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Peter Hall: My Mentor, Collaborator and Friend

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Abstract

Peter Hall left us about a year ago. His passing was an irreplaceable loss to the statistical community. I lost a long-time mentor, collaborator, and friend. In this article, I share with readers certain stages in my career during which Peter provided me much help, things that I learned from him about research and research attitude, our research collaborations, and more. I am only one of many statisticians who benefited from Peter's generosity in helping others, especially young researchers. My example demonstrates the importance and influence of Peter and his generosity on our growth and career development.

Key Words: Collaboration; Density deconvolution; Fond memories; Image processing; Inverse problems; Jump regression analysis; Photography; Steam trains.

1 Introduction

Professor Peter Hall passed away on January 9, 2016. His passing was a tremendous loss to our statistical community. According to Wikipedia (https://en.wikipedia.org/wiki/Peter_Gavin_Hall), Peter had a total of 606 publications listed in MathSciNet as of January 2016. In the past

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40 years or so, Peter made fundamental contributions to a wide range of statistical research areas, especially in bootstrap methods, nonparametric smoothing approaches, measurement error problems, and more. Peter possessed many characteristics that made him unique. Besides his talents and important contributions in statistical research, he was kind and always handled things gracefully. This demeanor made him many friends and research collaborators in our community. In MathSciNet, there were 240 distinct people listed as his co-authors as of January 2016, and these people were distributed in many departments/institutes around the world. Peter was generous in helping other researchers, especially young researchers. This generosity is seen in the large number of reference letters that he wrote for many of us during different stages of our career. Through research collaborations, formal or informal conversations, and many different kinds of precious and timely help, Peter had a great positive influence on the growth and career development of many statisticians, including myself.

In this article, I would like to share with readers certain episodes in my career during which Peter provided me much precious help and guidance. I will share with you certain things that I learned from him about research, and certain aspects of his scientific life that I observed during my visits with him. The remainder of the article is organized as follows. In Section 2, I will describe my early contacts with Peter and his influence on my research in jump regression analysis and image processing. In Section 3, I will introduce my research collaborations with Peter, and his talent, diligence, and efficiency in research. In Section 4, I will share with readers many of my fond memories of Peter, including some of our intersting conversations.

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2 Early Contacts

In 1990, I was an assistant professor in statistics at Fudan University in Shanghai, China. During that year, Professor Naihua Duan from RAND Corporation visited Fudan, and I was a seminar coordinator and responsible for arranging his accommodation during the visit. At that time, China was still quite isolated academically. For instance, we only had access to old issues (usually 2-3 years old) of a limited number of statistical journals, such as *Annals of Statistics*. Printing and copying were expensive, and in poor quality. After Naihua learned that I was doing research in jump regression analysis (JRA), regression analysis when the regression function has jumps or other singularities, he thought the research was interesting and it would be helpful for me to get advice from some related researchers in the West. After he went back to the USA, he made copies of two research manuscripts of mine and sent them to some researchers working on related topics. One of these researchers was Peter Hall. Peter wrote a letter to Naihua about my research, and Naihua forwarded his letter to me. The letter is shown in Figure 1.

In his letter, Peter mentioned that "The work in the second paper is particularly exciting in its potential. This is the sort of problem that is engaging the minds of many excellent scientists involved in image analysis ... It is striking to see someone working on these problems in isolation, in a corner of China, and quite impressive to see him develop the tools all by himself." In his letter, he also stated "Can this man be got out of China, to do a PhD in the West? We could possibly have him in Australia, although I would need to find a scholarship for him." At that time, I did not know Peter or his research. When there was an opportunity for me to visit the USA in the summer of 1991, I decided to pursue my PhD there. However,

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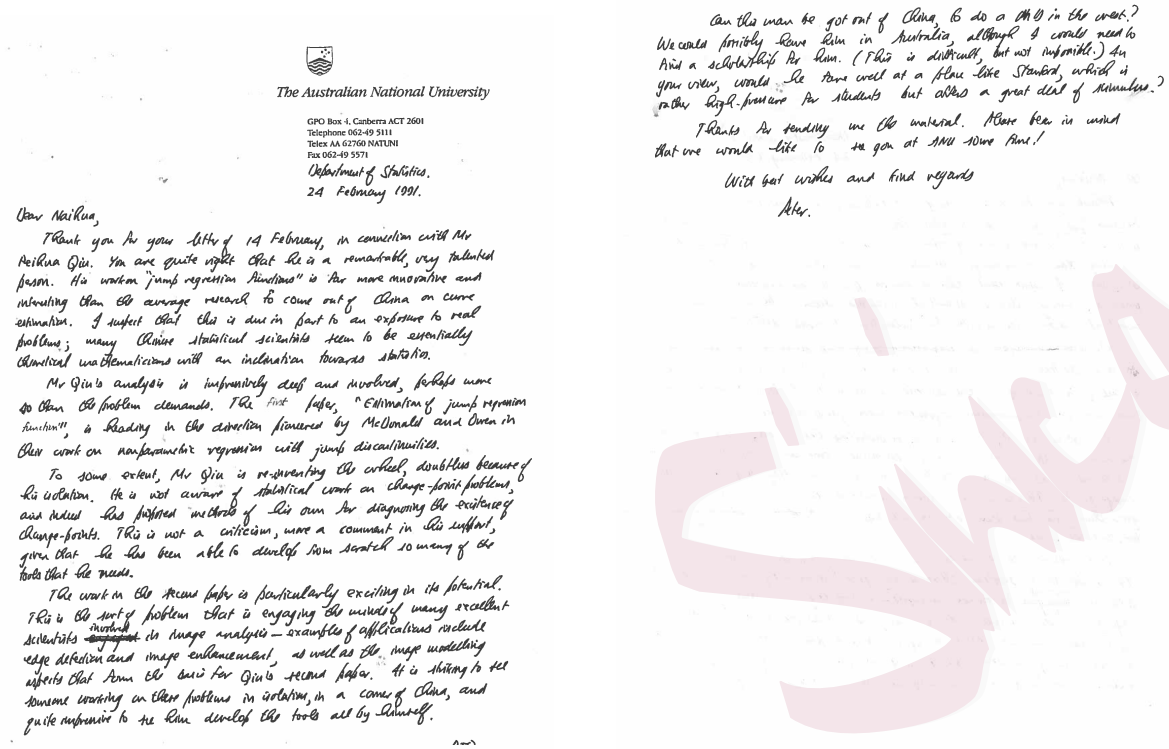

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Department of Statistics.
24 February 1991.

Dear Naihua,

Thank you for your letter of 14 February, in connection with Mr Naihua Qiu. You are quite right that he is a remarkable, very talented person. His work on "jump regression functions" is far more innovative and interesting than the average research to come out of China on curve estimation. I suspect that this is due in part to an exposure to real problems; many Chinese statistical scientists seem to be essentially theoretical mathematicians with an inclination towards statistics.

Mr Qiu's analysis is impressively deep and involved, perhaps more so than the problem demands. The first paper, "Estimation of jump regression functions", is heading in the direction pioneered by McDonald and Owen in their work on nonparametric regression with jump discontinuities.

To some extent, Mr Qiu is re-inventing the wheel, doubtless because of his isolation. He is not aware of statistical work on change-point problems, and indeed has proposed methods of his own for diagnosing the existence of change-points. This is not a criticism, more a comment in his support, given that he has been able to develop from scratch so many of the tools that he needs.

The work in the second paper is particularly exciting in its potential. This is the sort of problem that is engaging the minds of many excellent scientists ~~engaged~~ involved in image analysis — examples of applications include edge detection and image enhancement, as well as the image modelling aspects that form the basis for Qiu's second paper. It is shocking to see someone working on these problems in isolation, in a corner of China, and quite impressive to see him develop the tools all by himself.

Can this man be got out of China, to do a PhD in the west? We could probably have him in Australia, although I would need to find a scholarship for him. (This is difficult, but not impossible.) In your view, would he fare well at a place like Stanford, which is rather high-pressure for students but offers a great deal of stimulus?

Thanks for sending me the material. There has been interest that we would like to see him at ANU. More soon!

With best wishes and kind regards

Peter.

Figure 1: Peter Hall's letter about my research on jump regression analysis.

Peter's letter had given me encouragement in continuing my research in JRA. After I became a graduate student at the University of Georgia (UGA), I learned image processing by taking a course in computer vision and graphics from the UGA computer science department and by reading numerous image processing papers. Today, many JRA methodologies have been proposed, and JRA has become a powerful tool for analyzing image data. In the preface of my research monograph, Qiu (2005), I wrote "Encouragement and help from Peter Hall and Steve Marron have had a great impact on my research .... It was Peter who first told me the connection between jump curve/surface estimation and image processing."

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3 Research Collaborations

My first research visit to Peter was in 2002 when I took a single-semester leave from the University of Minnesota (UMN). At that time, Peter was at the Australian National University (ANU) at Canberra. That was our first meeting in person, although we had several email conversations about research and he helped me on several occasions before the visit, including a strong reference letter for my tenure and promotion case that was finalized that summer. Around that time, I was working on developing flexible edge detection methods for image analysis using local kernel smoothing. My methods did not require restrictive assumptions on the number and shape of the edge curves (e.g., Qiu (2002)). But, the detected edge pixels could not form curves. Instead, they were a set of disconnected points located around the true edge curves. I regarded this as a drawback and was thinking about possible ways to connect the detected edge pixels.

After I settled down at Peter's department, we had a meeting and discussed problems. He told me that he liked the edge detection problem, and that we might work on the problem together. I tried to come up with some possible ways to connect the edge pixels detected by an existing edge detector, and reported to Peter daily. After several meetings and rounds of modifications, he was still unsatisfied with my plan. He told me that he had two main concerns: 1) my proposed post-processing edge-linking method seemed inconvenient to use, and 2) it might be hard to formulate it well mathematically. Soon after that conversation, he came to my office with a brilliant idea based on edge tracking. From an initial edge point detected by an existing edge detector, one could track the edge curve step by step with a small step size along the most probable edge direction. At each step, the edge direction could

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be estimated by a weighted local maximum likelihood estimation approach considered in Hall and Rau (2000) and Hall et al. (2001). To handle the complexity of crossing edge curves, he borrowed the concept of a vertex of degree k in graph theory to describe an edge point at which k edge curves joined. We worked out the method and the related theory. In that process, Peter took the lead and I gave him feedback and suggested possible improvements. At that time, Professor Christian Rau was pursuing his PhD under Peter's supervision and our research was closely related to his topic. Peter suggested that we ask Christian to help us with the numerical studies. That work was later published in Hall et al. (2008).

My first impression of Peter was that he was very efficient. For that project, it took us roughly three weeks to determine the research topic, develop the methodology, and finish the theoretical justifications. Before I left Australia, we finished the design of the numerical studies. Peter often had several visitors at one time, and needed to work on several different projects simultaneously. He was efficient partly because he knew so many things in different areas and disciplines. For our project described above, he connected edge tracking in image processing with graph theory in mathematics and weighted local maximum likelihood estimation in statistics. Peter was efficient also because he worked extremely hard, perhaps the hardest working researcher I've ever met. He was thinking about things all the time, even while walking. For instance, sometimes he needed to leave the office for meetings or other commitments. Once he returned, he often stopped by my office to tell me new ideas that came to his mind during those short periods of time. At ANU, the regular working hours were between 9am and 5pm during week days. Peter usually arrived to his office before 9am and left the office after 7pm. He usually spent the morning of a Saturday for shopping

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and laundry, and spent the remaining part of a weekend in working. After a trip (even an international trip), if it was during working hours, he usually went to his office directly to work until his regular leaving time. Before the visit, it was difficult for me to understand how Peter could publish more than twenty papers a year, most published in top journals. But after the visit, I could see how he achieved this. Peter's greatness was reflected not only in his talent, but also in his passion and extraordinary effort in research. Peter deserved everything he achieved.

Peter was the Buehler-Martin Lecturer at the School of Statistics at UMN in 2003, delivering three lectures while spending only 4-5 days in Minnesota. After a dinner with him on the first night, we went to a drug store to buy pain relief medicine. He had a head-ache, probably due to a lack of sleep. The next morning, after Peter settled down in our department, we had a meeting. He had an idea about the nonparametric density deconvolution problem:

$$Z = X + \delta, \tag{1}$$

where Z was the observed version of X, δ was the random error, X and δ were independent, and the distribution of δ was assumed known. Our major goal was to estimate the density of X in a nonparametric context from certain observations of Z. There were several existing methods, including some kernel-based approaches (e.g., Delaigle and Gijbels (2002)). Peter believed he had a simpler and possibly more effective method to solve the problem, based on the discrete Fourier transformation and the following properties of the sine and cosine

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functions:

$$\begin{aligned} E\{\cos(jZ)\} &= E\{\cos(jX)\}E\{\cos(j\delta)\} - E\{\sin(jX)\}E\{\sin(j\delta)\} \qquad (2) \\ E\{\sin(jZ)\} &= E\{\sin(jX)\}E\{\cos(j\delta)\} + E\{\cos(jX)\}E\{\sin(j\delta)\}, \end{aligned}$$

with j an index in the trigonometric-series expansions and Z assumed to follow (1). In (2), $E\{\cos(jZ)\}$ and $E\{\sin(jZ)\}$ could be estimated from the observed data, while $E\{\cos(j\delta)\}$ and $E\{\sin(j\delta)\}$ could be computed from the assumed distribution of δ. So, $E\{\cos(jX)\}$ and $E\{\sin(jX)\}$ could be estimated easily by (2). By the inverse discrete Fourier transformation, the density of X could then be estimated. A major assumption in this method is that the support of the distribution of X be a compact interval, or be contained in a compact interval. This assumption could be reasonable in certain medical studies when a treatment (e.g., surgery) followed only when some medical indices were in some specific ranges. I suggested that besides the discrete Fourier transformation, we could consider cosine-series or sine-series expansions that were simpler. The next day, Peter told me that the cosine-series expansion would have a better theoretical property for estimating a density with a bounded support. So, that expansion was adopted in our method. Because of the close relationship between the density deconvolution problem and the errors-in-variables problem, a similar method was proposed for solving the errors-in-variables problem. When Peter left Minnesota, the methodology was mostly developed. Meanwhile, he gave three lectures, chatted with my colleagues at UMN, and attended some social activities arranged for him. Later Peter led the development of the theory and I worked on completing the numerical studies. The paper was finished in about a month, see Hall and Qiu (2005). Later again, Peter found our method could be modified to solve the Berkson errors-in-variables problem.

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Professor Aurore Delaigle provided substantial contributions to this project, later published in Delaigle et al. (2006). Aurore was Peter's major collaborator in such research areas as density deconvolution, errors-in-variables problems, functional data analysis, and more. See Delaigle (2016) for a more detailed description of their joint research.

I took a full-year sabbatical leave from UMN in 2004-2005, and decided to visit Peter again. This visit was between September 1 and November 30, 2004. At that time, I was exploring some challenging problems in image processing. One such was image deblurring, which could be described by the model

$$Z(x,y) = H\{f\}(x,y) + \varepsilon(x,y), \quad \text{for } (x,y) \in \Omega, \tag{3}$$

where $H\{f\}(x,y) = \int\int_{R^2} h(u,v) f(x-u, y-v)\, dudv$ denotes the convolution between a *point spread function (psf)* h and a true image intensity function f, $\varepsilon(x,y)$ is the pointwise noise, and Ω is the design space of the image. The psf h described how the true image f was spatially degraded (i.e., blurred) in the imaging process. Image deblurring was mainly to estimate $f(x,y)$ from $Z(x,y)$. In the literature, h is often assumed known. Otherwise, the problem could be "ill-posed" in the sense that there could be multiple sets of h and f that corresponded to the same Z, even when no noise was contained in Z. Most papers in the literature at that time tried to estimate $f(x,y)$ from $Z(x,y)$ when h was assumed known, using various inverse filtering algorithms. That task alone was challenging because the inverse filtering was numerically unstable, caused mainly by random noise. So, the major focus of that research was on how to overcome the numerical challenge in the inverse filtering. But, the assumption that h was known was not realistic for certain applications. For instance, satellite images were often blurred because of wind, atmospheric turbulence, aberrations of

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the optical system, relative motion between the camera and the object, and more. It could be difficult to describe the blurring mechanism in an imaging process by completely specifying the psf h, and I wanted to estimate $f(x, y)$ from $Z(x, y)$ without specifying a specific function for h. During my visit to Peter, this topic was the focus.

After I arrived at ANU and discussed the image deblurring problem with Peter, he was very interested. I believe his interest was partly because photography was his hobby. Thus he understood the concepts of image blur and psf extremely well. One night he came to my office to share with me an article that he downloaded from a web site which claimed that all pictures were actually blurred. So, we both agreed that the image deblurring problem was important. My thought was that while it was difficult to specify the psf h completely in certain applications, it might be possible to estimate it using test images of some known structures (e.g., lines of different widths). He agreed, and added that camera companies usually calibrated the lens of a camera by taking pictures of mesh grids or other structures. We began in the setup of model (3), where f would be the test image whose structure was assumed known, and we wanted to estimate the psf h from the observed image Z. We proposed an estimator based on the Fourier transformation and a ridge-regulated inverse Fourier transformation, see Hall and Qiu (2007a). In follow-up research, we focused on estimating $f(x, y)$ from $Z(x, y)$. We suggested a two-step procedure, with psf h estimated from an observed test image and, in the second step, observed image $Z(x, y)$ taken by the same camera deblurred using the estimated psf obtained in the first step. The psf h was assumed to have a parametric function with a parameter θ. For estimating θ, Peter suggested a novel metric for measuring the sharpness of a blurred test image, and the work

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was published in Hall and Qiu (2007b). The method without the parametric assumption on h was published in Qiu (2008). Later research made the method more flexible, see Qiu and Kang (2015).

Peter was careful about the conditions in a theorem, whether they were necessary, and whether they were already the weakest possible conditions. He was careful about the wording and punctuation in a paper to make sure that related methods, and/or their properties, were accurately described. His attention to details was reflected in all revisions of a paper during its review. I learned a lot from him about writing and revising papers. To my surprise, Peter also got many paper rejections, at least with our joint papers described above. During private conversations, he would express his disappointment after a paper rejection. In most cases, he would suggest alternative journals for resubmission. I only had one case when he thought that the reviewers did not understand our proposed method and their comments did not make sense to him. In this case, he chose to write back to the editor to further explain our method and explain why he thought the reviewers misunderstood our method. In revising a paper, he usually focused on the theoretical issues and I focused on the numerical issues. He then drafted the authors' response, and I gave my feedbacks. His draft response would address all issues raised in the review reports, plus certain issues that had not been noticed by the referees but rather we noticed during the paper revision. What impressed me about his draft response was its tone. It was polite and things were always stated positively. In some occasions, the referees misunderstood certain parts of a paper and made irrelevant comments. In such cases, Peter might say that it was our fault that we did not describe the related parts clearer and they were either modified in the revision or left as is but they

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actually meant such and such. On one occasion, I asked him why he said it was our fault when the fact was that the related description in the paper was already clear and appropriate. He explained that we should not expect our readers to be as familiar to our research subject as ourselves and it would always be a good idea to polish some statements from readers' perspective. I believe that my own authors' response has a similar tone nowadays.

4 Fond Memories of Peter

Peter had many visitors each year. A major benefit to visiting him was the opportunity to meet other visitors and make new friends. Besides the visits mentioned above, my last visit to Peter was in 2012 at the University of Melbourne. That year I took my second full-year sabbatical leave from UMN. During all these visits, I met many colleagues, including Ray Carroll, Ming-Yen Cheng, Aurore Delaigle, and Alexander Meister. Peter took care of his visitors well, often lunching with them on a daily basis. During these lunches, topics could range from US presidential elections to the unique traditions of a small town on a corner of the world. I learned many things from these conversations. For instance, Alan Welsh once mentioned that most animals we ate were vegetarian. This was in fact true, although I never realized it. For my first visit to Peter, he took care of all accommodations for me. He even arranged Christian Rau to pick me up from the airport, and then brought me some food the next day by himself. During my second visit, I remembered that I mentioned during our casual chat at a lunch that a bicycle I bought several days before was stolen although it was properly locked. Peter apologized for the incidence, although that was not his fault at

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all, and worried that the incidence might change my impression about ANU and Australia. He explored the possibility of buying another bicycle for me. I thanked him for his concern, and told him that another bicycle was unnecessary. Although many years have passed, these small but warm episodes are still vivid in my mind, and I am sure they will be in my memory for many years to come.

Peter usually took his visitors to a fun place for a half day or so if the timing was good for both himself and his visitors. During my first visit, two of us went to a quiet suburb of Canberra where Peter often took pictures when he was young. Of course I asked him about the tricks to taking a good picture. His major theory was that one should add dimension to the scene. He explained this with examples. Thus, for a picture of a house, it might be better to include a corner or the roof in the picture, which was three-dimensional, than just to include a flat part of the house, which was two-dimensional. For a picture of a tree, if our picture could give viewers an impression that some branches or leaves were being blown about would usually be more impressive than a more static picture. We discussed different social systems, the characteristics of different people and societies, different religions, gun control in different countries, and more. Peter knew many things besides statistics, and I learned a lot from our conversations. During my second visit, Peter and his wife Jeannie took Ray Carroll, Ray's wife, and me to a local winery in a suburb of Canberra to taste local wines. We also visited stores and had lunch together. That was an enjoyable trip that was full of warm conversations and laughs, which is reflected in the picture shown in Figure 2, taken by Ray. During my third visit, he and Aurore organized a trip to take a steam train in a suburb of Melbourne. He told us that he liked to take pictures of trains when he was

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Figure 2: A picture with Peter Hall during a local trip to a winery located in a suburb of Canberra.

young.

During my contact with Peter, many conversations were related to statistics. We often talked about certain active research areas, our opinions as to why they were active, and the basic problems in those areas. We once discussed the writing of a paper, and exchanged our views on writing styles and habits. One conversation that left me a deep impression was about mistakes that we found in research papers during our paper reviews. He felt that we should be flexible about them as long as they were not critical. He further explained that we all made mistakes in our papers and theoretically every paper had mistakes in it. As long as the mistakes were correctable, authors should be given a chance to correct them, and the editorial recommendations and decisions should not focus too much on these mistakes. These comments were especially helpful to me as I was named the editor-elect of *Technometrics* in 2012. Around the same time, he was named a co-editor of *Annals of Statistics*. During a lunch, he initiated a discussion about how to maintain a healthy academic environment. He thought that we should avoid using any prior information regarding which research group

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the authors belonged to when judging the quality of a paper. My term as the editor of *Technometrics* has ended, and during it, I never forgot his advice.

When I went to Peter's office to say goodbye on the last day of my visit in 2012, he said, "Peihua, please visit me more often. Do not wait until the next sabbatical. I can always make appropriate arrangements for your next visit. I myself will try to slow down and make less trips." I do not know whether Peter ever had any slowdown times in his life. All I know is that he still tried to work even during his last days in hospital. Peter was a real researcher! When the two of us visited a local church in a suburb of Canberra, we talked about the possibility of an afterlife. I told him that I tended to believe there was no afterlife because no scientific evidence was found about its existence, but there was the possibility since we human beings did not know much about the world. Today, I hope there is an afterlife and Peter is still doing his beloved research.

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