric induction (diastereomeric ratio of up to 72:1) in the Pd(II)-catalyzed β-methylene C(sp^3)–H bond activation of cyclopropanes and cross-coupling with aryl iodides. We proposed a plausible reaction mechanism in-



Scheme 1 Amino acid auxiliary controlled asymmetric C–H functionalization of cyclopropanes

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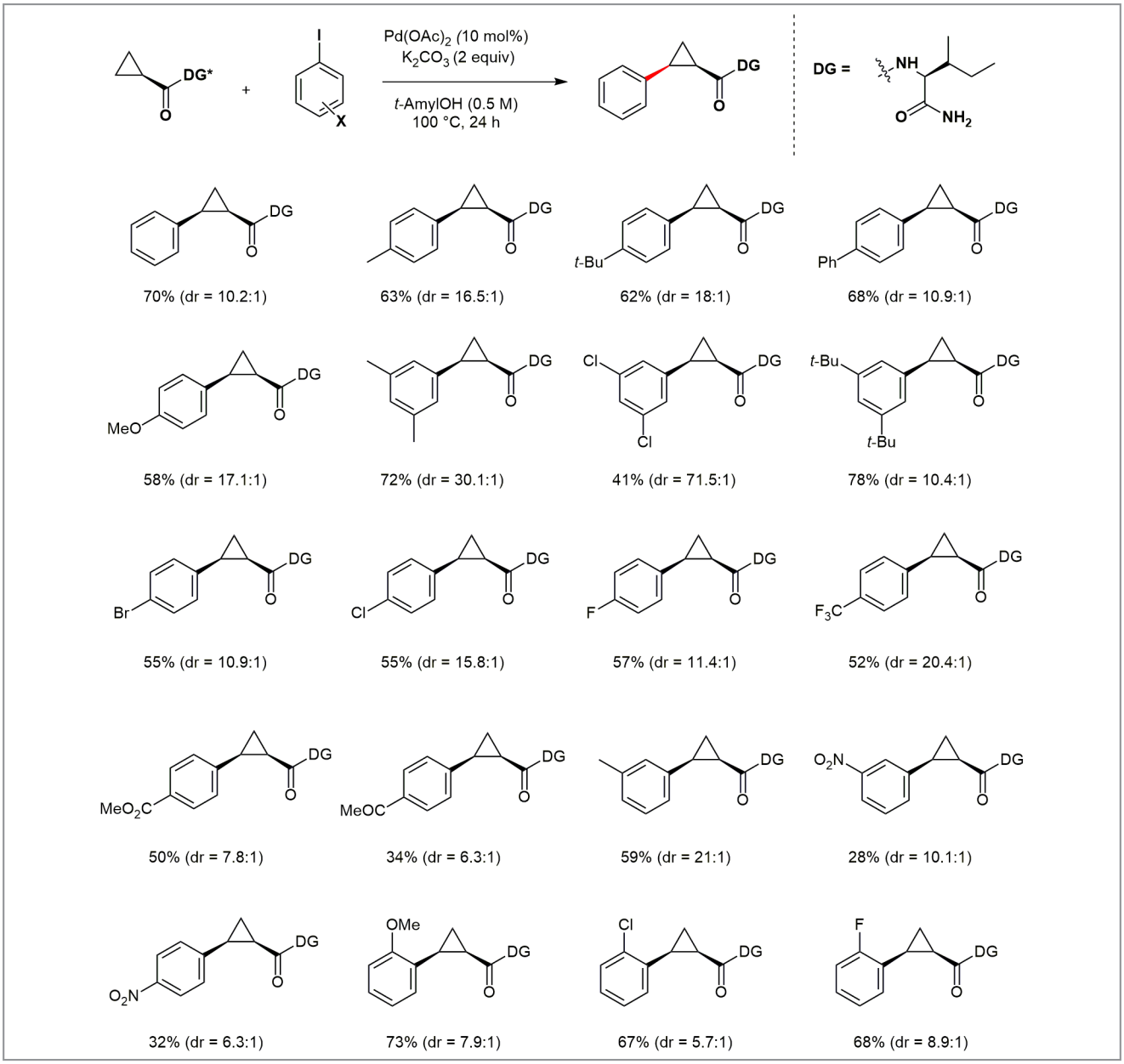
volving Ile-NH_2 auxiliary-controlled asymmetric C–H functionalization in which a Pd(II)/Pd(IV) catalytic cycle is invoked (Scheme 1)." According to this mechanism, the cleavage of the C(sp^3)–H bond on the cyclopropane ring through a concerted metalation deprotonation (CMD) process produces the palladacycle complexes **1** and **1′** which may exist in equilibrium. The oxidative addition path that proceeds through transition state **2** is favored over the other pathways, thereby leading to the major stereoisomer. On the other hand, according to the authors, the oxidative addition process for insertion of aryl iodide into Pd complex **1′** appears to be less feasible because the R substituent and the methylene group of cyclopropane cause blocking of the top and bottom faces of **2′**. Therefore, high levels of asymmetric induction could be achieved in the Pd(II)-catalyzed C(sp^3)–H functionalization of cyclopropanes. "The directing group is removable and the hydrolysis of the



Scheme 2 Substrate scope

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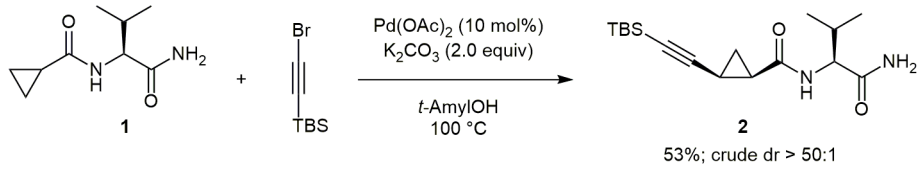


Scheme 3 Coupling with a bromoalkyne

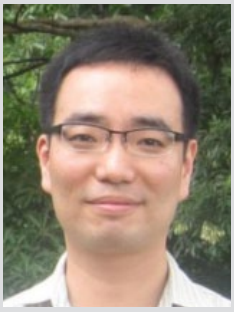
amino acid amide group occurred smoothly to afford arylated cyclopropanecarboxylic acid with conservation of the stereogenic centers," explained Professor Hong. "This study represents the first systematic investigation of substrate-bound α-amino acid amides as chiral bidentate directing groups in the asymmetric C(sp^3)–H functionalization of cyclopropanes."

"From a conceptual viewpoint, the ability of a substrate-bound α-amino acid auxiliary to promote asymmetric C–H functionalization is intriguing because the amino acid moiety derived from readily available chiral pools plays not only the role as a bidentate directing group, but also as a chiral auxiliary to provide efficient stereocontrol during C(sp^3)–H bond functionalization," said Professor Hong. The efficient protocol demonstrated a broad substrate scope and permitted for selective installation of a variety of substituted aryl groups on cyclopropanes (Scheme 2).

Professor Hong continued: "Furthermore, we preliminarily investigated the diastereoselective C–H alkynylation and observed that **1** reacted with a bromoalkyne under the same reaction conditions, resulting in the single diastereomer **2** (Scheme 3)."

This novel synthetic methodology has interesting potential applications since the cyclopropyl group is commonly found in many biologically active natural products. It is frequently used for structure–activity relationship studies in medicinal chemistry because of its unique steric and conformational properties. In particular, the rigidity of cyclopropane can be utilized as a conformationally restricting linker in medicinal chemistry to improve the binding activity in drug discovery. Professor Hong concluded: "Developing efficient catalytic methodologies for the functionalization of cyclopropane has received special attention in recent years. This convenient and powerful synthetic tool allows for the rapid and diastereoselective installation of the aryl groups into the cyclopropane scaffolds for delivery of potent biomolecules."

About the authors



Prof. S. Hong

Sungwoo Hong is an Associate Professor at the Department of Chemistry at Korea Advanced Institute of Science and Technology (KAIST, Korea) and a Group Leader of the Center for Catalytic Hydrocarbon Functionalizations at the Institute for Basic Science (IBS). He graduated from Seoul National University (Korea), where he gained his BS (1996) and MS degrees (1998). He then went on to Pennsylvania State University (USA) for his PhD program. After he had finished his postdoctoral course at Harvard University (USA, 2006), under the supervision of Professor E. J. Corey, he joined GlaxoSmithKline (GSK, USA) as a Principal Scientist. In 2009, he started independent work at KAIST and was promoted to Associate Professor in 2012. His research interests are in the field of development of new reactions and synthesis, advanced medicinal chemistry, and bioorganic chemistry.

J. Kim

Jinhee Kim graduated from Kyungpook National University (Korea) with a degree in applied chemistry in 2011. After graduation, she joined the Department of Chemistry at KAIST. She is currently in a PhD program under the supervision of Professor Sungwoo Hong. Her research is focused on transition-metal-catalyzed C–H activation and medicinal chemistry.

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M. Sim

Mikyung Sim earned her BS in pharmacology in 2011 and a MS in life & pharmaceutical science in 2013 from Ewha Womans University (Korea). She is currently doing her doctoral course at KAIST under the supervision of Professor Sungwoo Hong. Her research interests focus on developing catalytic methodologies for the preparation of biologically active compounds and their application to medicinal chemistry.

N. Kim

Namhoon Kim received his BS degree in chemical and biomolecular engineering in 2014 from Korea Advanced Institute of Science and Technology (KAIST). Currently he is in an integrated Master's & PhD program under the supervision of Professor Sungwoo Hong. His current research focus involves transition-metal-catalyzed C–H bond functionalizations.

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Chemoselective Boron-Catalyzed Nucleophilic Activation of Carboxylic Acids for Mannich-Type Reactions

J. Am. Chem. Soc. **2015**, *137*, 7075–7078

The carboxyl group (COOH) is a ubiquitous chemical function present in a very large number of compounds essential for life itself – such as amino acids and fatty acid derivatives – as well as in countless bioactive molecules, natural compounds and drugs. The development of efficient methods for achieving the structural modification and homologation of carboxylic acid derivatives without requiring the use of protecting groups continues to attract a great deal of interest in organic chemistry. In particular, novel carbon–carbon bond-forming reactions allowing for a stereocontrolled and direct functionalization of carboxylic acids are in great demand.

Recently, the group of Professor Motomu Kanai at The University of Tokyo's Graduate School of Pharmaceutical Sciences (Japan) has developed a method for generating carboxylic acid derived enolates under mild conditions, and extended this method to the first carboxylic acid selective catalytic Mannich-type reaction. "The carboxyl group is ubiquitous in organic molecules, especially in biologically active lead drug molecules," said Professor Kanai. "Its Brønsted acidity is among the highest in naturally occurring molecules. Therefore, carboxyl groups can be chemoselectively recognized by a Brønsted base catalyst even in the presence of multiple functional groups. However, use of carboxylic acids as carbon nucleophiles has been limited due to the difficulty in generating dianionic enolates."

Professor Kanai explained: "A reversible acid/base covalent interaction between carboxylic acids and a simple boron catalyst (precatalyst = $BH_3{\cdot}SMe_2$) acidified the α-protons, so that a mild organic base, DBU, was able to deprotonate the activated substrate, thus generating the corresponding carboxylic acid enolates." He continued: "The catalytically and chemoselectively generated enolates from carboxylic acids were trapped by *N*-tosyl imines through Mannich-type reaction."

According to Professor Kanai, there are two main aspects worthy of note in this catalysis: (1) chemoselectivity (Scheme 1), since carboxylic acid enolates were generated even in the presence of intrinsically more enolizable ketone, ester, and amide functionalities; an impressive entry in this aspect is a successful application to side-chain modification at a glutamic acid residue of a tetrapeptide, and (2) enantioselectivity (Scheme 2), as shown by the fact that introduction of a BINOL-derived chiral ligand to the boron catalyst afforded a highly enantioselective Mannich-type reaction of carboxylic acids.

Professor Kanai said: "We now know that chemoselective (chiral) enolate formation is possible from carboxylic acids by action of a boron catalyst and an organic base. Thanks to

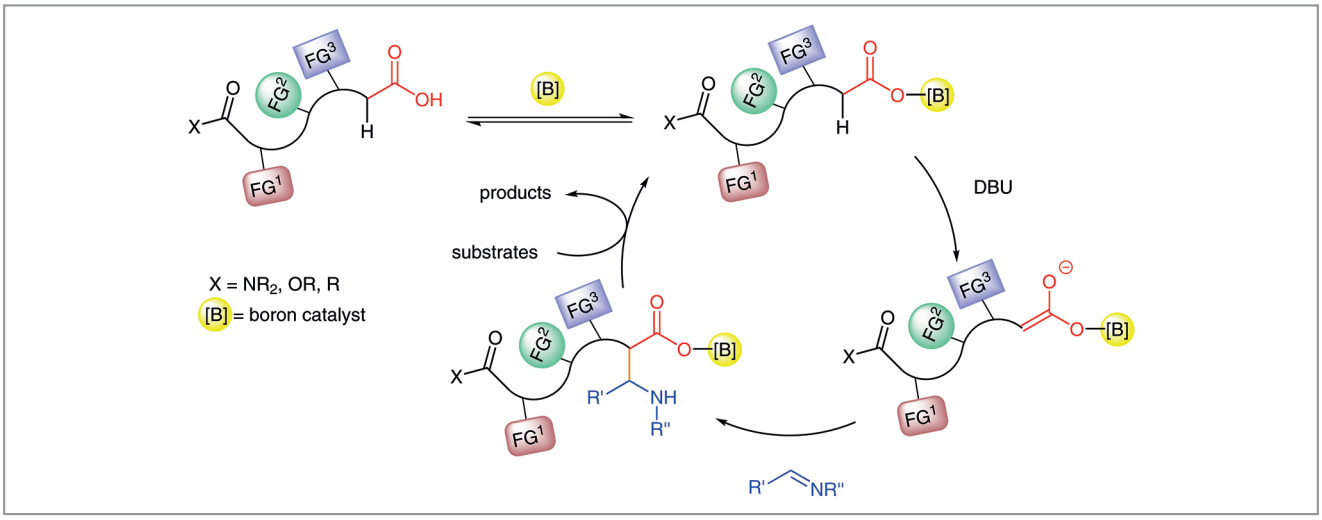

Figure 1 Plausible catalytic cycle of boron-catalyzed Mannich-type reaction of carboxylic acids

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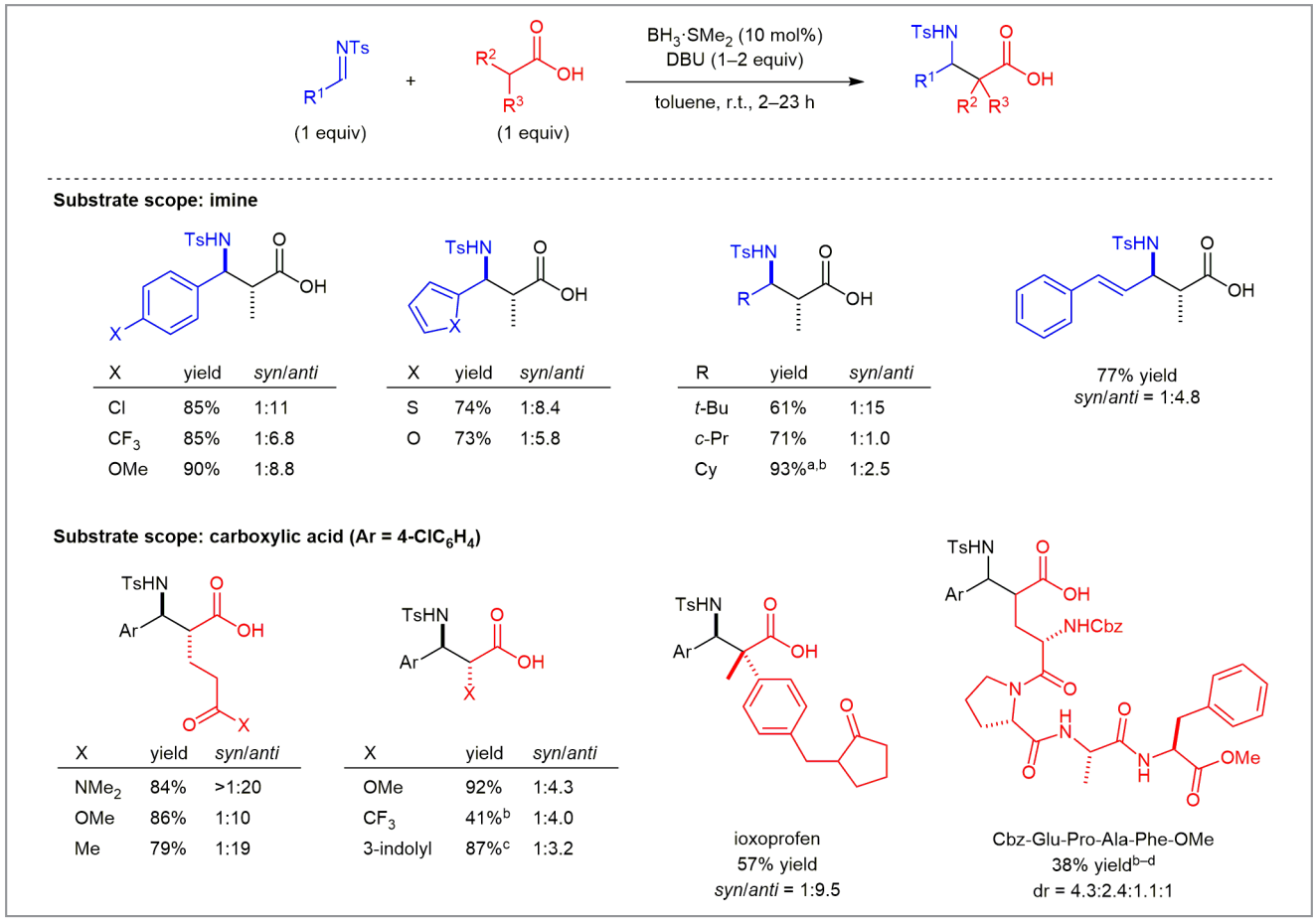

Scheme 1 Representative examples of the boron-catalyzed Mannich-type reaction of carboxylic acids. Isolated yields and diastereomeric ratios were determined after conversion of the Mannich products into methyl esters. [a] 20 mol% of $BH_3{\cdot}SMe_2$ was used. [b] 2.0 equiv of imine were used. [c] THF was used as solvent. [d] 33 mol% of $BH_3{\cdot}SMe_2$ was used.

the wide scope of enolate chemistry, our catalytic method can find many extensions." He continued: "As a future direction, we are especially interested in the late-stage catalysis to diversify complex molecule structures at their carboxyl groups, including biologically active peptides and functional proteins, by taking advantage of the high chemoselectivity of the boron catalysis."

For many conceivable future directions, however, elucidation of the active enolate structure is the first priority for the group. "This will allow us to design more sophisticated catalysts for expansion of potential applications," explained Professor Kanai. "More broadly, we need to develop more comprehensive protecting-group-free catalytic processes as well as isolation processes." In Schemes 1 and 2, the Tokyo-based researchers isolated the products after protection of the carboxylic acids as esters. However, Professor Kanai remarked: "We feel uneasy on this point. Our dream is streamlining complex molecule synthesis by minimizing non-productive protection/deprotection processes by developing new catalysts that can recognize and selectively activate each functional group. The boron catalysis is the starting point for us," he concluded.

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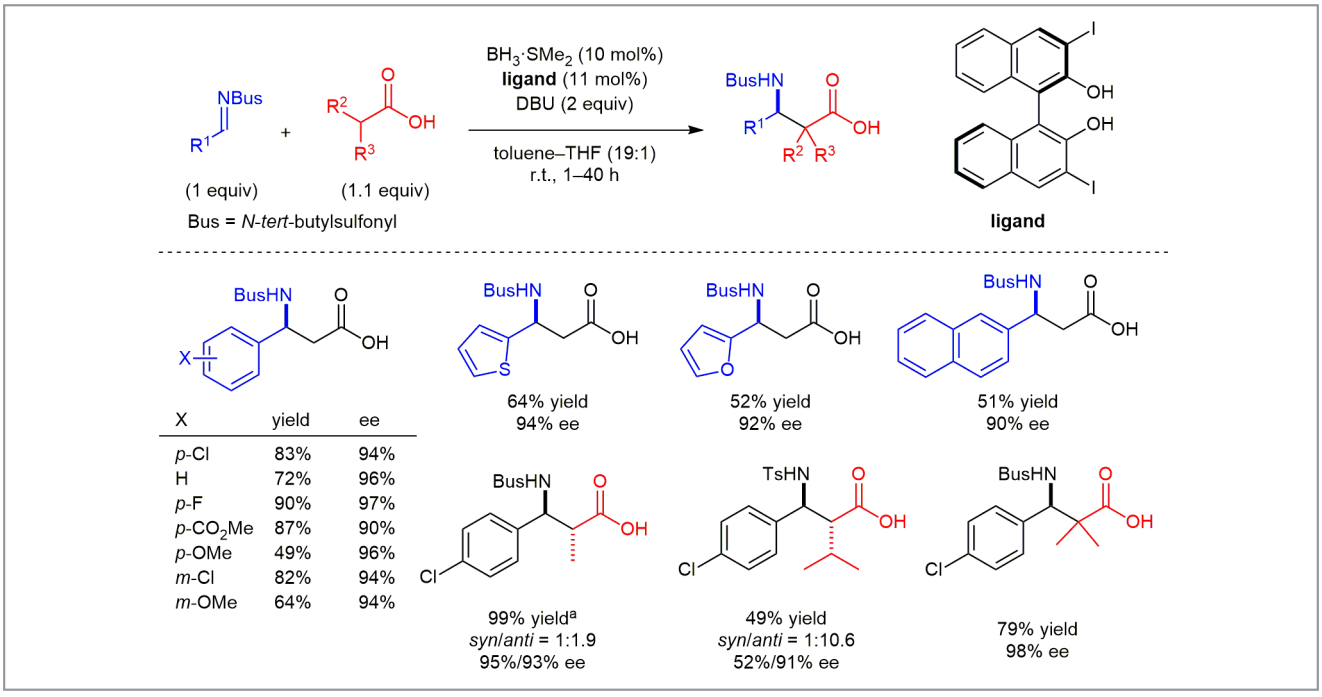
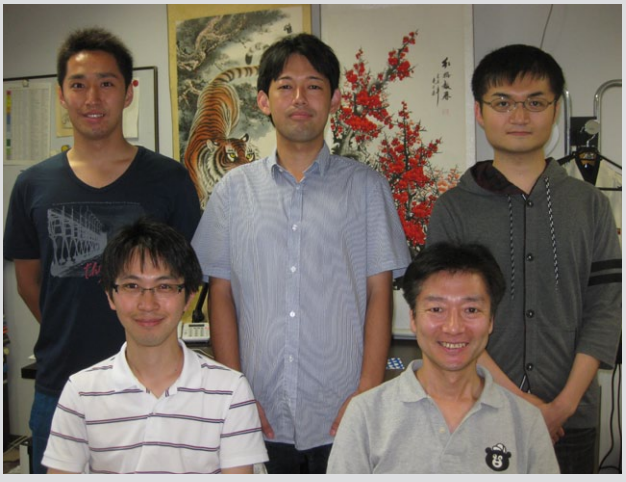


Scheme 2 Representative examples of the boron-catalyzed asymmetric Mannich-type reaction of carboxylic acids. Isolated yields, diastereomeric ratios, and enantiomeric excess values were determined after conversion of the Mannich products into methyl esters. [a] 1.0 equiv of propionic acid was used.

About the authors



Back row, from left: H. Nagai, Y. Morita, T. Yamamoto; front row, from left: Prof. Y. Shimizu, Prof. M. Kanai

Motomu Kanai was born in Tokyo (Japan) in 1967. In March 1991 he obtained his MSc from the Graduate School of Pharmaceutical Sciences, The University of Tokyo (Japan) under the supervision of the late Professor Kenji Koga. In April 1992 he was appointed as Assistant Professor at ISIR, Osaka University (Japan) and in June 1995 he was awarded a PhD from ISIR, Osaka University under the supervision of Professor Kiyoshi Tomioka. From January 1996 to August 1997 he was a postdoctoral researcher at the University of Wisconsin (USA) in Professor Laura L. Kiessling's laboratory, and from September 1997 to April 2010 he worked in Professor Masakatsu Shibasaki's laboratory at the Graduate School of Pharmaceutical Sciences, The University of Tokyo, firstly as Assistant Professor (September 1997 to July 2000), then as a Lecturer (July 2000 to January 2003), and finally as an Associate Professor (February 2003 to March 2010). Since then he has been a Full Professor. From October 2011 to present, he has been the principal investigator on the JST-ERATO Kanai Life Science Catalysis Project. His research interests lie in the design and synthesis of molecules that have functions, such as catalytic or biological activities.

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Yohei Shimizu – who in this work conceived and designed the experiments together with Professor Kanai – was born in Nagano (Japan) in 1984. He gained his MSc in March 2008 from the Graduate School of Pharmaceutical Sciences, The University of Tokyo under the supervision of Professor Masakatsu Shibasaki, and his PhD in March 2011 from the same institute, under the supervision of Professor Shibasaki initially and then Professor Kanai. He has been an Assistant Professor in Professor Kanai's lab from April 2011 to present. From July 2012 to September 2012, he was a visiting scientist at the Department of Chemistry, University of Cambridge (UK), under the supervision of Professor Matthew J. Gaunt. His main research interests are the development of novel reactions which enable easier synthesis of complex molecules, and application of the reactions to total synthesis.

Yuya Morita – who in this work found the BH3 catalyst conditions and developed the catalytic asymmetric reaction – was born in Osaka (Japan) in 1989 and gained his MSc from the Graduate School of Pharmaceutical Sciences, The University of Tokyo in March 2014, under the supervision of Professor Kanai. Since April 2014 he has been a PhD student in Professor Kanai's lab. His research interests include methodology development and total synthesis.

Tomohiro Yamamoto – who, together with Hideoki Nagai, performed the experiments for chemoselective Mannich-type reactions – was born in Hokkaido (Japan) in 1986. He obtained his BSc from the School of Pharmaceutical Sciences, University of Shizuoka (Japan) under the supervision of Professor Toshiyuki Kan in March 2011 and his MSc in March 2013 at the Graduate School of Pharmaceutical Sciences, The University of Tokyo under the supervision of Professor Kanai. He has been studying for his PhD since April 2013, also in Professor Kanai's lab. His research interests include methodology development and total synthesis.

Hideoki Nagai was born in Tokyo (Japan) in 1990 and obtained his BSc in March 2013 from the Department of Applied Chemistry, Faculty of Science and Technology, Keio University (Japan) under the supervision of Professor Kazunobu Toshima. Since March 2013 he has been an MSc student at the Graduate School of Pharmaceutical Sciences, The University of Tokyo under the supervision of Professor Kanai. He is a keen climber and reached the summits of Mt. Mont Blanc and Mt. Kilimanjaro in 2014. His research interests are methodology development and total synthesis, as well as marketing.

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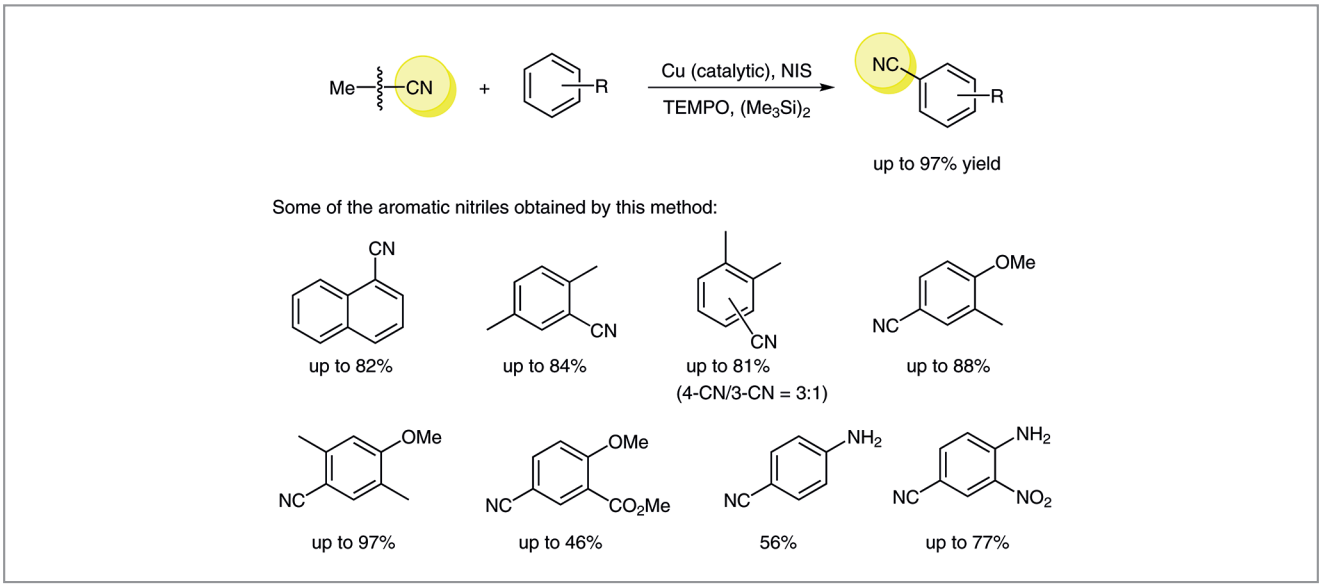
Acetonitrile as a Cyanating Reagent: Copper-Catalyzed Cyanation of Arenes

Org. Lett. **2015**, *17*, 2602–2605

Acetonitrile is a common solvent in organometallic chemistry, and can coordinate to a metal center as a weak ligand. "The acetonitrile C–CN bond is usually inert to transition metals because it has a rather strong bond energy (133 kcal/mol) compared to the alkane C–C bond energy (ca. 83 kcal/mol)," explained Professor Zengming Shen of the Shanghai Jiao Tong University (P. R. of China). "Accordingly, acetonitrile C–CN bond cleavage mediated by transition metals has rarely been explored. However, if acetonitrile, the most widely used organonitrile, was able to act as a nitrile source via C–CN activation, this strategy would be of great interest for the development of new cyanation reactions and avoidance of highly toxic metal cyanides (such as KCN, NaCN, CuCN, $Zn(CN)_2$, TMSCN, etc.)," said Professor Shen.

In 2013, Professor Shen's group reported an efficient and novel method for acetonitrile C–CN bond cleavage used for the aromatic C–H cyanation (*Chem. Eur. J.* **2013**, *19*, 16880). In this work, they found a key additive, $(Me_3Si)_2$, which plays a critical role in promoting C–CN cleavage and in enhancing the reaction rate. Professor Shen said: "The cyanation of simple arenes, i.e. arenes without a directing group, is an attractive and modern approach to making benzonitriles. This strategy avoids the need for prefunctionalization of substrates and, importantly, simple arenes are abundant starting materials. Thus far, few examples have been reported in this field due to their low reactivity." Now Professor Shen and co-workers have designed and executed a new approach for the copper-catalyzed cyanation of simple arenes using acetonitriles as a cyano source via C–CN bond cleavage (Scheme 1). "This C–H functionalization strategy involves a sequential iodination/cyanation process to furnish the corresponding aromatic nitriles in good to excellent yields," explained Professor Shen. "Moreover, we found a highly efficient Cu/TEMPO/Si system for acetonitrile C–CN bond cleavage. TEMPO plays a significant role in promoting this cyanation transformation: 1) TEMPO, a cheap oxidant, allows the reaction to be catalytic in copper; 2) $TEMPOCH_2CN$ is formed in situ and acts as the active cyanating agent (Scheme 2)."

This system represents a new avenue to break the relatively inert C–CN bond. "Notably, $Cu(ClO_4)_2$ is required and serves in three roles: as Lewis acid for initial iodination, as catalyst for C–CN bond cleavage and as promoter



Scheme 1 The novel synthesis of aromatic nitriles and some of the over 20 products that were obtained by this method

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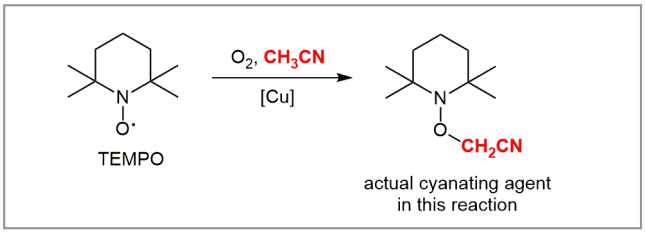


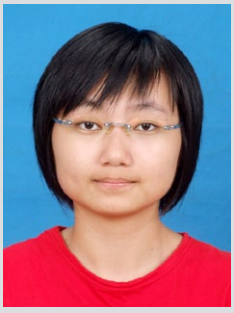
Scheme 2 Formation of the active cyanating agent

for new C–CN bond formation," explained Professor Shen, concluding: "The next goals in our laboratory are the cleavage of acetonitrile under mild conditions and the development of new cyanation reactions with acetonitrile."

About the authors

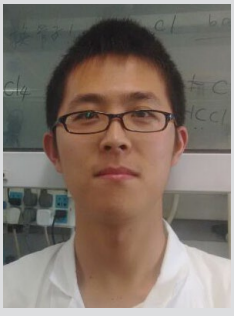
Y. Zhu

Yamin Zhu was born and raised in Shandong Province (P. R. of China). She obtained her B.S. in chemistry from Linyi University (P. R. of China) in 2010. Then she joined the research group of Professor Zengming Shen at Shanghai Jiao Tong University (P. R. of China) where she is pursuing her Ph.D. in organometallic chemistry. Her research focuses on copper-catalyzed C–C bond cleavage. Outside the lab, she enjoys music, jogging and reading.



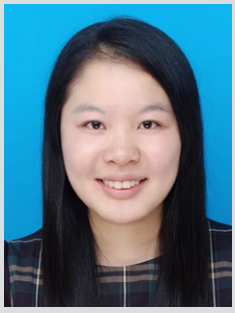
M. Zhao

Mengdi Zhao was born in Zhejiang (P. R. of China) in 1989. After receiving her B.S. degree at Zhejiang University of Technology (Hangzhou, P. R. of China) in 2012, she joined the research group of Professor Zengming Shen as a Master's student at Shanghai Jiao Tong University. In autumn of 2014, she started her doctoral studies at the same university under the guidance of Professor Wenjun Lu.



W. Lu

Wenkui Lu was born in Shandong (P. R. of China) in 1988. He obtained his Bachelor's degree in 2013 from Taiyuan University of Technology (P. R. of China) and is currently performing research under the guidance of Professor Zengming Shen at Shanghai Jiao Tong University as a Master's student. His research interest concerns boron chemistry.



L. Li

Linyi Li was born in Sichuan (P. R. of China) in 1990. She obtained her B.S. in chemistry from Sichuan Normal University (P. R. of China) in 2013. She is currently in the second year of her postgraduate course and conducting research under the guidance of Professor Zengming Shen at Shanghai Jiao Tong University. What she believes is: 'attitude is your life'.

Prof. Z. Shen

Zengming Shen was born in Zhejiang Province (P. R. of China) and obtained her Bachelor's degree in chemistry in 2001 from Sichuan Normal University (P. R. of China). From 2001–2006, she studied at the Shanghai Institute of Organic Chemistry (P. R. of China) as a Ph.D. student under the supervision of Professor Xiyan Lu, working on transition-metal-catalyzed tandem amination reactions. After obtaining her Ph.D., she joined the research group of Professor Vy M. Dong at the University of Toronto (Canada) as a postdoctoral fellow, working on the Rh-catalyzed ketone hydroacylation via aldehyde C–H bond activation. In 2010, she joined the faculty of Shanghai Jiao Tong University as an Associate Professor. Currently, her research interests focus on copper-catalyzed C–H and C–C bond activation.

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Young Career Focus: Dr. Nitin T. Patil (CSIR – National Chemical Laboratory, India)

Background and Purpose. From time to time SYNFORM meets young up-and-coming researchers who are performing exceptionally well in the arena of organic chemistry and related fields of research, in order to introduce them to the readership. This Young Career Focus presents Dr. Nitin T. Patil (CSIR – National Chemical Laboratory, India).

Biographical Sketch

Dr. N. T. Patil

Nitin T. Patil completed his doctoral studies at the University of Pune (India) in 2002 under the supervision of Professor D. D. Dhavale. After working as a postdoc at the University of Göttingen (Germany) with Professor Christoph Schneider, he moved to Tohoku University (Japan) as a JSPS fellow. In April 2005, he was appointed as Assistant Professor in Professor Yoshinori Yamamoto's laboratory. In June 2006, he joined Professor K. C. Nicolaou's Chemical Synthesis Laboratory@Biopolis in Singapore, moving later to The Scripps Research Institute (USA). He began his independent career in September 2008 at IICT, Hyderabad (India). In August 2013, he moved to CSIR-NCL, Pune (India). He was the recipient of the INSA Young Scientist Medal (2010) and the Alkyl Amines-ICT Foundation Day Young Scientist Award (2010). He was also elected as 'Young Associate' of the Indian Academy of Sciences, Bangalore, in 2010.

INTERVIEW

SYNFORM *What is the focus of your current research activity?*

Dr. N. T. Patil The development of catalytic cascade reactions by integrating multiple catalytic cycles in one pot is of prime importance in organic chemistry. The reaction, catalyzed by two different catalysts at the same time, can provide access to reactivity and selectivity not otherwise possible by a single catalyst alone. Unlike biological processes, where nature takes advantage of enzyme architecture to facilitate a multiple reaction manifold, it is difficult to exploit such processes in a flask because of obvious compatibility issues. The main focus of our research is to merge metal- and organocatalysis to develop novel synthetic methods which are otherwise impossible to realize by a single catalyst alone.

SYNFORM *When did you get interested in synthesis?*

Dr. N. T. Patil Since childhood, I have been always curious to know how nature creates molecules, though I was too immature to understand the chemistry of living systems. It was only during school/college days that I became familiar with nature's way of synthesizing molecules. In a real sense, I got interested in synthesis when I joined Professor Dhavale's laboratory for my Ph.D. studies. Further experience in the development of catalytic methods in Professor Schneider's and Professor Yamamoto's laboratories and total synthesis in Professor Nicolaou's laboratory triggered my interest to work in organic synthesis. This is the reason why I embarked on my independent career and chose to challenge myself with organic synthesis.

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SYNFORM *What do you think about the modern role and prospects of organic synthesis?*

Dr. N. T. Patil The field of synthetic organic chemistry has evolved considerably since Wöhler discovered the synthesis of urea – the first organic molecule synthesized in the laboratory. Undoubtedly, modern life without organic molecules is difficult to imagine, as they have found extensive applications not only in healthcare but also in agrochemicals, materials science, etc. However, the field of organic synthesis faces some problems – it is considered a traditional branch of science. Moreover, organic chemists communicate in the language of formulas, which is often not understood by non-experts and bureaucrats. While it is true that the most interesting challenges for organic chemistry will be derived from interdisciplinary fields, it does not mean that the field of organic synthesis will start to decline soon. Many new types of reactivities of fundamental interest have yet to be discovered, which would enable designed organic molecules to be obtained in an elegant and efficient manner. It is our belief that the field of organic synthesis will continue to flourish and would be considered as matured only when there exist techniques to make designed organic molecules in buckets (rather than flasks!).

SYNFORM *Your research group is active in the areas of organic synthesis and stereoselective catalysis. Could you tell us more about your research and its aims?*

Dr. N. T. Patil Our research work mainly focuses on the field of 'gold catalysis' and 'merging gold catalysis with organocatalysis' for developing newer methods in Diversity Oriented Synthesis (DOS) amenable for accessing natural-product-like molecules. In recent years, the branching cascade, considered as one of the forms of DOS, has gained much interest because of its potential to transform a common type of substrate into diverse and distinct molecular frameworks under the influence of either different reagents or different reaction conditions. However, there was no precedence of a catalytic branching cascade that generates large scaffold diversity despite the fact that scaffold diversity is very important to populate chemical space efficiently. Recently, our group developed relay[1] catalytic branching cascades (RCBC) – a new technique for accessing scaffold diversity.[2] The reaction of common starting materials (alkynes **A**) with variables (scaffold building agents **B**) under gold catalysis produces a series of multifunctional skeletally different polyheterocyclic scaffolds **AB** in an efficient manner (Figure 1).

We are also working on merged organo/gold catalysis – the technique wherein gold catalysts and organocatalysts exist in one pot. This chemistry is supposed to be interesting for Au(I) catalysis, given the difficulty of transferring chiral information from a ligand disposed 180° from the substrate. The phenomenon of merging gold catalysts with organocatalysts is quite remarkable as now there are many ways to access enantiopure products by varying chiral organocatalysts. Our

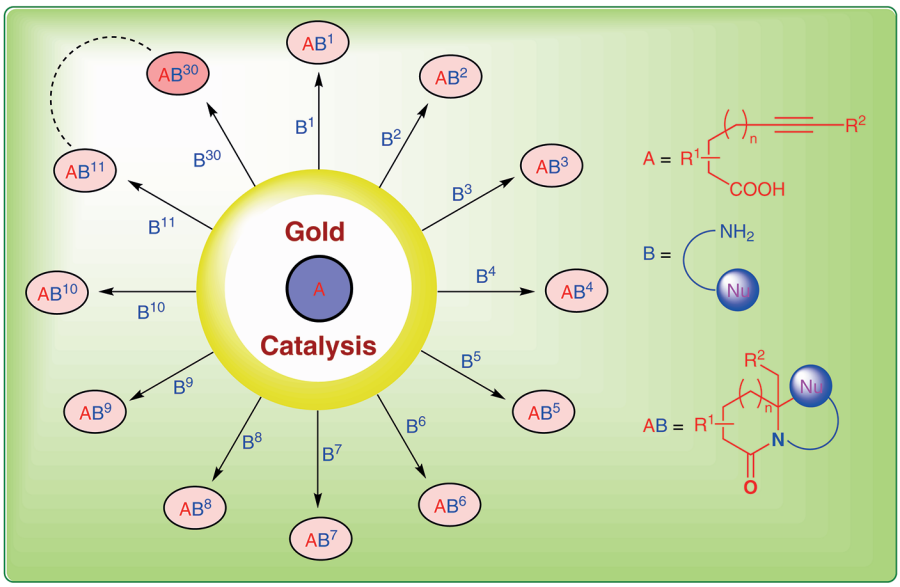

Figure 1 Relay catalytic branching cascade

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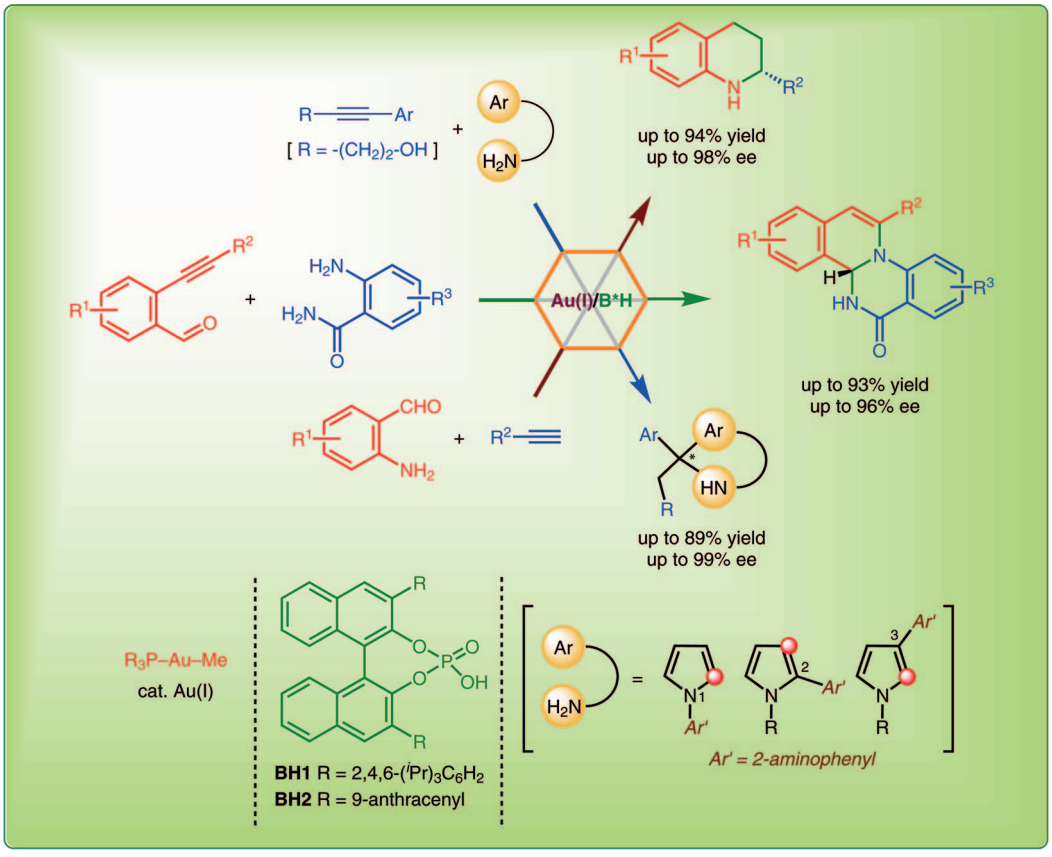

Figure 2 Enantioselective catalysis utilizing merged organo/gold catalysis

research in this area, based on gold and chiral Brønsted acid, led to some of the most important aspects and salient features of our activities, highlighted in Figure 2.[3]

SYNFORM *What is your most important scientific achievement to date and why?*

Dr. N. T. Patil It's really tough to answer this question as I stand at the foundation of my independent research career. However, if I were pressed, I would say that the ongoing research of my group is very exciting. We have developed the relay catalytic branching cascade (RCBC) as a new technique to access a series of multifunctional polyheterocyclic scaffolds.[2] This is the first report wherein we have shown that the catalytic branching cascade strategy generates a large scaffold diversity. In addition, we showed that merged organo/gold catalysis is a very important technique for accessing enantiopure heterocyclic scaffolds. This technique is supposed to be appealing as a number of imino/alkyne-based substrates could be easily envisaged.

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